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Review Process

Abstracts and full-text reports uploaded to the conference system undergo a review procedure. Abstracts will be evaluated on the basis of abstracts/proposals. The conference system allows the full text to be sent if the abstract is accepted. Participants must wait for the evaluation results after uploading their article abstracts to the conference system. If their abstracts are accepted, they can upload their full texts to the conference system. The full texts are then sent to at least two reviewers for review. **The conference has a double-blind peer-review process.** Any paper submitted for the conference is reviewed by at least two international reviewers with expertise in the relevant subject area. Based on the reviewers' comments, papers are accepted, rejected or accepted with revision. If the comments are not addressed well in the improved paper, then the paper is sent back to the authors to make further revisions. The accepted papers are formatted by the conference for publication in the proceedings.

Aims & Scope

In the past, accessing information was tiring both financially and morally, but today, thanks to technology, it is easier and faster to access information. With this feature, technology not only makes daily life easier, but also accelerates the developments in science. Therefore, the focus of the conference is to share the studies on the developments in technology and the applications of technology in fields such as science and engineering by the participants. Studies in the fields of technology are accepted to the conference.

The aim of the conference is to bring together researchers and administrators from different countries, and to discuss theoretical and practical issues in the field of technology. At the same time, being aware of the applications of technology in different fields (such as engineering) is among the objectives of the conference.

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

Articles: 1- 26

CONTENTS

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2024

Volume 27, Pages 1-15

IConTech 2024: International Conference on Technology

The Trends in Carbon Emissions, Climate Change, Carbon Footprint, Carbon Tax, Green Technology Diffusion from 2015 to 2024: A Bibliometric and Visual Analysis

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OSTIM Technical University

Abstract: The aim of this study is to present a comprehensive review of carbon emissions, carbon footprint, carbon tax, carbon emissions pricing, trade openness, GDP per capita, R&D investment, green technology diffusion, urbanization, energy consumption, renewable energy, industrialization, and climate change research. Between 2015 and 2024 (limited to March 21st, 2024), we screened 5002 documents from the Web of Science and subjected them to analysis using the VOSviewer application and R programs. Biblioshiny (an R-based graphical interface of Bibliometrix) has been utilized to conduct performance and scientific mapping analyses for this study due to its proven effectiveness in building clear visualizations of literature using text mining functionality; and revealing the conceptual and intellectual structure of the field. The analysis revealed the publication trends and emerging themes in the research landscape. For the purposes of this research, the database was limited to open-access articles published in English, under the categories of business, business finance, economics, and environmental studies, indexed in the Social Sciences Citation Index (SSCI) and the Science Citation Index (SCI-Expanded). Advanced bibliometric techniques, such as co-citation analysis, co-occurrence of keywords, co-word analysis, scientometric mapping, are included in the methodology. The top five most frequently used keywords with the highest connection power are climate change, renewable energy, economic growth, energy, and sustainability respectively. This research has revealed that the journals with the highest number of articles in this field and the highest number of citations were Energy Policy, Energy Economics, Ecological Economics, Economic Research-Ekonomska Istrazıvanja, Environmental & Resource Economics, Technological Forecasting, and Social Change. In terms of the number of articles and citations by country in these fields, the USA, England, Germany, China, and the Netherlands ranked the highest. This research provides information gaps and research opportunities in the field, and contributes to shaping future research paths in this area.

Keywords: Carbon tax, Carbon emissions, Climate change, Carbon footprint, Green technology diffusion

Introduction

Climate change emerges as a pressing concern worldwide, evoking serious apprehensions. With its ramifications including global warming and the degradation of natural habitats, climate change stands as one of humanity's and the world ecosystem's most formidable challenges. In combating this global threat, strategies such as lowering carbon emissions, reducing carbon footprints, and embracing renewable energy sources are pivotal. These strategies form the foundational steps towards a sustainable future, crucial not only for environmental preservation but also for economic and social well-being.

In particular, the reduction of carbon emissions and carbon footprint aims to mitigate the effects of climate change by regulating greenhouse gas levels in the atmosphere. Research on this topic underscores the significance of policy measures geared towards lowering carbon emissions and promoting the utilization of renewable energy sources (Wang et al., 2020; Issa & In'airat, 2024).

Simultaneously, the concept of carbon footprinting has also garnered significant attention today. A carbon footprint serves as a metric to gauge the quantity of greenhouse gases generated by individuals, organizations, or nations, evaluating their environmental impacts. The escalating temperatures have a detrimental effect on the growth of gross domestic product (GDP) (Abidoye & Odusola, 2015).

The concept of renewable energy has been at the forefront of extensive debates due to its pivotal role and impacts on energy policies. There have been ongoing discussions even on the definition and framework surrounding renewable energy (Harjanne & Korhonen, 2019). Renewable energy is regarded as a focal point in global politics, with arguments suggesting that this transition could potentially bring about a structural transformation in the world order. It is emphasized that renewable energy has the potential to reshape models of economic growth and military competition. Scholars delve into how the shift towards renewable energy carries implications across various domains such as energy policy, economic growth, global politics (Xie et al., 2019), and climate change (Bastarrica et al., 2023; Grubler et al., 2021; Winkler et al., 2022). Therefore, comprehending the significant dimensions of the transition to renewable energy and evaluating its impacts play a crucial role in shaping future energy policies and societal transformations (Koirala et al., 2023)

In this context, this paper offers a thorough literature review and delves into critical concepts including carbon emissions, carbon footprint, carbon tax, emission pricing, trade openness, R&D investments, green technology diffusion, renewable energy, and climate change. These concepts are currently under intense debate in both academic circles and among policymakers, given their crucial roles in fostering both environmental sustainability and economic growth. 5002 documents from the Web of Science between 2015 and 2024 were analyzed using the VOSviewer application and R program. Biblioshiny, Bibliometrix's R-based graphical interface, was utilized to uncover trends and emerging themes in research concerning strategies to reduce carbon emissions and combat climate change. With its text mining functionality, Biblioshiny generates clear visualizations of the literature and is considered an effective tool for revealing the conceptual and intellectual structure of the field.

The research was carried out within the categories of business, business finance, economics, and environmental studies, which encompass open access English language articles. The methodology employed advanced bibliometric techniques including co-citation analysis, keyword co-occurrence frequency, word analysis, and scientific mapping. These techniques span a broad spectrum of studies focusing on policy strategies for carbon emissions, the diffusion of renewable energy sources, the relationship between economic growth and environmental sustainability, and other related topics.

Finally, this study aims to pinpoint the existing gaps in research concerning climate change, carbon emissions, green technology, and economic growth, and to outline a roadmap for future research directions. By offering a comprehensive review of the literature in this field, it seeks to contribute to the identification and implementation of effective policy strategies to combat climate change.

The study aims to address this need by discussing the following three broad research questions (RQs):

RQ1. What is the current state of research on Carbon Emissions, Climate Change, Carbon Footprint, Carbon Tax, Green Technology Diffusion?
RQ2. Which research contexts and themes in this area have been explored in the existing literature?
RQ3. What avenues or themes could be addressed in future research?

The findings of the study can facilitate the formation of a comprehensive understanding of this evolving research landscape and contribute to the advancement of both theory and practice. The results from the bibliometric analyses provide scholars with a deeper insight into the complexity and interdisciplinary character of previous research in the field. Additionally, through content analysis, various agendas for future research have been identified that scholars can explore.

Methodology

Database and Research Strategy

Bibliometric analysis, introduced by Pritchard (1969), has emerged as a valuable scientific method for comprehending the temporal evolution of a research field from a multidisciplinary standpoint. This method

enables a thorough understanding of a research field, mapping its boundaries, identifying influential authors, and highlighting new directions for future research (Tandon et al., 2021).

The selection of keywords was informed by a preliminary review of the existing literature. A search was conducted in Web of Science using the keywords 'Climate Change' and 'Carbon Footprint'. The first 1000 studies retrieved were then analyzed in VOSviewer to identify additional terms commonly employed in the literature. As a result of this initial search, terms such as 'carbon emissions', 'carbon emissions price', and 'carbon tax' were also deemed valid keywords. To further validate the selected keywords, we convened a panel of three experts from academia with extensive publications in the field of Climate Change, following the methodology outlined by Tandon et al. These experts were briefed on the research questions (RQs) and tasked with reviewing the relevance of the chosen keywords. Based on their recommendations, the following keywords were included in the database search: 'trade openness', 'GDP per capita', 'R&D investment', 'green technology diffusion', 'urbanization', 'energy consumption', 'renewable energy', and 'industrialization' (Figure 1). This information is summarized in Table 1, providing key details about the data.

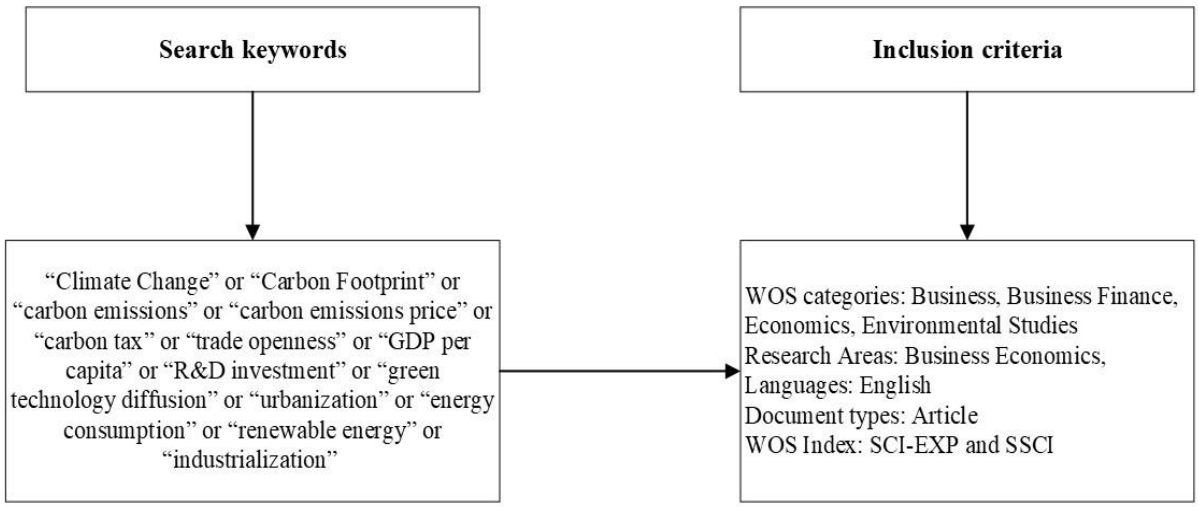

Figure 1. Search keywords and inclusion criteria

Table 1. Main information about data

Description	Results
Timespan	2015:2024
Sources (Journals, Books, etc)	433
Documents	5002
Keywords Plus (ID)	6395
Author's Keywords (DE)	12207
Average citations per doc	23.68
Authors	11572
Authors of single-authored docs	603
Article	4922
Book Chapter	23
Article; Proceedings Paper	57
References	213472
Single-authored docs	646
Co-Authors per Doc	3.01
International co-authorships %	46.12

Analysis and Findings

Publication by Year

The total number of studies in the Web of Science (WoS) database with the selected keywords is 5002, as depicted in Figure 2. It is evident that the number of studies in this field has been steadily increasing since 2015

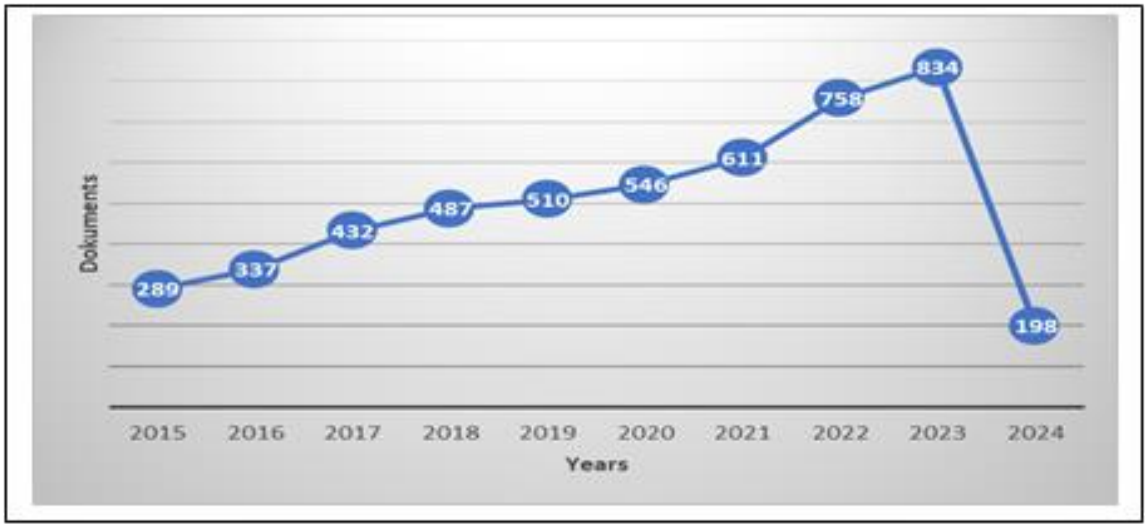

Figure 2. Annual scientific production

The techniques of bibliographic matching, co-occurrence, co-authorship, citation, and co-citation analyses were employed to address RQ1 and construct a comprehensive profile of the research landscape in this field.

Bradford Law and Journal Index Analysis

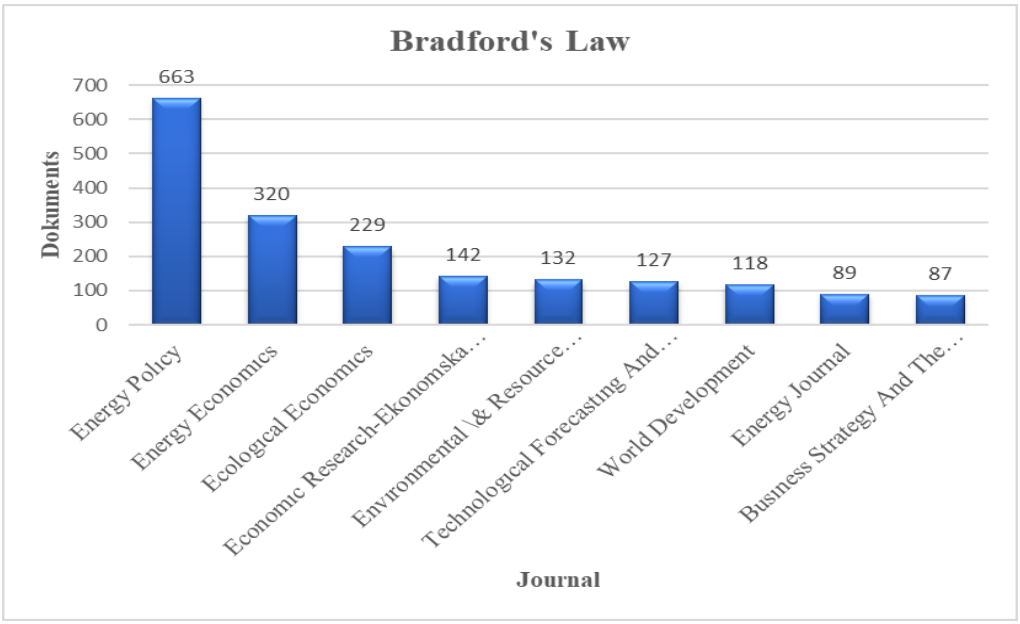

Figure 3. Bradford law

Table 2. Journal index

Journal	h_index	g_index	m_index	TC	NP
Energy Policy	76	112	7,6	23094	663
Energy Economics	59	100	5,9	12456	320
Ecological Economics	41	63	4,1	5751	229
World Development	41	63	4,1	4663	118
Technological Forecasting and Social Change	39	63	3,9	4554	127
Economic Research-Ekonomska Istrazivanja	28	40	2,8	2158	142
Business Strategy and The Environment	25	44	2,5	2144	87
Journal Of Environmental Economics and Management	25	42	2,5	2032	79
Environmental & Resource Economics	24	41	2,4	2127	132

TC: Total Citation; **NP:** Number of Production

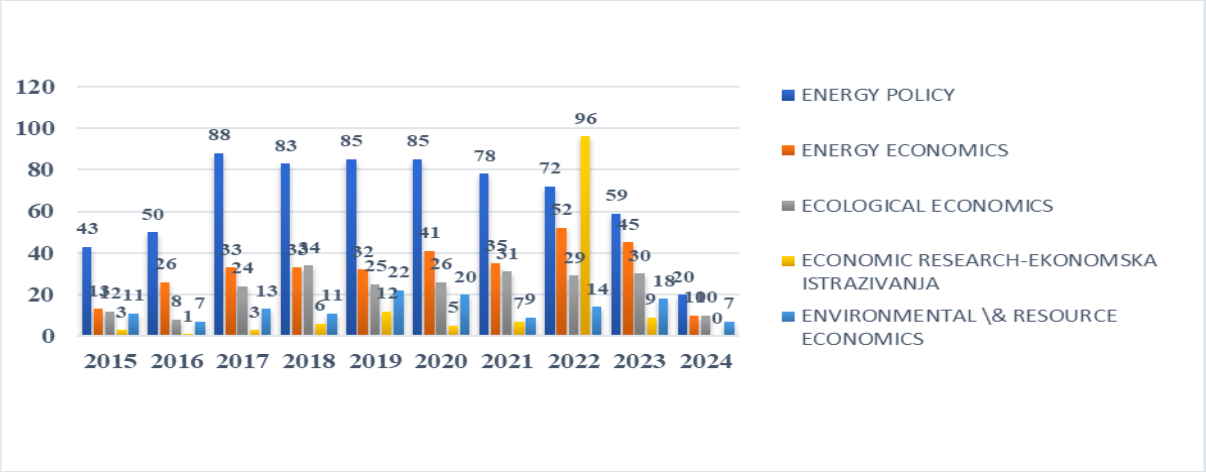

Figure 4. Number of articles published in sources by years

Author and Organization Publishing Trends

Table 3 displays the most cited institutions and authors. Out of 4,119 institutions that published in the research area, 596 institutions have contributed more than 5 publications

Table 3. Citation analysis for top 10 organizations and authors

Id	Organization	Documents	Citations	Author	Documents	Citations
1	Oxford University	96	2693	Shahbaz, Muhammad	26	4774
2	Cambridge University	84	2506	Sovacool, Benjamin K.	17	862
3	Swiss Fed Inst Technol	76	1954	Paramati, Sudharshan Reddy	16	804
4	Vrije Univ Amsterdam	74	1424	Van Der Ploeg, Frederick	16	246
5	UCL	72	2363	Shi, Xunpeng	14	650
6	Utrecht University	69	2028	Managi, Shunsuke	12	652
7	World Bank	61	1288	Apergis, Nicholas	11	560
8	NBER	59	2714	Rausch, Sebastian	11	213
9	Sussex University	59	2543	Edenhofer, Ottmar	10	146
10	Leeds University	56	2211	Mahalik, Mantu Kumar	10	1382

Publishing Activity by Country

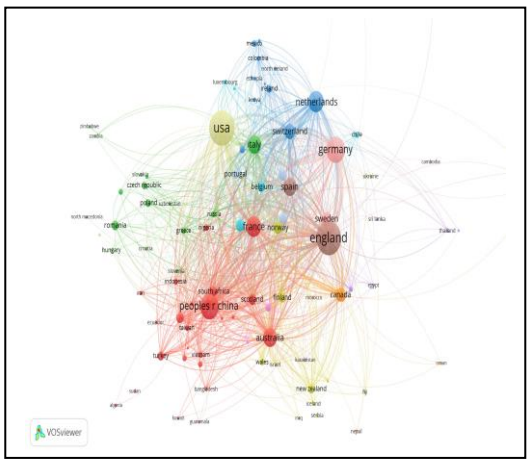

Figure 5. Countries analysis

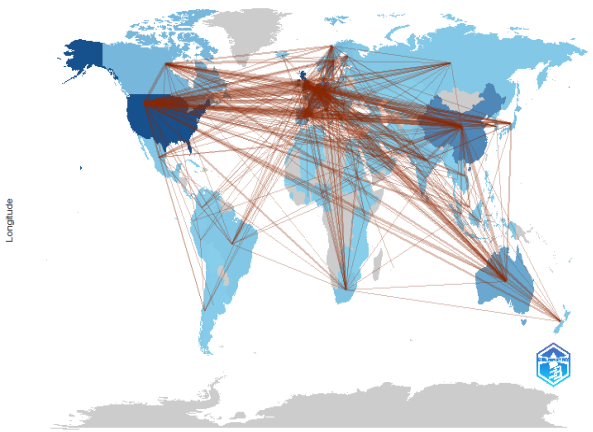

Figure 6. Countries' Collaboration

Within the scope of this research, the countries involved in studies with international co-authors were examined (Figure 5). Figure 6 displays the world map of international co-authorships in the 5,002 studies subjected to bibliometric analysis. Among the 34 countries that contributed to this topic, 23 countries produced only one publication. Table 4 presents the top 25 countries with the highest number of publications, with Turkey ranking 25th. Collaboration among the top 10 countries is outlined in Table 4.

Table 4. Citation analysis for countries

Id	Country	Documents	Citations	Total Link Strength	Id	Country	Documents	Citations	Total Link Strength
1	Usa	1145	33737	2877	13	Norway	156	3020	325
2	England	1075	35122	2900	14	Denmark	136	3831	333
3	Germany	645	14590	1695	15	Japan	135	3402	218
4	Peoples R China	609	15967	1254	16	Austria	128	2768	419
5	Netherlands	416	9916	1218	17	Scotland	119	3636	409
6	France	392	13085	1317	18	India	107	3930	361
7	Australia	330	8863	836	19	Belgium	99	2968	294
8	Italy	323	7142	973	20	Finland	96	2049	188
9	Spain	314	8502	697	21	South Africa	93	2670	229
10	Switzerland	221	5346	699	22	Portugal	91	2047	147
11	Sweden	197	5157	436	23	Romania	88	610	79
12	Canada	194	5525	615	24	Pakistan	81	2869	361
					25	Turkey	80	2359	224

Table 5. Collaboration for top 10 countries

From	To	Frequency
Usa	Unıted Kıngdom	179
Unıted Kıngdom	Chına	128
Unıted Kıngdom	Germany	125
Usa	Germany	104
Unıted Kıngdom	Netherlands	100
Germany	Netherlands	91
Usa	Chına	89
Unıted Kıngdom	Italy	74
Usa	Italy	69

Dynamic co-citation and common word analyses were conducted to comprehend the evolution of this field and to discern the focal areas investigated by previous scholars (RQ2). PageRank and citation analyses were performed to identify the 10 most influential publications in each focus area or research theme. Content analysis was utilized to delineate the key topics within each area.

Keyword Analysis: The most frequently recurring words in the author's keywords (a), titles keywords (b), abstract keywords (c), and keywords plus (d) sections of the studies examined in the research are shown in the word cloud in Fig7.

Thematic Map

Climate change stands as one of the paramount environmental challenges of our time. Effectively addressing this challenge necessitates the consideration and implementation of a blend of policies, technologies, and societal approaches across various domains. In order to grasp the ontological and epistemological foundations of the field, a coupling analysis clustering has been conducted (Tandon et al., 2021; Kaur, 2024). The selected keywords are determined to best reflect the content of the articles, offering insights into the topics covered in the publications. Furthermore, through network and text analysis, the embedded keywords and patterns within these words can illuminate the composition of the publications. In this context, a Conceptual Structure Factorial Analysis, based on Multiple Correspondence Analysis, was conducted using the Bibliometrix package integrated into Biblioshiny user interfaces. The resulting thematic structures are depicted in Figure 8. Based on

the analysis, four thematic areas were delineated corresponding to the four clusters identified through dynamic co-citation analysis (Table 6). The most influential articles published in each cluster (Table 7) serve as indicators of the thematic focus within this domain. Consequently, the top 10 most influential articles from each cluster were subjected to content analysis to extract the primary insights and objectives of each analyzed article (Tandon et al., 2021).

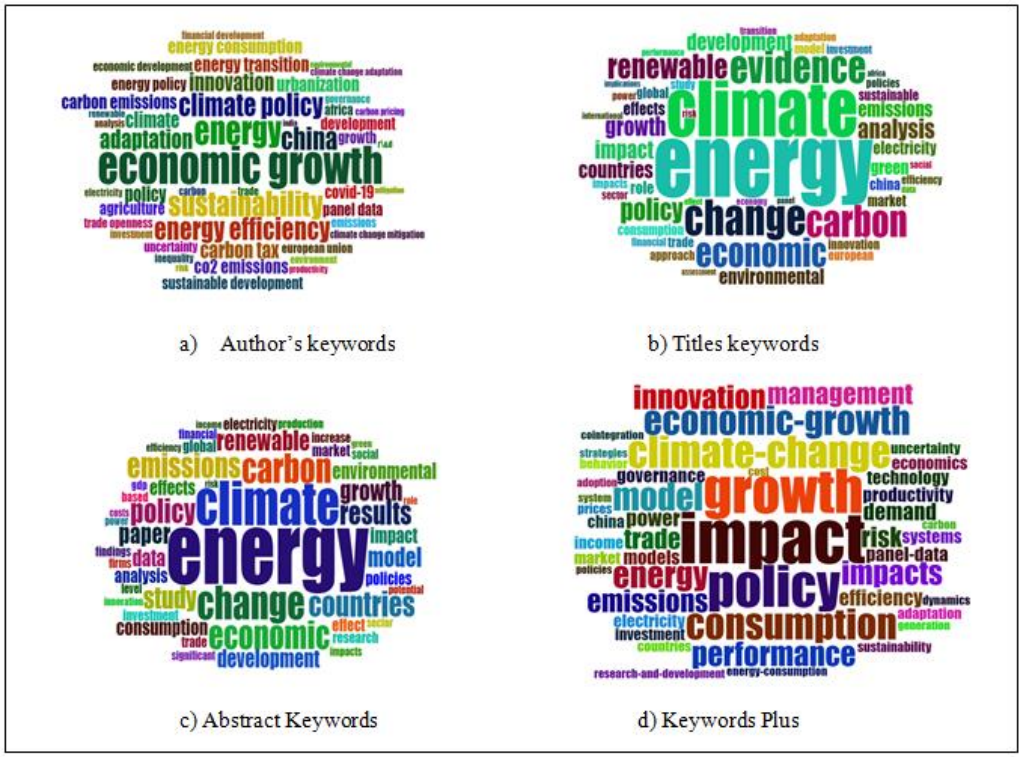

Figure 7. Keyword analysis

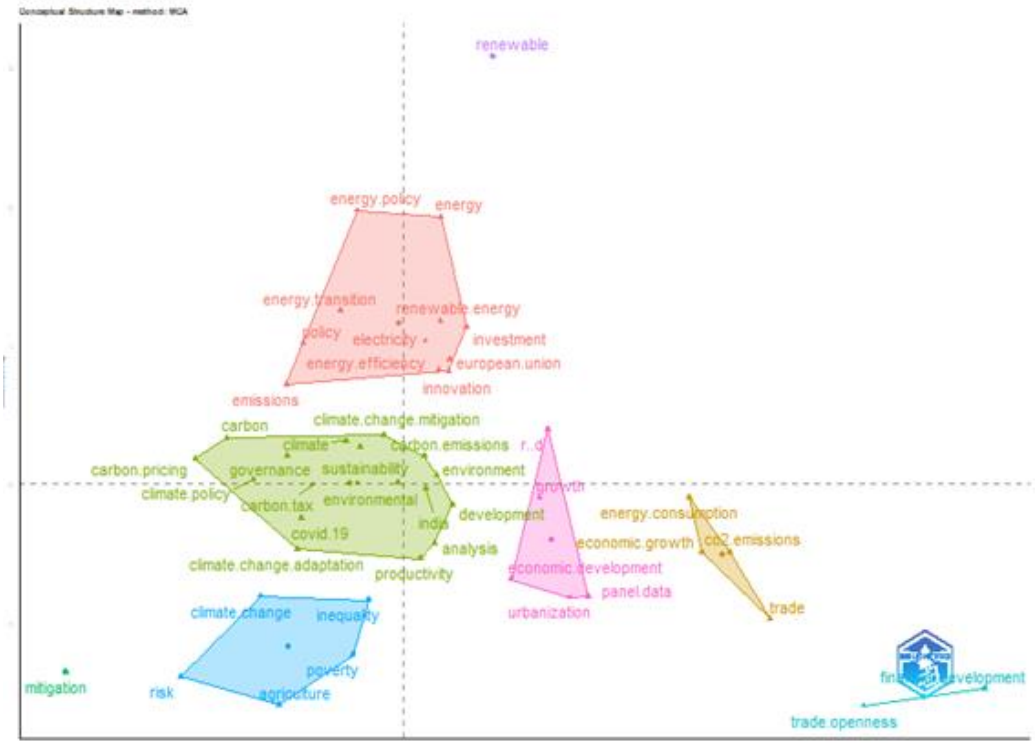

Figure 8. Factorial analysis

Table 6. Clusters analysis

Cluster	CallonCentrality	CallonDensity	RankCentrality	RankDensity	ClusterFrequency
Climate Change	0,01750499	1,43511606	2	1	1207
Renewable Energy	0,02663892	1,45768705	4	2	1056
Climate Policy	0,01044803	1,70783574	1	3	436
Economic Growth	0,01931001	1,82951589	3	4	847

Table 7. Top 10 prestigious publications according to thematic clusters.

S. No	Authors	Pagerank	Authors	Pagerank
	Cluster 1 Climate Change		**Cluster 2 Renewable Energy**	
1	Pleegıng et al. (2021)	0,107325	Mecu et al. (2023)	0,131724
2	Ferreıra et al. (2020)	0,103048	Harjanne and Korhonen (2019)	0,101646
3	Gosslıng et al. (2016)	0,100224	Albert (202)2	0,101313
4	Berner et al. (2022)	0,097934	Bastarrıca et al. (2023)	0,098734
5	Abidoye and Odusola (2015)	0,096986	Hılber et al. (2019)	0,093551
6	Nippa et al., 2021	0,095855	Handayanı et al. (2019)	0,092754
7	Duran-Romero et al, 2020	0,088611	Ghadge et al.(2020)	0,092754
8	Andrade and De Olıveıra (2015)	0,088204	Cao et al. (2017)	0,092754
9	Steınbuks and Hertel (2016)	0,088179	Baum et al. (2023)	0,092754
10	Belaia et al. (2021)	0,085668	Mclaughlin et al. (2019)	0,082495
	Cluster 3 Climate Policy		**Cluster 4 Economic Growth**	
1	Macaluso et al. (2018)	0,092925	Leitao and Balogh (2020)	0,14526
2	Mukanjarı and Sterner (2020)	0,091128	Salari et al. (2021)	0,113742
3	Klenert et al. (2020)	0,089271	Jınqıao et al.(2022)	0,107228
4	Budolfson et al.(2019)	0,087594	Kuzemko et al., 2019	0,09197
5	Kornek et al. (2021	0,080638	Desmet and Rossi-Hansberg (2015)	0,091876
6	Andersson (2023)	0,078078	Ansell and Cayzer (2018)	0,091239
7	Dıng et al. (2023)	0,076525	Casey (2024)	0,091239
8	Lahcen et al. (2020)	0,076297	Fernandes et al. (2021)	0,088478
9	Balint et al. (2017)	0,075954	Kahn et al. (2021)	0,088478
10	Tol (2019)	0,075954	Rezai (2018)	0,088478

Cluster 1. Climate Change

The ten most influential publications on climate change are outlined in Table 7. These studies were subjected to content analysis, revealing a common theme emphasizing the pivotal roles of policy, technology, and societal interactions across various domains in combating climate change. The findings underscore the necessity of considering policy, technology, and societal approaches collectively to effectively address climate change. Furthermore, these studies delve into topics such as climate change and economic growth in Africa, carbon emissions and the policies of multinational corporations, circular economy practices, the role of the private sector in global climate and energy governance, and global land use and solar geoengineering.

Abidoye and Odusola (2015) demonstrate that rising temperatures have a detrimental effect on gross domestic product (GDP) growth, particularly highlighting the African continent's vulnerability to the adverse effects of climate change on economic growth. The role of the private sector in global climate and energy governance is expanding. This research underscores the private sector as a pivotal stakeholder in the development and implementation of climate and energy policies. Engaging the private sector is crucial for the effective functioning of climate and energy regimes. Global land use dynamics involve a complex interplay of economic, agricultural, and biophysical factors. Steinbuks and Hertel (2016) explored various modeling and analytical methods to comprehend the impacts of climate change on global land use. Among various sectors, the agricultural sector is particularly experiencing significant impacts due to climate change.

The transportation sector stands out as a significant contributor to climate change, emphasizing the crucial importance of policies in this domain. In an assessment of climate policies within the European Union and Gossling et al. (2016) delved into mitigation targets and policy effectiveness, focusing on twelve policy officials from three Directorates General. This research sheds light on differing and common perspectives regarding climate policy objectives and challenges in policy implementation. Multinational corporations have emerged as integral players in carbon mitigation efforts. According to Nippa et al. (2021), multinational companies demonstrate more consistent carbon reductions and overall better carbon performance compared to domestic

firms. National and international carbon regulations play a pivotal role in shaping companies' carbon policies. Incentives for green energy, policies for technology transfer, climate regulations in the transportation sector, and measures to enhance energy efficiency are all critical components in the effective fight against climate change.

The promotion of green energy stands as a pivotal step in combating climate change Pleeging et al. (2021) reveal that individuals with a hopeful outlook are generally more inclined to pay a premium for green energy. In this context, it is underscored that hopeful individuals exhibit an enhanced willingness to invest in green energy, while acknowledging the gravity of the issue. Research on technology transfer and the impact of environmental patents in Europe yields significant insights. Ferreira et al. (2020), in their investigation of technology transfer within the European continent, explored the effects of environmental water-related adaptation technologies and climate change mitigation patents on economic growth. These studies shed light on the influence of environmental patents on Europe's economic performance and how geographical location determines levels of entrepreneurial activity. Enhancing energy efficiency has emerged as a crucial avenue for reducing greenhouse gas emissions.

A study conducted by Berner et al. (2022) delved into the economy-wide recovery effects of energy efficiency improvements and their long-term impact on energy use. This study underscores that innovations in energy efficiency can offer limited assistance in curbing future energy consumption and may be associated with economic growth. The concept of Circular Economy (CE) is emerging as a pivotal strategy in the fight against climate change. Research by Durán-Romero et al. (2020) demonstrates that CE eco-innovations can make substantial contributions to climate change mitigation objectives. Evaluating the interplay between CE and climate policies represents a crucial stride towards sustainability. Solar geoengineering (SE) and carbon dioxide removal (CDR) technologies hold significant promise as methods for mitigating climate change. Studies by Belaia et al. (2021) reveal that the integration of SE and CDR technologies can serve as an effective strategy for reducing greenhouse gas emissions. The contributions of these technologies to climate policies underscore their vital role in decreasing the carbon intensity of energy systems and industrial processes.

Cluster 2. Renewable Energy

The research within this cluster underscores that the shift towards renewable energy carries significant implications across various domains such as energy policy, economic growth, global geopolitics, and climate change. Within this context, these studies bring the attention of policymakers and society towards a more sustainable energy future. By centering on renewable energy, this body of research urges contemplation on the reformation of energy policies and its multifaceted economic, social, and environmental aspects. It also serves as a crucial reference point for comprehending the ramifications of the energy transition on global politics and economy, thus shaping future policies and strategies. These studies hold the potential to enhance awareness and galvanize pertinent stakeholders into action, offering insights into the opportunities and challenges stemming from the transformation of the energy sector. Hence, grasping the pivotal dimensions of the transition to renewable energy and evaluating its impacts stand as integral components in steering future energy policies and fostering societal transformation.

The concept of renewable energy has been a subject of extensive debate due to its central role and impact on energy policies. Harjanne and Korhonen (2019) shed light on this discourse by providing a theoretical analysis of the definition and framework of renewable energy. Within the realm of global politics, the transition to renewable energy emerges as a pivotal focal point, with arguments suggesting it could precipitate a structural transformation in the world order. Albert (2022) and other scholars underscore that renewable energy has the potential to reshape patterns of economic growth and military competition. Significant revisions in strategies to combat climate change have been observed within the European Union. Studies within this context have unveiled that ambitious targets set forth in energy policies prove effective in curbing greenhouse gas emissions and bolstering economic growth (Mecu et al., 2023).

The decarbonization of electricity supply stands out as a crucial step in the battle against climate change. Bastarrica et al. (2023) highlight the welfare implications of scenarios aimed at reducing CO2 emissions from electricity generation, alongside the substantial costs associated with the deployment of renewable energy. Studies have also delved into the effects of historic preservation policies on energy efficiency. Hilber et al. (2019) investigate the impact of these policies on energy costs and the social costs of carbon, specifically examining the influence of national energy prices on household energy efficiency installations. Moreover, the significance of technological learning in the diffusion of renewable energy is underscored. Handayani et al. (2019), in their examination of the electricity system, demonstrate that investments considering technological

learning can diminish the costs of electricity generation, rendering renewable energy competitive with other energy sources.

Bioethanol production emerges as a pivotal issue concerning its impacts on climate change. Ghadge et al. (2020) underscore that bioethanol supply chains hold the potential to mitigate the risks of climate change, emphasizing the criticality of sustainable feedstock utilization. Addressing the nexus between fossil fuel consumption, climate change, and bioenergy solutions, Cao et al. (2017) assert that bioenergy technologies can offer substantial contributions through carbon sequestration. Furthermore, the study delves into the role of advanced technologies such as solar radiation management and carbon dioxide removal in climate response strategies. Baum et al. (2023) elaborate on the impacts and viability of these technologies, accentuating their significance in confronting the climate challenge. Finally, the literature also includes studies on the role of accounting professionals on carbon taxes and energy companies' compliance with these taxes. McLaughlin et al. (2019) summarize the research on this topic and assess what role accounting and tax policies can play in the field of renewable energy.

Cluster 3. Climate Policy

The papers within this cluster provide an intricate analysis of the multifaceted effects of carbon tax scenarios on sectoral output, energy consumption, and the broader US economy. The analyses aim to discern how differences in trajectories of carbon tax and various revenue utilization options impact sectoral-level patterns (Macaluso et al., 2018). Furthermore, these studies delve into the potential impacts of the COVID-19 crisis on the green economy, the corporate environmental responsibility, and diverse facets of carbon emissions. Additionally, they explore the potential effects of environmentally friendly construction projects on both the economy and the environment (Mukanjari and Sterner, 2020).

When assessing the relationship between income inequality and carbon emissions over time, it is important to consider the potential effects of environmentally friendly construction projects on both the economy and the environment. This examination suggests that this relationship should be thoroughly understood and taken into account in policy-making (Andersson, 2023). There is a notable emphasis on the economic and social dimensions of climate change, global inequality, and the feasibility of climate policies. It is argued that by drawing lessons from the COVID-19 crisis, there is a necessity to enhance the applicability of climate policies and prepare for future crises (Klenert et al., 2020). In the evaluation of various scenarios regarding the relationship between the COVID-19 pandemic and the green economy, the impacts of investments in environmentally friendly construction projects to stimulate the economy are analyzed (Lahcen et al., 2020). Additionally, carbon tax scenarios are examined with a focus on changes in sectoral output and energy consumption, assessing their impact on the competitiveness of the US economy (Macaluso et al., 2018)

In considering the implications of the COVID-19 crisis for climate change policies, ethical considerations arise regarding how much future generations should be expected to sacrifice to reduce carbon emissions today (Budolfson et al., 2019). Ding et al. introduce optimal taxation models that account for the social cost of carbon, addressing the distributive aspect of climate policies. They also highlight the importance of increased climate-related disclosure for companies with high carbon emissions, aiming to enhance their environmental responsibility (Ding et al., 2023). Furthermore, the study delves into the role of complex systems models in the fight against climate change and their economic implications. It examines national climate change impact functions used to estimate the social costs of carbon in poorer countries, as well as the sensitivity of these models to economic growth. The recommendation is made to estimate the national social costs of carbon in impoverished nations and assess the impacts of climate policies on a global scale (Tol, 2019).

The articles in cluster 3 provide recommendations for companies, governments and researchers in combating climate change in a wide range of areas:

There are several important steps that companies can take to fulfill their environmental responsibilities and reduce carbon emissions. These steps include setting decarbonization targets that aim to reduce carbon emissions over a certain period of time (Ding et al., 2023). At the same time, transitioning to green energy use by meeting their energy needs from green and renewable energy sources (Mukanjari and Sterner, 2020) stands out as an effective way to reduce carbon emissions.

Decarbonizing production processes or investing in technological innovations to reduce carbon emissions (Macaluso et al., 2018) can assist companies in achieving their sustainability objectives. Furthermore,

collaborating with sustainable suppliers, considering environmental impacts in supply chain management (Andersson, 2023), implementing waste management policies, and initiating recycling programs all contribute significantly to reducing companies' environmental footprint. Training employees in environmentally friendly practices and fostering environmental awareness within the organization are crucial steps in promoting environmental responsibility (Balint et al., 2017). Lastly, regular reporting and maintaining transparency regarding their environmental performance (Ding et al., 2023) are essential tools for companies to monitor their progress toward achieving environmental goals. These strategies collectively enable companies to fulfill their environmental responsibilities and establish a sustainable business model for the future.

States can adopt various policies and strategies to play a crucial role in combating climate change. These include implementing a range of economic instruments and incentives to promote reductions in carbon emissions and the adoption of green energy (Klenert et al., 2020). For instance, efforts to reduce carbon emissions can be incentivized through mechanisms such as carbon taxes or emissions trading (Macaluso et al., 2018). Additionally, states can offer financial support and incentives to encourage investments in renewable energy sources (Mukanjari and Sterner, 2020).

States can introduce various standards and regulations to enhance energy efficiency (Andersson, 2023), which can both reduce energy consumption and lower carbon emissions. Additionally, they can accelerate the transition to a carbon-free economy by investing in green infrastructure projects and developing environmentally sustainable transportation systems (Lahcen et al., 2020). National and international cooperation is also crucial in the fight against climate change. By participating in international climate agreements and setting common goals on climate change, states can facilitate the implementation of effective policies globally (Kornek et al., 2021). Finally, raising awareness and mobilizing society on climate change through environmental education and awareness campaigns is another crucial step that states can take (Tol, 2019). The combination of these policies and strategies can empower states to effectively combat climate change and pave the way for a sustainable future.

Researchers can play a pivotal role in combatting climate change through their scientific endeavors. Initially, they can engage in interdisciplinary studies aimed at better understanding the causes and ramifications of climate change. These endeavors might involve the development of climate models, analysis of the carbon cycle, research into the economic and social impacts of climate change, and related areas (Balint et al., 2017). Additionally, researchers can focus on research and development efforts to cultivate green technologies and enhance efficiency (Klenert et al., 2020). Providing policymakers and companies with precise data and analyses to inform effective climate change policies and strategies is also among the responsibilities of researchers (Mukanjari and Sterner, 2020). Furthermore, they can contribute to communication and advocacy campaigns to raise awareness and educate the public about climate change (Tol, 2019).

Moreover, researchers can disseminate their knowledge and findings at international conferences, prepare reports assessing the impact of climate policies, and collaborate with policymakers to help shape evidence-based policies (Kornek et al., 2021). Finally, they can contribute to mobilizing the public and influencing policy demands by presenting information about climate change in a clear and accessible manner (Andersson, 2023). All of these endeavors can empower researchers to play a significant role in combatting climate change and make a valuable contribution to a more sustainable future.

Cluster 4. Economic Growth

In the fourth cluster, research delves into the impacts of diverse economic and environmental factors on climate change, alongside policy measures. Studies within this cluster delve into the effects of variables such as energy consumption, financial policies, technological innovations, trade dynamics, and CO2 emissions on both economic growth and environmental sustainability across different countries and regions. These inquiries underscore crucial factors and potential solutions that policymakers and economists must take into account when addressing the challenges of climate change.

The European Union's endeavors to attain its 20% reduction target in greenhouse gas emissions by 2020, aimed at addressing climate change, are bolstered by research assessing the environmental ramifications of factors such as energy consumption, agriculture, and trade (Fernandes et al., 2021). Similarly, the correlation between CO2 emissions, energy consumption, and economic growth in U.S. states has been scrutinized utilizing state-level data, with a particular emphasis on the influences of various energy consumption types on CO2 emissions (Salari et al., 2021). Within the Emerging Seven Countries, investigations into the impacts of financial

development and technological innovation on climate change have been conducted using dynamic panel data models, showcasing that while financial development holds a direct adverse effect, its impact turns positive through technological innovation (Jinqiao et al., 2022).

These studies illustrate that sustainable technology transfer and innovation promote green growth, and this green growth, in turn, positively influences economic growth (Fernandes et al., 2021). The long-term impacts of climate change on economic activities have been investigated on a global scale, revealing that the global temperature rise negatively affects world GDP, with these effects varying significantly among countries (Kahn et al., 2021). Furthermore, the effects of energy policies and the role of technological innovations in energy use have been explored, with a focus on the dynamics of energy consumption following increases in energy efficiency and the impacts of incentivizing policies (Casey, 2024). These studies underscore crucial factors and solutions that policymakers and economists must consider in the fight against climate change. Researchers have explored the relationship between climate change and economic growth, aiming to discern the impacts of financial development and technological innovation on climate change (Jinqiao et al., 2022).

In a separate study, which focused on energy consumption and CO2 emissions, the environmental impacts in U.S. states were analyzed, investigating the effects of various forms of energy consumption on CO2 emissions (Salari et al., 2021). Moreover, research on the enduring consequences of global warming has revealed that the global rise in temperature detrimentally affects economic activities on a global scale, with considerable variation among countries based on climatic conditions (Kahn et al., 2021). Researchers have put forth recommendations to improve the efficacy of climate change policies and advance sustainable growth based on these insights. Additionally, research on the correlation between green growth and economic expansion underscores that sustainable technology transfer and innovation foster green growth, ultimately benefiting economic advancement (Fernandes et al., 2021). These studies underscore critical factors and solutions that policymakers and economists should take into account when addressing the challenge of climate change.

Among the critical considerations for economists are the following: First, the heterogeneous economic impacts of climate change, which vary across countries, sectors, and income groups, must be acknowledged (Kahn et al., 2021). Hence, these distinctions are crucial when crafting policies to adapt to and mitigate the effects of climate change. Second, the influence of environmental factors such as energy consumption and CO2 emissions on economic growth warrants examination (Salari et al., 2021). It is noted that policies promoting green growth positively affect economic advancement while bolstering environmental sustainability. Third, the ramifications of financial development and technological innovation on climate change should be factored in (Jinqiao et al., 2022).

Certainly, the promotion of sustainable technology transfer and innovation should be highlighted, as they stimulate green growth and exert a positive influence on economic advancement. Lastly, comprehending the enduring impacts of global warming on economic activities and discerning the variability of these effects across diverse geographical regions and income groups is crucial (Desmet & Rossi-Hansberg, 2015; Rezai et al., 2018). All these factors collectively aid economists and policymakers in formulating effective policies and strategies to combat climate change.

Future Research Directions

Based on the outcomes of dynamic co-citation, coupling, and citation analyses, several promising avenues for future research have been suggested in response to RQ3. These potential areas of exploration aim to further enhance our understanding of the complex interplay between climate change, economic growth, and policy interventions. Here are some proposed avenues:

1. Environmental factors and economic growth: Delving deeper into the effects of environmental factors, such as energy consumption and CO2 emissions, on economic growth can offer valuable insights. Future research could explore the nuanced relationships between these variables, considering various policy interventions and their effectiveness.
2. Financial development and technological innovation: The role of financial development and technological innovation in climate change mitigation and adaptation strategies presents a rich area for exploration. Investigating how these factors interact and influence each other, particularly in the context of green growth, could provide actionable policy recommendations.
3. Sustainable technology transfer and innovation: A focus on the promotion and dynamics of sustainable technology transfer and innovation can significantly contribute to green growth. Future studies might delve

into the mechanisms, drivers, and barriers to effective technology transfer, especially in the context of developing economies.
4. Long-term effects of global warming: Understanding the enduring repercussions of global warming on economic activities remains crucial. Future research could aim to forecast and model these effects, considering different climate scenarios and their implications for economic sectors and regions.
5. Policy evaluation and effectiveness: Continual assessment of the effectiveness of climate change policies is essential. Future studies could focus on evaluating existing policies, identifying best practices, and proposing innovative policy frameworks that integrate economic growth with environmental sustainability.

Conclusion

This paper offers an evaluation of global research trends in publications on carbon emissions, climate change, carbon footprint, carbon tax, and green technology diffusion from 2015 to 2024. These subjects have constituted a comprehensive research field since 2015, characterized by a marked growth in publication output. This field of study is divided into four main research areas: (1) Climate Change, (2) Renewable Energy, (3) Climate Policy, and (4) Economic Growth. These studies, subjected to content analysis, have revealed a common theme emphasizing the pivotal roles of policy, technology, and societal interactions across various domains in combating climate change. The findings underscore the necessity of considering policy, technology, and societal approaches collectively to effectively address climate change.

Several positive aspects can be drawn from bibliometric analysis. Firstly, since multi-authored publications constitute approximately three-quarters of all publications, it can be concluded that there is a considerable amount of collaborative research in this field. Secondly, there is a wide variety of journals publishing on the subject, with diverse topic categories allocated to the publications in the field, indicating a broad range of research themes and the interdisciplinary nature of the field. This research has revealed that the journals with the highest number of articles in this field and the highest number of citations were Energy Policy, Energy Economics, Ecological Economics, Economic Research-Ekonomska Istrazıvanja, Environmental & Resource Economics, Technological Forecasting, and Social Change. In terms of the number of articles and citations by country in these fields, the USA, England, Germany, China, and the Netherlands ranked the highest.

Finally, it is important to note some limitations of this bibliometric study. Firstly, the search was limited to publications listed in the Web of Science. While Web of Science is one of the largest global databases, it does not encompass all publications in the field of carbon emissions, climate change, carbon footprint, carbon tax, and green technology diffusion. Other international databases such as Scopus could have also been utilized.

Recommendations

The author of this study recommends examining carbon emissions, climate change, carbon footprint, carbon tax, and green technology to acquire guidance and insight into the topics that future researchers may focus on in their own studies. Additionally, they suggest finding journals, countries, and other authors that may be interested in their work.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

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Internet of Things (IoT) in Intelligent Transportation Systems: Benefits and Challenges of Implementation

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Abstract: This study examines intelligent transportation systems and evaluates the applications of the Internet of Things technology in intelligent transportation systems. Moreover, this study discusses the many challenges and benefits of the functionalization of the Internet of Things (IoT) in intelligent transportation systems. Based on the increasing demands of transportation development, the concept of an intelligent transportation system and Internet of Things technology has received increasing attention both in the academic and transportation industries. The increase in traffic accidents in transportation and the lengthening of travel times have led to the emergence of the need for IoT. Developing a sustainable intelligent transportation system requires seamless integration and interoperability with emerging technologies such as connected IoT and vehicles. IoT in intelligent transportation systems decreases the number of vehicles in traffic and reduces harmful gas emissions. Intelligent transportation systems play a key role in increasing traffic safety, optimizing existing road capacity, and reducing delay times. In addition, it contributes to the country's economy and the environment by reducing the inefficient use of time and energy. The IoT in intelligent transportation systems will be one of the most important competitive elements for all countries. This study sheds light on IoT technology in intelligent transportation systems and points out possible future research directions.

Keywords: Internet of Things, Intelligent transportation systems, Benefits, Challenges.

Introduction

Nowadays, IoT technologies are assumed to be one of the key pillars of the fourth industrial revolution because of their significant potential for innovation and useful benefits for the population. Intelligent transportation systems are a rapidly developing concept within the framework of sustainability and IoT worldwide, especially in countries such as the United States, Netherlands, Sweden, Japan, Canada, Singapore, Germany, United Kingdom, Australia, France, and South Korea. New-generation technology in transportation facilitates a range of revolutionary implementations. This technology is designed to solve operating problems on highways and improve service quality. It has been enriched with different transportation modes, such as airports, ports, and subways, over time. With the rapid development of the Intelligent Transportation System, transportation infrastructure has significant potential, and due to the widespread demand for services associated with transportation cheaper, sustainable, efficient, and safer (Camacho et al., 2018).

IoT can modify the business processes, strategies, and competencies across the transportation sector through a new computing paradigm. Through the adoption of IoT, objects, and machines may correspond with each other, locate, sense, and control via the global platform (De Vass et al., 2018). The Internet of Things (IoT) brings a new era to transportation systems. Nowadays smart devices collect and enhance important data over the Internet and also connect the devices to intelligent transportation (Muthuramalingam et al., 2019). Recently, transportation modes have changed greatly, and the concept of the internet of vehicles has come to the fore. Thus, transportation infrastructures must be developed to adapt to certain vehicle technologies. Smart vehicles are a concept that is integrated into the Internet of Things technology and focuses on optimization (Shen et al., 2020). Using the IoT will increase driving comfort and safety. In addition, this technology will collect data on

the vehicle and provide information in areas such as fuel filling, early detection of possible malfunctions, and regular maintenance indicators. IoT prevents collisions with autonomous vehicles and greatly reduces transportation problems (Nižetić et al. 2020). It has helped reduce accidents, especially by simultaneously monitoring the location and directions of autonomous vehicles from security systems (Bylykbashi et al., 2020).

The motive of our research is to define the breadth, depth, and diversity of present research IoT in intelligent transportation. As a result, an enormous number of research publications in journals and conferences are based on IoT in intelligent transportation. This paper presents an overview of IoT in intelligent transportation applications and explores its benefits and challenges. It is organized to give a big picture of IoT applications in intelligent transportation.

Literature Reviews

Intelligent Transportation Systems

Intelligent Transportation Systems (ITS) is an emerging transportation construction that incorporates real-time information and corresponds between passengers, roads, and vehicles. The fundamental goals of ITS have been focused firstly on these applications presenting a large amount of information while increasing safety and improving mobility and efficiency. In addition, it is now well-known that ITS can be used to decrease transportation-related environmental impacts. Intelligent transportation is a framework that enhances sustainability and public transportation and optimizes modes of transportation (Papadimitratos et al., 2009).

The concept of ITS has witnessed remarkably enhanced applications in recent years, with traffic information systems, driver control systems, intelligent vehicle parking systems, traffic monitoring systems, longitudinal assistance systems, and lateral assistance systems (Barth et al., 2015). This technology is combined with advancement utilizing equipment, PCs, communications, and impelled sensors. ITS has been designed and implemented in many countries such as the U.S., Japan, and Europe (Camacho et al., 2018).

Japan is the first country Which conducts intelligent transportation system applications in the world. This country has developed intelligent transportation systems that focus on reducing traffic congestion and increasing traffic safety and fuel efficiency (Suryadithia et al. 2021). Intelligent transportation systems in the U.S. were first established between 1960 and 1970 to ensure effective communication between vehicles and roads. It developed in the 1980s with the cooperation of the public and private sectors. Intelligent transportation systems in the U.S. vary by state, and no integration covers the entire country. The most important element is that intelligent transportation systems should not be seen as a national strategy. Canada has broken new ground in intelligent transportation system technology. The first computer-controlled traffic signal system in the world was implemented in 1959. The full electronic toll system was applied worldwide in Canada in 1999 (Al-Dweik et al., 2017).

Table 1. Benefits of ıntelligent transportation systems

Benefits	**References**
Improving safety Increasing traffic accidents Reducing environmental impacts Enhancing mobility Improving transportation efficiency Decreasing energy consumption Real-time information Selecting the optimal routes in the roadway network Spreading out the peak traffic volume Reducing greenhouse gas emissions Managing travel demand Estimating traffic flow Promoting and increasing the use of public transportation	Barth et al. (2015), Ran et al. (2012), Camacho et al. (2017), Haynes et al. (2000), Shaaban et al., (2021) and Cheng et al.(2020).

The history of intelligent transportation system applications in Australia dates back to the 1970s. Australia has focused on road transportation and is expected to gain economic benefits by increasing investments in intelligent transportation systems because of geographical factors to ensure efficiency (Chowdhury et al., 2020). Today, route guidance and communication systems called navigation have been implemented as the Electronic

Route Guidance System in the USA (1969), the Comprehensive Automobile Control System in Japan (1973), and the Driver Radio Broadcast Information System in Germany (1974). The transition to intelligent transportation systems in Turkey began in 1992 with the implementation of automatic toll payment systems on highways (Bıyık & Yigitcanlar, 2020).

The International Intelligent Transportation Systems Congress held in Paris in 1994 is recorded in history as an example of the first steps in the formation of worldwide standards. Singapore is among the leading cities in traffic congestion. The average vehicle speed in Singapore was measured at 27 km/h, compared to an average speed of 16 km/h in London and 11 km/h in Tokyo. This country proposes to reduce traffic congestion by utilizing an Electronic Road Pricing system, where tolls vary according to traffic flow, The Highway Monitoring and Advisory System warns drivers of traffic accidents on main roads (Muthuramalingam et al., 2019).

Internet of Things (IoT)

IoT is a dynamic network structure that proposes to confederate the physical and the virtual fields by utilizing the internet as the medium for communication and transmission of data (Balaji et al., 2019). The concept of the "Internet of Things" was first founded by Ashton (1999). Since then this technology began to be used effectively in the medicine, industry, agriculture, and defense sectors and paved its way into our day-to-day lives. IoT applications software authorizes interaction between devices, and human-to-device communications modes are reliable and decisive (Lee et al., 2022). This application is a combination of managing sensor data calculating data analytics and arranging the traffic system effectively (Muthuramalingam et al., 2019).

Table 2. Benefits of IoT Applications

Benefits	**References**
Providing competitive advantage Increasing proactivity Ensuring a good planning strategy Decreasing the costs Having more control over operations Synchronizing information flow with physical flow Boosting the ability to supply chain integration Rising transparency and visibility of data Improving life quality Enhancing customer satisfaction	Nižetić et al. (2020), Selvaraj and Sundaravaradhan (2020), Reyna et al. (2018), Narasimha Swam (2016), Zikria et al. (2021), Yao et al. (2021), Nayak et al. (2016), Balaji et al. (2019), Porkodi and Bhuvaneswari (2014) and Lee et al. (2022).

Shaaban et al. (2021) identified the challenges of IoT applications such as the cultural structures of countries, stakeholder coordination, and integrating existing systems. On the other hand, Camacho et al. (2018) categorized the challenges in IoT applications as strategic challenges, system capabilities challenges, legal challenges, organizational challenges, and standardization challenges. One of the IoT challenges is the development of different tools for monitoring network operations. (Kakkavas et al. 2020). Additionally, several IoT problems exist, such as security issues related to IoT networks, software errors, and maintenance demands of IoT networks (Almusaylim et al., 2020).

The slowest Wi-Fi speeds are found in Latin America, the Middle East, and Africa, which also prevents the effective use of IoT. Moreover, another challenge in IoT is data privacy. Since all data transferred from source to destination is transported on the internet, it is very difficult to ensure data security. There is a lack of a standard in the field of IoT. Connecting devices to the internet via IoT is expected to increase in the next years. Managing large numbers of devices over various networks will become harsher. Also, IoT infrastructure is significantly crucial in that when new devices are added to the system, current devices running on the existing infrastructure should not be affected (Lee & Lee, 2015).

Internet of Things Technology (IoT) in Intelligent Transportation Systems

ITS' purpose is to recompose the transaction of vehicles, administrate vehicle traffic, and assist drivers with security. The development of IoT in intelligent transportation systems depends on the interaction between objects, vehicles, machines, and infrastructure (Martínez-Torres et al., 2013).

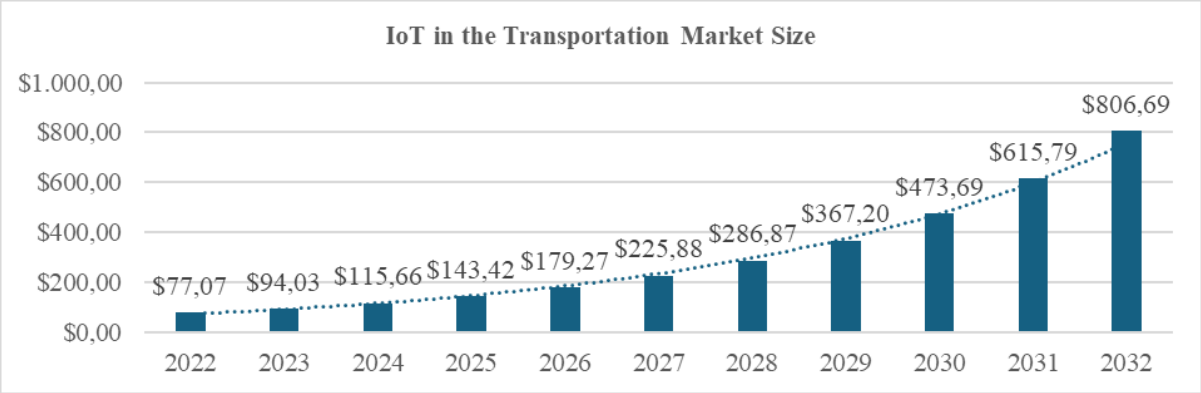

Figure 1. IoT in the transportation market size

According to Figure 1, it is predicted that IoT applications will gradually increase between 2022-2032. IoT in transportation market size is expected to increase by approximately 10.5 times from $77.07 in 2022 to $806.69 in 2032 (Precedence Statistics, 2024).

Table 3. IoT applications in ıntelligent transportation systems literature reviews

References	**Results**
Kaluvan et al. (2021)	IoT-based techniques provide the traffic flow data using machine learning algorithms. These data help to calculate travel time estimation, optimum route planning, and traffic forecasting.
Guevara and Auat Cheein (2020)	IoT will be characterized by the widespread in intelligent transportation services: anywhere, anytime, via any device. 5G technology is projected to enable brand-new classes.
Srinivas et al. (2020)	The data collected in the IoT-based ITS environment has a colossal volume. These data are analyzed to provide information flow to passengers and lead to an increase in the safety, capability, and security of the transportation system.
Luo et al. (2019)	IoT in intelligent transport systems assists a new framework for public transport for consubstantiating the scheduling problems of subway, bus, and shared taxi.
Muthuramalingam et al. (2019)	IoT-based Intelligent transportation system helps automate railway, road, air, and sea transportation which increases customer experience.
Salazar-Cabrera et al. (2019)	IoT applications in Intelligent Transportation Systems can solve mobility issues in cities, decrease traffic accidents, and improve tracking systems for public transport vehicles.
Chand and Karthikeyan(2018)	The IoT device collects, stores, and processes faster way of traffic information, which solves optimizing traffic problems. IoT improves the performance of intelligent transportation management.
Dubey et al. (2017)	The IoT data acquired from different lanes are examined and inspected by the Traffic Control Office from one place in the Intelligent Transport System. Thus, it reduces waiting times and pollution in traffic and increases traffic efficiency.

Results and Discussion

IoT technology and intelligent transportation systems integration provide detailed information to both passengers and drivers about the current empty-full or free-paid status in vehicle parks (Muthuramalingam et al., 2019). Route Guidance Systems considerably developed in a diversity of forms involving on-board, off-board,

and smartphone-based systems. It can cut back on redundant travel that emerges when a driver gets lost or selects along. Moreover, IoT technology and intelligent transportation systems integration utilize geographic and real-time traffic information and can elect optimal routes in a roadway network between destinations (Srinivas et al., 2020).

Computer vision technology and other sensors coupled with wireless communications in IoT-based intelligent transport systems are utilized to ensure lane departure warnings and alert drivers of pending lateral collisions. IoT based on intelligent transport systems is an effective technology for early detection in returning traffic operations to normal as quickly as possible after traffic accidents occur (Kumar et al., 2020). Furthermore, Electronic Payment Systems are becoming more widespread day by day in many countries. It allows the driver to pay tolls without stopping the vehicle. These systems aim to reduce travel time, travel distance, and GHG emissions. Moreover, they play a key role in reducing traffic accidents and traffic congestion (Barth et al., 2015).

The geographical location of the vehicle, parking availability, pre-reservation information, parking lot location, details about the vehicle, and current traffic information is collected in real-time through sensors used in the intelligent vehicle parking system (Vaidya et al., 2021). Geo-location systems are integrated with route guidance systems to convince drivers to find specific destinations, cutting down on extravagant driving (Srinivas et al., 2020). The Microwave radar delivers signals in the recognition district and receives the reflected signals from public transportation. This signal is conducted to determine the speed and direction of the vehicles (Peng et al., 2016).

Sensors in Longitudinal Assistance Systems are used to monitor headways between vehicles and provide feedback to the vehicle's braking system. These systems not only allow the driver to choose the desired speed but also empower them to adjust the following distance and encumber front and rear collisions (Ouallane et al., 2022). Lateral Assistance Systems are deliberated to develop the performance of vehicles during lane changes, merges, or any type of turning movement. By placing temperature and humidity sensors in public transportation, after a specific threshold it may automatically shift the air conditioner on through a relay cycle or it can point out the driver to switch on the air conditioner because of the intense temperature in the vehicle (Bojan et al., 2014).

The smart station contains appliances agglomerating the dynamic road traffic status and passenger flow around the vehicles. When a smart station defines the approach of a vehicle, it is acquainted with the Radio Frequency Identification (RFID) tags on the bus, train, vessel, and airplane that correspond with them, and admit data from the vehicle. Passengers can learn all schedules in the system via wireless stations like smartphones, which can present geographical location data. Shared taxis utilize smart tools to get the signal from the satellite and engage the control and scheduling center (Luo et al., 2019).

Some sub-system of transportation based on IoT has the capability of self-coordination and self-autonomy, which may diminish the amount of data transmission. For instance, an intelligent traffic light controller comprehends the approaches of vehicles at a crossroads and adjusts the times of traffic signal stages. An automatic passenger counter on vehicles senses the existence of passengers, calculates the number of passengers by using its set identification algorithm, and forwards the evaluating results to the terminal box of the vehicles. Therefore, IoT will advance the quality of public transportation (Wang et al., 2020). Travel Demand Management is another essential element of IoT in intelligent transportation that improves traffic flow by identifying the locations with the highest traffic volume and then spreading the density to other points. Moreover, this technology can provide better design, faster, and better quality, at a low cost that authorizes ecological sustainability in transportation (Camacho et al., 2018).

Conclusion

Traffic congestion, traffic accidents, and environmental pollution have become a major phenomenon in metropolises in developing countries. For example, in Beijing, the capital of China, people have to spend 3 hours in traffic every day (Luo et al., 2019). The high rate of traffic accidents worldwide causes loss of property and life. Approximately 1.19 million people die in traffic accidents and as a result of this situation, 500 billion dollars of economic loss occurs every year (World Health Organization, 2024). Traffic congestion in urban areas reduces the performance of transportation systems and therefore, postpones economic growth. The most effective way to solve traffic congestion and decrease traffic accidents in developing countries is IoT in Intelligent transportation systems.

The main outcomes of the review contributed to a better understanding of IoT applications in intelligent transportation systems and the explained benefits and challenges. IoT based on intelligent transport systems has several benefits for decreasing the uncertainty of the transportation network and enhancing the ability of rapid response and can assist in administrating efficiently the public transportation system. These systems significantly provide alternative routes to drivers and passengers with real-time traffic information and minimize human errors, shorten travel times, increase traffic safety. IoT in intelligent transportation ensures drivers and passengers new data processing techniques are advanced to forecast traffic density and speed which ensures public transportation is more convenient and reliable. IoT may bring considerable business advantages in intelligent transportation providing a potential for enhancing the accuracy of the traffic flow, and operational processes. In addition, it enables the optimum use of existing road capacities, increases energy efficiency, and reduces environmental damage, costs, and risks.

IoT based on intelligent transport systems has great challenges in terms of coverage availability and less complexity. Many technical challenges are likely to be encountered such as high mobility of vehicles, a major span of relative speeds between knots, the real-time nature of implementations, and a plurality of system and implementation-related requirements. The integration of IoT and intelligent transportation technologies should be planned to take into account the challenges identified such as the slow Wi-Fi speeds, security issues, and maintenance demands of IoT networks. Moreover, standardization and legal regulations will be expected to play a key role in the adoption of IoT in intelligent transportation. For future studies, it would be interesting to analyze the impact of IoT-Blockchain integration on intelligent transportation.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

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Mixed Reality Technology and Its Opportunities to Improve Soft Skills

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Abstract: Mixed reality is a technology that combines virtual and augmented reality. Mixed reality provides students with the opportunity to engage in direct treatment within various practical processes. The use of mixed reality is often implemented in courses that are abstract in nature, require expensive equipment and materials, or involve dangerous practicum activities. This research is a literature study using a systematic literature review to provide an overview of the use of mixed reality in learning. The sample used consisted of Scopus articles in the last 20 years from various branches of science from various countries. Data were analyzed quantitatively and descriptively. The research results showed that 16 articles using mixed reality were relevant to the research objectives. The study notes that the application of mixed reality has been conducted in several fields, most frequently in the medical field. The use of mixed reality can enhance scientific attitudes, cognitive abilities, performance, and more.

Keywords: Mixed reality, Technology, Soft skills,

Introduction

One kind of hybrid environment is called mixed reality (MR), in which interactive virtual items can be transferred to the actual world, combining the virtual and the real. Over the past 20 years, MR has seen further changes in principle (Milgram et al., 1995). While the initial Milgram et al. (1994) notion of MR was limited to visuals, modern MR encompasses a variety of human-computer interface (HCI) techniques, including gestures, spatial sound, and environmental input (Cheng et al., 2020). The primary application of AV is in entertainment. AR is more widely used than AV because AV has been adopted by a significantly smaller range of fields than AR. Because of this, it can occasionally be difficult to distinguish between AR and MR (Raja, 2024). As an illustration, Microsoft introduced the HoloLens (Microsoft, 2017) head-mounted device (HMD), which is classified as an MR device even though it overlays virtual data on the physical world—an application that falls under Milgram's definition of augmented reality.

Recent developments in MR have great potential to be significant in a number of fields, including training and education. According to recent studies, VR/MR can effectively improve secondary school pupils' effectiveness and learning attitudes. While there have been studies looking at how effective university students are at learning, there hasn't been much research done on them comparing the MR or ER experience with standard teaching

methods in learning design courses (Fernández-Batanero et al., 2024). MR is an innovative approach that incorporates content learning along with the application of practical instruments for realization (Dalinger et al., 2020). The development of mixed reality research can be seen in Figure 1 below.

Figure 1. MR's position is between the physical environment and the virtual environment

One kind of hybrid system that combines virtual and physical components is called mixed reality (MR). A sliding scale between a wholly virtual and fully physical environment and one that is entirely tangible is how many experts define mixed reality (Rokhsaritalemi, 2020). An explanation on MR was given in (Milgram et al., 1995) many years ago. It was described as a linear continuum, with fully real environments (reality) and fully virtual environments (virtuality) at either end. The Even after many years, the definition of the traits of MR remains true. Within the reality-virtuality-continuum, MR applications have a higher proportion of real aspects; for example, virtual objects situated in the real world can be classified as augmented reality (AR). On the other hand, augmented virtuality (AV) describes the integration of real-world physical things into a virtual environment. Despite the defnition of MR evolving, it is still possible to observe the major characteristics of MR. Parveau and Adda (2018) classifed MR into 3iV classes: First, it consists of both real and virtual contents and allows data contextualization. Second, the digital content is required to be interactive in real time. Third, the content needs to be spatially mapped and correlated with the 3D space.

Figure 3. Hololens device for MR/eR

Mixed reality (MR) is widely used for training and education, and early research suggests that it is an effective teaching tool (Ke et al., 2016; Robinson et al., 2020). Research of (Awang et al., 2018; Cecil et al., 2013; Roberts et al., 2010) investigated how to use a virtual learning environment (VLE) in education to work together on problems related to training, education, and entertainment utilizing VR and AR technologies. The findings showed that learners' comprehension of some events might be improved, motivated, and stimulated by the suggested VLE in ways that the traditional learning technique could not readily accomplish. Under the virtually entertaining environment, users can learn quickly and engagingly. Several studies on MR show that MR has a very good effect on improving students' abilities in various fields such as medicine, biology, genetics, earth, physics, art chemistry and even in educational training. The use of MR in the world of health and medical sciences has been widely carried out, including research by (Veer et al., 2022) using MR to increase students' knowledge of the content of physiology, anatomy, pharmacology and pathology. Researchers use MR to describe the impact of asthma on the anatomy of the bronchioles and the effectiveness of the drugs used and management of asthma attacks. The potential use of MR can be widely adopted in education, from primary school to higher education levels.

Science learning in Indonesia varies depending on the region and the teacher's abilities (Ahmad Ahid Syaifulloh et al., 2023; Husaen & Yuliani, 2023). However, in general, science learning is assisted using simple technology both in the learning process and in practical activities. Practical activities cannot be carried out on all materials due to several things such as tools and materials that are not available, labor that is still very simple, activities that involve dangerous materials and resources that are still inadequate (Meyer et al,2018). These limitations can be overcome by providing an online (virtual) practicum environment. The weakness of virtual laboratories is

that students cannot directly experience or carry out practical activities directly. The use of immersive technology in the form of mixed reality is able to overcome the weaknesses of virtual practicum activities. Unreal performance from virtual practicum can be overcome with immersive practicum. The discovery of MR technology is very necessary in implementing practicums in science learning. This research aims to look at opportunities for using mixed reality in practical activities in science learning in Indonesia.

Method

This research work uses a procedure known as a literature study or systematic review, which involves searching several search keywords in journals published after 2004 on Google Scholar. The results are displayed in Table 1. Numerous academic databases, including Scopus, IEEE Explore, Science Direct, Sage Pub, and others, are still accessible through Google Scholar. The use of keywords for the mixed reality science education focus. Eleven journals from diverse academic subjects made up the research sample, which demonstrated how using MR affected different students' soft skills. Both quantitative and qualitative data analysis was done to identify potential uses of MR in science education in Indonesia.

Results and Discussion

Based on the data, it was found that in Mixed Reality research, the software used varied. Specifically, 54% of studies used HoloLens, 7% used Mursion, 13% used Smallab, and 13% used Unity 3D and unidentified software 13%. The percentage of HoloLens usage of 54% reflects the dominance of this device in Mixed Reality research. HoloLens, as a high-class Mixed Reality device developed by Microsoft, offers an immersive and interactive three-dimensional visualization experience.

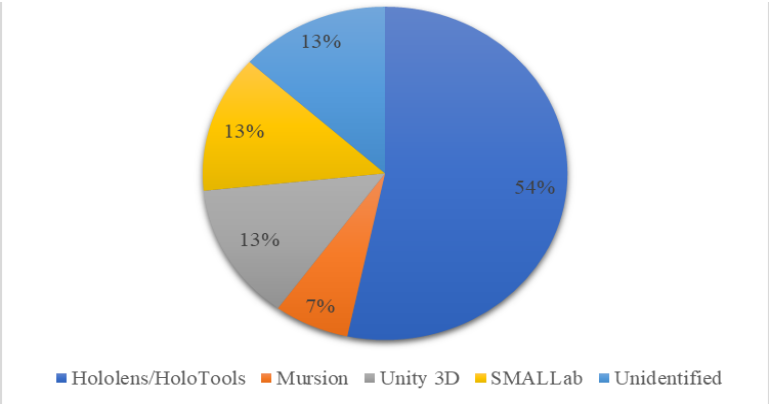

Figure 4. Type of hard and software used in developing and using MR

Microsoft created the cutting-edge augmented reality (AR) gadget HoloLens in 2016. It is a wearable, mixed reality (MR) head-mounted display (HMD) that enables users to interact with the world through holograms while engaging all of their senses (Leonard & Fitzgerald, 2018; Liu et al., 2018). With its central processing unit, graphics processing unit, and holographic processing unit, HoloLens is a set of perspective holographic glasses that can do real-time spatial mapping and processing (Al Janabi et al., 2020; Wyss et al., 2021, 2022). Furthermore, compared to traditional AR equipment, its features are more sophisticated and include stereoscopic three-dimensional (3D) displays, gaze and gesture designs, spatial sound designs, and spatial mapping (Furlan, 2016; Wangm et al., 2018). Based on Park's research, 2021, it shows that there are 44 articles that use Microsoft Hololens in various fields, namely 19 papers in the field of medical auxiliary devices and systems, 5 papers about medical education and simulation, 8 papers about industrial engineering and 7 papers about civil engineering and architecture (Park et al., 2021). In my research, some article used hollolens wich is (Robinson et al., 2020; Ruthberg et al., 2020; Tang et al., 2020) and other.

The diversity of software used, such as Mursion, Smallab, and Unity 3D, creates a wider research scope and shows that Mixed Reality research involves various platforms. Mursion, for example, is known as a virtual simulation for interpersonal skills training. The term "mixed reality" refers to the fact that both human and computer elements collaborate to produce a realistic experience in the Mursion environment. The system requires little setup. A computer, a camera, and a microphone are part of the setup, which allows users to communicate with avatars in personalized scenarios displayed on a screen. Because of the human element, the

avatars may communicate and engage with the user in real time just like real people would (Ferguson & Sutphin, 2022; Hartle & Kaczorowski, 2019). According research from Dalinger et al. (2020) Musion software can be used to develop mixed reality in the teaching practice of prospective teachers. The use of mixed reality with Mursion software can increase self-confidence, self-efficacy and transfer or knowledge.

Unity 3D is a game development engine that can also be used to create Mixed Reality applications. We created a three-dimensional universe with software called Unity3D. Video games and computer simulations are the main uses for Unity Technologies' cross-platform game engine (MV & Tippannavar, 2024; Zulfadli et al., 2023). The use of Unity 3D and Smallab suggests that some research may focus more on developing custom content or simulations.

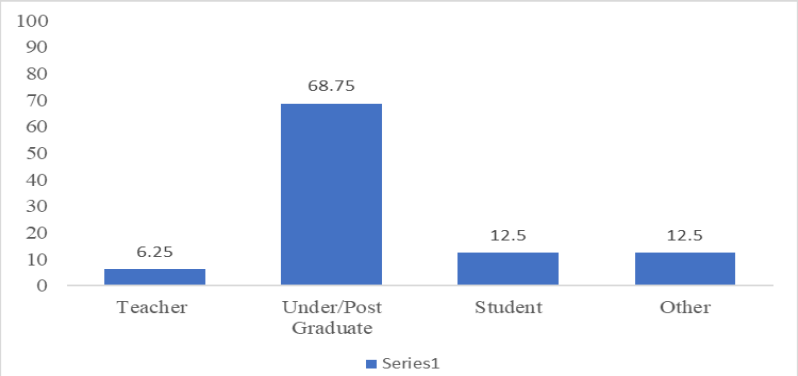

Figure 5. Subject research of MR

The data from the figure above shows that the majority of research subjects using mixed reality are under/post graduates with a percentage of 68.75%. while teachers were the smallest sample with a percentage of 6.25% or only 1 person. Meanwhile, 12.5% of students, both junior and high school, were in the mixed category or a combination of teachers, students, academics and college students. The percentage of subjects in the research sample shows that the use of mixed reality in learning is still very limited and is mostly done at the university level. This is because the development of mixed reality requires quite high capabilities with a combination of several research areas such as informatics engineering, software and others (Banjar et al., 2023; Cindioglu et al., 2022). Apart from that, the devices used to access mixed reality, for example Hololens, are very sensitive and very expensive so not all campuses or schools have these devices. Based on articles that use students as subjects, the majority of those sampled are medical and health students (Hang et al., 2023; Lu et al., 2022; Maniam et al., 2020).

Students who dominate as research subjects show a great opportunity for the application of Mixed Reality technology in the tertiary environment. This research can provide a basis for developing Mixed Reality-based curriculum and learning strategies at the tertiary level. Although the numbers are relatively smaller, research involving teachers and students also provides important insights. The implications can extend to the development of Mixed Reality technology that suits the needs and challenges at the primary and secondary education levels (Mihaela, 2013). The combination of teacher, student, and student participation provides a more comprehensive understanding of the effects of using Mixed Reality at various levels of education. Combining these perspectives supports a holistic approach in designing and implementing Mixed Reality technology in various educational contexts.

The figure above shows that the most mixed reality research is carried out in medical and health science study programs with a percentage of 43.75%, while in the fields of education and science each 12.5% and the least is carried out in the fields of architecture and arts 6.25% each. %. Many studies in the health sector show that learning or practical activities, especially those related to surgery, require ideal stimulation by approaching real conditions in the field or actual objects (Chen et al., 2020; Ruthberg et al., 2020). Research conducted shows that the use of mixed reality can produce results that are not much different from the use of direct objects (Barrie et al., 2019). The use of mixed reality in health and medicine can help reduce the costs of purchasing practical objects and can be used repeatedly (Lu et al., 2022). Use of Mixed Reality in health education may involve virtual surgical simulations, diagnostic training, or clinical skills development (Pellas et al., 2020). In addition, this technology allows students and health professionals to practice and deepen their understanding without real risk (Silvero Isidre et al., 2023)

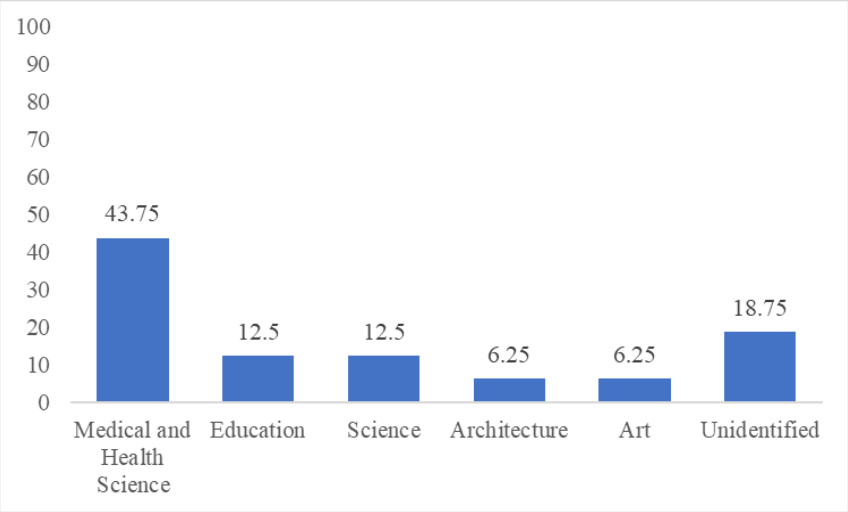

Figure 6. Area research MR

The use of mixed reality in the field of education in the sense of faculties that will produce teacher candidates is very rare. There are several factors that underlie why mixed reality is rarely used. Because it uses very high costs both to develop products and to purchase facilities, apart from that, learning for prospective teachers, especially in Indonesia, still focuses on simple concepts that can be carried out in the field when they become teacher. The very diverse condition of school facilities in Indonesia makes it impossible to implement mixed reality in classroom learning at both middle and high school levels. Based on the picture above, there are 2 articles that use mixed reality for preservice teachers. The use of mixed reality for preservice teachers aims to help students anticipate obstacles during teaching practice at school (Walters et al., 2021). Based on this research, prospective teacher students using mixed reality in teaching simulations can increase self-confidence, self-efficacy and knowledge (Dalinger et al., 2020). Apart from that, the use of mixed reality can be used in various fields such as architecture and construction (Wang, 2009), art (Hang et al., 2023), science (Uhomoibhi et al., 2020) and other fields (Tang et al., 2020).

The selection of a particular study program for Mixed Reality research needs to be linked to the special needs and characteristics of each field of study. The contextuality of the study program will ensure that the implementation of Mixed Reality has a relevant and beneficial impact (Plecher et al., 2019). Seeing that health and chemistry related study programs are also involved in Mixed Reality research, there is an opportunity for interdisciplinary collaboration. This collaboration can bring great benefits, combining knowledge and approaches from various disciplines to create a holistic learning experience.

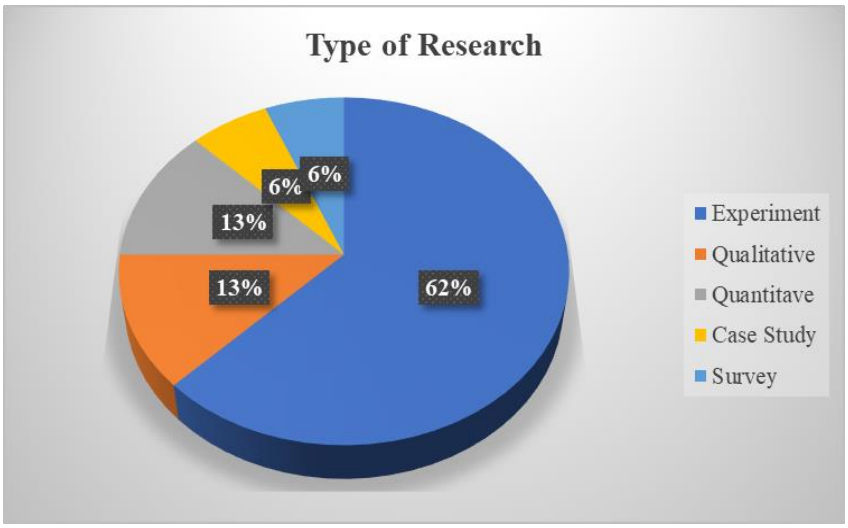

Figure 7. Method of resarch in MR

The dominance of quantitative experiments in Mixed Reality research reflects efforts to provide empirical and objective evidence of the effectiveness or successful use of this technology. This approach allows researchers to directly measure the impact of implementing Mixed Reality on specific variables, such as increased student

understanding, performance of a particular task, or level of user engagement. Quantitative experimental results can provide a strong basis for making decisions and recommendations regarding the effectiveness of Mixed Reality in the context of science learning (Papastergiou, 2009).

The advantages of quantitative experiments include their ability to provide data that can be measured and tested statistically, allowing for the generalization of research results to a larger population. However, the challenge that may be faced is the complexity and contextuality of the user experience in Mixed Reality technology which may be difficult to measure precisely with quantitative methods alone. Therefore, a combined approach with qualitative methods or case studies may be needed to gain a more complete and in-depth understanding of the implications of applying Mixed Reality in science learning.

Table 1. Dependent Variabel in MR Research

Author & Years	**Thema**	**Dependent Variabel**
(Dalinger et al., 2020)	A mixed reality simulation offers strategic practice for pre-service teachers	confidence, self efficacy and transfer of learning
(Tang et al., 2020)	Evaluating the efectiveness of learning design with mixed reality (MR) in higher education	learning outcomes
(Chen et al., 2020)	Can virtual reality improve traditional anatomy education programmes? A mixedmethods study on the use of a 3D skull model	theory and indentifikasi test
(Robinson et al., 2020)	Evaluating the Use of Mixed Reality to Teach Gross and Microscopic Respiratory Anatomy	Understanding and Activities
(Ruthberg et al., 2020)	Mixed reality as a time-efficient alternative to cadaveric dissection	time management and Mastery Concept
(Birchfield et al., 2009)	Earth science learning in SMALLab: A design experiment for mixed reality	Mastery Concept
(Veer et al., 2022)	Incorporating Mixed Reality for Knowledge Retention in Physiology, Anatomy, Pathology, and Pharmacology Interdisciplinary Education: A Randomized Controlled Trial	Attitude, Cognitive and Retention
(Tolentino et al., 2009)	Teaching and Learning in the Mixed-Reality Science Classroom	Concept, Spatial Reasoning, Reformed Teaching Observation Protocol (RTOP)
(Maniam et al., 2020)	Exploration of temporal bone anatomy using mixed reality (HoloLens): development of a mixed reality anatomy teaching resource prototype	Cognitive and Psikomotoric
(Uhomoibhi et al., 2020)	A study of developments and applications of mixed reality cubicles and their impact on learning	learning environment
(Walters et al., 2021)	Mixed-Reality Simulation With Preservice Teacher Candidates: A Conceptual Replication	conceptual replication
(Hang et al., 2023)	The impact of mixed reality serious games on mortise and tenon learning in college students	Knowledge, Retention and motivation
(Almufarreh, 2023)	Exploring the Potential of Mixed Reality in Enhancing Student Learning Experience and Academic Performance: An Empirical Study	Performance, Experience and statisfaction
(Lu et al., 2022)	Applications of Mixed Reality Technology in Orthopedics Surgery: A Pilot Study	communication and understanding, spatial awareness and effectiveness
(Vasilevski & Birt, 2020)	Analysing construction student experiences of mobile mixed reality enhanced learning in virtual and augmented reality environments	learning environment
(Wainman et al., 2020)	The Critical Role of Stereopsis in Virtual and Mixed Reality Learning Environments	learning modality and streopsis

The use of Mixed Reality (MR) technology has had a positive impact in various learning domains. Mixed Reality creates an environment that combines the real world with virtual elements, opening up new opportunities in education. Several studies contained in the table provide in-depth insight into how Mixed Reality can impact various aspects of learning, one of which is students' soft skills. Some soft skills that can be improved by using mixed reality as follows:

1. Cognitive Domain: Based on the article analysis that has been carried out, the use of mixed reality can improve students' cognitive abilities and knowledge (Lu et al., 2022; Maniam et al., 2020; Walters et al., 2021). Students who use mixed reality have quite a good effect on their knowledge and even several studies show that there is no significant difference between the use of mixed reality and actual practicum (Robinson et al., 2020). Several types of cognition that can be trained with mixed reality are concept mastery, reasoning, understanding, spatial reasoning, conceptual replication and learning outcomes.

2. Psychomotor Domain: Apart from the cognitive domain, students' abilities in the psychomotor sector remain a concern. Many research activities are carried out in practicum activities in the fields of health, arts, education and architecture (Almufarreh, 2023). Some psychometrics that can be trained are performance in surgery, time management, activities in practicum etc.

3. Effective domain: Attitude is one domain of learning that is often a concern. Attitude formation can be carried out during the learning process and practical activities in the laboratory (Veer et al., 2022). Based on the article analysis, it shows that attitudes can be trained and improved in learning using mixed reality. Some attitudes that can be improved are spatial awareness, retention, confidence, self-efficacy, attitude, static action etc

4. Other soft skills: Apart from the three domains above, mixed reality can train, improve various other variables such as motivation, communication, experience, learning environment, learning modality and stereopsis (Lu et al., 2022; Vasilevski & Birt, 2020; Wainman et al., 2020).

Summarizing the Table 1 that Mixed Reality has a significant role in improving various aspects of learning. By creating a more interactive, realistic and engaging learning experience, this technology opens up new potential in improving the quality of education. Therefore, the implementation of Mixed Reality can be considered a progressive step in designing effective and innovative learning methods.

Conclusion

Based on the research conducted, it can be concluded that the use of mixed reality is not yet widely used and has a very good opportunity to be implemented in Indonesia. Apart from that, the research results also show that mixed reality can be used to train students' cognitive, psychomotor and affective and other abilities. Apart from that, mixed reality research in the field of education, both in learning and in science practicum activities, is still very rare and few. This provides an open space for researchers in the field of education who collaborate with the field of technology to develop and test the effectiveness of MR in improving various domains of learning.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Gaming Technology of Mass Media

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Abstract: The language of mass communication, on the one hand, enriches the literary language in its own way, saturating it with evaluative phrase, on the other hand, one cannot help but see the negative role of the language of some media technologies and gaming technologies of mass media, which is replete with various deviations from the norm, flooding speech with jargon and foreign words. The article reveals the concept of the "Global Network" - the Internet as a special media tool and how the Internet influences the development of language processes and education in the conditions of society digitalization. Definitions of words are given: language, media texts, linguistic culture, Internet, media, linguistic and cultural situation, Americanization, linguistic tradition and gaming technologies. Language is undergoing significant changes, and this article examines the role of media technologies in development and preservation of linguistic traditions. A huge role in human development and education belongs to the game. Game has an important impact in human's life, what a person is in the game, so in many respects he will be in the work. It has been found that media game technologies have a significant influence in learning English language and culture. Gaming technologies improve speaking, listening, reading skills, develop logical thinking, form volitional, moral qualities of personality. Thus, the application of game elements in learning English helps to reveal students' creative abilities, it is approved that in the game a student cognizes himself, his abilities and disadvantages. Nowadays, the state and position of media games technologies in learning English are been analyzed. This article describes and analyzes, the importance of the application of gaming technologies in the educational process, emphasizes the effectiveness of media game activities as the formation of personality, as an educational technology.

Keywords: Media texts, Media technologies, Gaming technologies, Gaming activities, Educational technology

Introduction

The twenty-first century has seen enormous growth in mass communication, modern information technology as well as game technology in media by helping learners to improve their knowledge. The rapid development of the media - print, radio, television, as well as the emergence and spread of the "Global Network" - the Internet, led to the creation of a single information space, an unusual virtual environment formed by the combination of many media streams. Media text (from Latin media textus) is a message, text of any media type and genre

(Masoud, 2009). The Internet is a global voluntary association of networks containing a variety of resources and owned by all kinds of government, educational, commercial and other organizations, as well as individuals. The Internet is a means of open storage and dissemination of information. Along the transportation route, unprotected information can be intercepted and read. The Internet is a powerful media tool. The Internet is a worldwide system of interconnected computer networks for storing and transmitting information (Burlak & Starostin, 2005). Nowadays, game technologies in media materials (Mass Media) can play an important role in learning English language and culture. Games, game elements, gaming situations are components that form the basis of game technology. They include the various objects, rules, mechanics, and systems that players interact within the game world. Additionally, virtual learning and virtual models are of great importance in modern educational games (Masoud, 2009). Game technologies in media materials can rapidly introduce students to new words and expressions, neologisms, phraseologies, jargonisms and of course grammar practice, etc. Through game individuals begin to feel himself a member of a society, a group, a team, honestly analyzes his actions and achievements. And the teacher's task is to focus the student in achieving a high level of language proficiency, promoting the establishment of connections between students based on mutual responsibility. Blatantly, game technologies will help to expand students' vocabulary and contribute to refine their speech more expressive, interesting, and engaging.

The research topic is relevant because intellectually challenging games with specific characteristics have firmly established their place in the broadcasting grid of Kyrgyz television and radio channels. Despite the abundance of materials in the field of television journalism and game theory, the understanding of television games for English language and culture studying is generalized and has not yet undergone scientific analysis. Therefore, the goal is to identify the features of intellectual gaming technologies on local television for learning English language and culture, as gaming technologies in Mass Media have not yet been explored. Thus, the teachers and students of Osh State University were interviewed on the topic « Gaming technology of mass media in learning English language and culture ».

Table 1. People who were interviewed

Teachers and students		N
Teachers		18
Students of	2 course	30
	3 course	40
Age	18-40	75
	Other	8
Gender	F	86
	M	2
Total		88

Method

The paper used variety of methods to analyze different sources and obtain the most accurate information as possible. The research utilized the following approaches: observation, analysis, synthesis, comparison, and generalization. Over 10 TV programs of the intellectual game format airing on various Kyrgyzstan television channels were selected for examination. Books, manuscripts, video, audio, and statistical data were studied. The authors of the article conducted and analyzed a questionnaire and found out the importance of using media materials in learning English. It was a serious experience of analyzing a sufficient number of English teachers and students who learn English, which requires and deserves attention. At the same time, the research apparatus chosen by the authors made it possible to draw interesting and valid conclusions, namely, to find out the importance of using media technologies in learning English language and culture. The factors and types of media technologies in learning English language and culture have been analyzed based on the findings from interview. The autonomy of a person in the middle of the game plot is boundless, it can go back to the past, look into the future, repeatedly repeat the same action, which brings and satisfaction, gives the opportunity to feel significant, omnipotent, desirable. Also, the study focuses on intellectual games (broadcast recordings) on television in the city of Osh, Kyrgyzstan.

Game technologies in media materials, provide many opportunities for active learning of English, expanding knowledge and developing communicative skills. They make the learning process more interesting and practical, helping students to apply the language in practice and in life, to improve their skills in media and culture of English-speaking countries. Here are some of the main game elements:

• Characters: Game characters are controlled or uncontrolled entities in the game. They can be protagonists, enemies, allies, or non-player characters, thus practicing English in life.
• Levels: Levels are divisions of the game world into different segments or stages. They may have different landscapes, tasks, obstacles and challenges that the player needs to overcome. The same is true for learning English, if a learner has moved to a new level of English, he or she is faced with the appropriate tasks to overcome them and move up to a higher level. Different levels of difficulty can be incorporated into instruction to cater for different learner preferences. This allows the experience to be tailored to different skill levels and preferences.
• Assignments and Goals: Assignments and goals set specific tasks for the learner to accomplish. They are usually related to progression, unlocking new levels, earning rewards, or moving on.
• Multiplayer: Media game elements can also include the possibility of multiplayer play, where learners can compete or collaborate, communicate or debate with each other within the world where the language is being learned.

These are just some of the common media game elements in English language learning that can be incorporated into instruction. Combinations and variations of these elements can create diverse and interesting play and learning experiences. In order to find out the specifics of using media materials in learning English language and culture, the authors of this article conducted a survey among English language teachers. The survey consisted of 5 questions in which 88 teachers of English at Osh State University participated.

Nowadays the main volume of speech use occurs in the sphere of mass communication and media technologies. It is impossible to imagine the life of a modern person without the Internet and television, without radio and modern means of communication, with the help of which people quickly learn the latest and most relevant news and can inform each other about certain events in a matter of seconds. Due to the rapid development of the modern media technologies, the Internet, for example, has gained such popularity that today it is not only a means of communication and information transfer, but also a means of manipulating public consciousness and influencing the course of language processes. Texts of mass information or media texts are one of the most common forms of modern language, and their total length far exceeds the total volume of speech in other spheres of human activity. At the same time, the volume of texts produced and transmitted daily through media channels continues to constantly increase. This, in particular, can be judged by the number of indicators: the number of television channels, radio, newspapers and magazines is growing. It becomes obvious that today mass communications (and therefore media products - media texts) are acquiring enormous importance in the life of society. Thus, according to the German sociologist Niklas Luhmann, reality today is constructed precisely by the media, and almost everything we know about the world we get from the media. (Luhmann, 1996) Obviously, the media act both as an instrument of power and as a tool for the implementation of information flow and a key influencing language processes.

That’s why, speaking about the role of the media technologies in the development of education processes and social life, it is necessary to emphasize that we mean not only changes caused by the introduction of new information technologies, but also qualitative transformations in the general linguistic and cultural situation. On the one hand, the language of mass communication enriches the literary language in its own way, saturating it with evaluative phrases. On the other hand, one cannot help but see the negative role of the language of texts in some media, which are replete with various deviations from norms, flooding speech with jargon and foreign words. It is in the media that active language processes take place, such as the “Americanization” of the language; following speech fashion; a conscious departure from the literary and linguistic norm (Americanization is the influence of the United States on popular culture, business models, language and politics of other countries. The concept was invented in 1907 and originally referred to the growing popularity of the American way of life in Canada) (Berghahn &Volker, 2010). In this regard, the question of the formation of a high information technology, linguistic culture and the preservation of cultural traditions, ethics of speech in the media and control over compliance with these issues arises especially acutely.

Results and Discussion

An intellectual game is a type of game based on the participants'application of intellect and erudition Participants can compete with each other, the host, computer, or viewers. Television games can be classified similarly to regular games, as outlined by Caillois (1958):

- Competitive (agon),
- Gambling (alea),

- Mimicry (mimicry),
- Psychological (ilinx).

The goal of television games is to develop the intellectual abilities of participants in entertainment shows on television by directly involving viewers in the evolving, live game process, where everything unfolds not according to a script but based on the emerging circumstances within the game situation. A telegame (also a game show) is a type of television show where competition or a game serves as the central plot element. Participants can compete with each other or with the host or viewers (Abdulrahim, 2009). In the mid-20th century, game shows in this format began to appear on television, gaining immense popularity. In the U.S., shows like "The $64,000 Challenge," "Twenty-One," and "Dotto" were highly popular . Bob Barker, host of "The Price Is Right," remarked, "We play games at home, play at parties, go to clubs and play games. Americans love games" (Venanzi, 1997). Since 1958, following some scandals related to certain genres of TV games, game shows increasingly shifted focus towards prominent personalities. Celebrity entertainment became a major product in the game show universe, leading to successful series such as "Hollywood Squares" and "Match Game" (Burlak & Starostin, 2005).

Similar shows emerged in the USSR, starting with "An Evening of Merry Questions" (1958), followed by "Club of Merry and Resourceful" in 1961, where participants competed not only in knowledge but also in wit and esourcefulness. In 1975, one of the most popular TV games in the USSR was launched - "What? Where? When?". In the show, a team of participants collaboratively answers questions sent in by viewers in advance. September 4, 1975, is officially considered the birthdate of the game "What? Where? When?". From 1975 to September 2007, 259 games were played. Boris Kruyk hosted 87 games from May 2001 to September 2007. From 1976 to 1982, "What? Where? When?" games took place at the Ostankino TV center bar, and since 1990, all games of the television elite club "What? Where? When?" are held at the Hunter's Lodge in Neskuchny Sad. Television in Kyrgyzstan began in 1958, associated with the construction of the television tower in Bishkek. As of 2020, television remained the primary means of information for the residents of Kyrgyzstan (Zhumagulova, 2010). The largest television and radio broadcasting company in Kyrgyzstan is the state-funded KTRK (also known as the National Television and Radio Corporation of the Kyrgyz Republic, OTRK) - the largest broadcasting corporation in the Kyrgyz Republic. The organization unites TV channels such as "National First Channel," "Music," "Balastan," "Madaniyat Tarikh Til," "KTRK Sport," "Ala-Too 24," radio stations including "Birinchi Radio," "Kyrgyz Radiosu," "Miñ Kıyal FM." The corporation also includes the Republican Radio and Television Center and the studio "Kyrgyztelefilm." KTRK has a history of over 80 years and, as the flagship of domestic television broadcasting in the country, played a key role in its development. It has captured and broadcasted all significant events during the transformation of Soviet Kyrgyzstan into modern independent Kyrgyzstan (Zhumagulova, 2010). The first private radio and television company in independent Kyrgyzstan was "Piramida." Subsequently, other entities like "Koort," "Vosst," "Asman-TV," NBT (Independent Bishkek Television), "Mezon-TV" and "Keremet" in Osh, and "Osh-TV" emerged in the market . After the events of the "Tulip" revolution, new channels like "Pyaty Kanal," "Echo Manas," and "ElTR" appeared .

For many residents in rural Kyrgyzstan, participating in the intellectual quiz "Akyl Taymash" on UTRK became a real opportunity to enter one of the country's best educational institutions. In the format of a popular TV game, students reinforce the knowledge acquired at school, train logical thinking and resourcefulness, broaden their horizons, and demonstrate what they have learned in school lessons. The game's tasks are presented in the form of quiz questions.

The "Akyl Taymash" game is held with the support of surgeon traumotologist Alymbek Suyorkul uulu from Talas city, Kyrgyzstan. The goals of the game are to create conditions for students to choose future professions. The winning team gets the chance to go on an excursion to higher educational institutions in Bishkek, get a closer look at universities for future career choices, expand their horizons, showcase erudition, and demonstrate the ability to act in the given choice conditions. A brief description of the game is as follows: 5 participants, 1st round consisting of 15 questions from various subjects and disciplines with multiple-choice answers. 2nd round consists of tasks in 5 disciplines: Kyrgyz language, Kyrgyz literature, history of Kyrgyzstan, biology, and questions in category "A" (where all answers start with the letter A). Participants choose one category of questions and answer them. Participants with the highestscores from the first and second rounds can proceed to the third round. In the third round, only 2 participants who achieved maximum scores participate, while others exit the game. The 3rd round of the game consists of 3 logical questions. The participant who answers the logical questions correctly advances to the superfinal. Game rules are given to participants in advance. A qualifying round is held before each stage. Answers are immediately evaluated by the hosts, who check the correctness. At the end of the game, results are summarized. The host delivers a concluding speech, awards the winners, and all participants in the game.

On the ElTR channel since 2022 is broadcasted the quiz game "Tez Tap." This TV game uses the online application Kahoot, allowing more than 1000 people to participate simultaneously. The quiz comprises 10 questions from various fields of activity, covering different subjects from the school curriculum (mathematics, biology, geography, physics, Kyrgyz language, English, etc.). At the beginning of the TV game, a QR code for the game is shown on the screen, allowing participants to join the online game. Participants are given 1 minute to join the game, and then the hosts start the game. After each question, the names of participants who answered correctly and quickly are displayed on the screen, demonstrating the lucidity of the game. At the end of the TV game, the first five participants are awarded prizes. The TV game lasts approximately 40 minutes and has already built a steady audience. There are many game formats like this, but not all of them maintain high viewership ratings and attract advertising clients as this game.

Language is a means of communication and belongs to all participants in communication and even in a sphere of technology. The term “language”, understood in a broad sense, can be applied to arbitrary sign systems, although more often it is used for narrower classes of sign systems. Close attention to the language of the information space is determined by its main role - to be a means of communication. As it was written above, in the current media, media texts are an instrument of global influence on the mentality, value systems and culture of language use, therefore, violation of literary norms, a large number of grammatical errors observed in the media, negatively affects the level of speech culture not only of native speakers, but also for language learners. The language of the media and gaming technology are important bridge between culture and people. All languages of the world are rich in their own way and all languages in the world tend to change. Every year, neologisms, new formations in the field of youth slang, and borrowings from other languages appear. And the media technologies play a big role in this. For example, the modern Russian language is already very different from the language of A.S. Pushkin.

Is the Russian language enriched by such modifications or, on the contrary, is it deteriorating? And what role does the media tools play in the development and preservation of linguistic traditions? Borrowings with the introduction of the Latin alphabet and various graphic symbols have filled the media: headlines of newspapers, magazines, titles and names of gaming technologies, advertising on television, radio, signs with the names of cafes, restaurants - all this is filled with “slang” words. What is all this for? Maybe society wants to be more original or more fashionable. But these “broken” borrowed words play a huge role in the preservation of linguistic traditions. A number of the most popular cafes and restaurants operate in the city of Osh and throughout Kyrgyzstan. In the Google search “Note for Travelers,” a list of cafes and restaurants comes up and almost 50% are in foreign or broken languages. For example: cafe “Café Zhyz-Byz”, Ovest-to, Toomanbar, Sohobar, Banzay, Borsok, etc. Let’s take the name “Boorsok” for discussion. Boorsok is a traditional dish of the Kyrgyz people, which is always prepared for the festive table. Such strange inscriptions on posters and on the Internet and signs on the walls of the Boorsok cafe chain. Why not to write this word in Cyrillic. Such inscriptions seem to hurt the eyes. It becomes unclear what they want to achieve with this, why they treat such traditional words of the national language so frivolously. Let’s take modern English for discussion regarding the role of the media in the development of language processes. Everything that the viewer sees on TV seems to him to be happening before his eyes, right now, this very minute. He feels like a participant in the events. That is why the use of television media makes the process of teaching foreign languages more lively, convincing and emotional (Yurovsky & Ya, 2002, p. 112). As already noted, the interlinguistic level involves the study of the mechanisms of interaction between languages, in particular the methods of borrowing lexical units, the functional and stylistic specificity of borrowings, and the mutual influence of communicative and broadcast styles. In the conditions of the information society and digitalization, linguistic influence is most actively carried out through the channels of mass communication; the dominant impact of English-language media speech on the global information space, including on Kyrgyz society, is clearly visible when analyzing the relevant media discourses.

The impact of Anglo-American mass media on Kyrgyz media is noticeable both at a high level of content and at the level of language. Widespread distribution of English-language samples of television and radio production, copying (both licensed and unlicensed) of format and content, a powerful wave of English borrowings, imitation of communication and broadcasting styles - all these are characteristic features of modern Kyrgyz media texts. One of the most striking examples of English-language media influence on the format and content of mass media texts in Kyrgyzstan are programs modeled after well-known Western programs. Thus, many popular projects on Kyrgyz television are analogues of well-known Western television shows. For example, “Voice” is an American version of the television vocal competition format that is successfully running in many countries around the world. In Kyrgyzstan, “Asman” is the Kyrgyz version of this vocal competition.

Some innovative technologies are universal software systems focused on solving problems in the field of automation, modernization of the educational process, giving the teacher a convenient and flexible learning tool; Innovative technologies - obtaining a new or efficient production of an existing product, product, technique, new or improved technological processes. Electronic library defined as an ordered collection of heterogeneous electronic documents (including books, magazines) equipped with navigation and search tools. This can be a website where various texts (more often literary, but also scientific and any others, up to computer programs) and media files are gradually accumulated, each of which is self-sufficient and can be requested by the reader at any time. An “open library or electronic library” is a library where you can find a lot of materials distributed under an open license, which gives you the right not only to freely use, but also to modify, study and process these materials. Everyone can find various textbooks, video-audio materials, rare books from library archives and dissertations on the sites of electronic libraries. Also, all these materials are available in electronic form and for download.

At the moment, the following software technologies are actively used in the educational process of "Osh State University": "Electronic Library System of Osh State University" https://ibooks.oshsu.kg/. Such resources of these modern technologies are known not only to employees and students of Osh State University, working with these systems, but also foreign specialists coming to our country who visit Osh State University. This electronic library is a management system for high-tech electronic textbooks. Therefore, you can use all electronic resources and technologies both in the classroom (computer class) and remotely, via mobile phone or tablet. In this way, students can learn independently with the help of a modern innovation system.

Today, any gadget user with an Internet connection can easily install various software applications for working with electronic textbooks from the website of many educational organizations on their computer or phone in Kyrgyzstan. Developed (advanced) opportunities for educational material, including various types of self-control and support for any multimedia information, allow you to create effective tutorials in various disciplines. Multimedia is a form of communication that combines various forms of content, such as text, audio, images, animation, or video, into a single presentation, as opposed to traditional media such as printed materials or audio recordings. Popular examples of multimedia include video podcasts, audio slideshows, animated shows, and movies. Tutorial files can be protected with individual installation keys, which makes it possible to use them commercially. Such systems manage high-tech electronic textbook. The main principle underlies such a teaching aid: the main emphasis in the approach is on INTERACTIVITY - the ability of an electronic textbook to interact with a student, so the student can analyze his actions and work results, or choose other alternative options for studying educational material, i.e. on feedback that printed textbooks and their electronic counterparts in well-known formats such as Word, PDF or web page format cannot provide. In advanced books one can see a sufficient interactive approach. For example, all textbook material is packed into one file, including multimedia data (video and audio files) and tests for self-control, exercises and other related files, in other words, the student can interact with the textbook. The next type of resource is undoubtedly a new innovative technology in learning English. The benefits of these resources are felt by every user learning a foreign language. Online tests have advantages for e-learning courses. There may be hesitation about the accuracy, validity, security, integrity, and quality of online testing. However, this type of assessment offers so many benefits for online learners and educators, mostly in terms of administration, grading, that it deserves a closer look:

1) Students can take multiple short tests throughout the e-Learning period. Tests can be personalized and tailored to each student.
2) Multiple choice tests (such as multiple choice or True/False) can be graded instantly, allowing students to see how they did on the test at a glance, and online instructors to make real-time changes to instructions based on the data. This allows teachers to spend more time giving feedback to students rather than reading and checking papers.
3) Voice feedback tools such as Kaizen or a built-in feature inside the LMS allow teachers to provide voice responses to tests or other assignments, which is convenient for both the teacher and the student. Online tests offer many opportunities for versatile assessment of students: synchronous and asynchronous tests, using special online platforms and without them, in real time, and with the ability to download and take the test at a convenient time, as well as using various devices (phone, tablet or laptop).
4) Such tests are especially important for final assessment, which determines whether a student graduates, moves to the next level or receives a certificate.

Today's time is the time of free access to any information technologies, in a few seconds, you can get an answer to any question. Dictionaries and encyclopedias are becoming so popular. For students, the process of obtaining additional knowledge, preparing for seminars, writing essays, etc. has been simplified. Nevertheless, there is not

enough educational material that does not analyze and does not require active user actions, but users achieve the goal. The advantages of innovative technologies described above are aimed at the ability to present the studied material in the most cognitively beneficial form, including the possibility of multiple presentation of the same material in order to achieve the goals of the teacher and the student. Information technologies (IT), also - information and communication technologies - processes that use a set of tools and methods for collecting, processing, accumulating and transmitting data to obtain information of a new quality about the state of an object, process, phenomenon, information product. In addition to this, the mechanism of our virtual textbooks is equipped with tools that allow you to turn ordinary content into presentational learning material. These are context-sensitive pop-up windows, means of sound support for arbitrary text fragments, means of focusing attention on individual fragments of material, hiding and showing secondary and auxiliary information, the possibility of alternative presentation of individual information elements, etc.

Online tests are a kind of presentation of educational technologies that allows you to organize the process of consolidating knowledge and establishing a connection between knowledge, skills and reflexes that are required for a solid assimilation of the acquired knowledge. Online tests are a kind of "knowledge recorder and checker", most often representing interactive exercises on the previously covered material. Specific benefits include the following:
- no time limits for completing tasks;
- the student can take a test to strengthen knowledge at any time;
- after the completion of the work, the user does not get a mark but rather receive a formative assessment, a recommendation for further actions; Having no time limits, the user calmly passes the online test, while knowledge is recorded, which confirms the effectiveness of these resources.

Finally, the teachers and students of Osh State University were interviewed on the topic «Game technology of Mass Media in learning English language». The results were illustrated by the following diagrams:

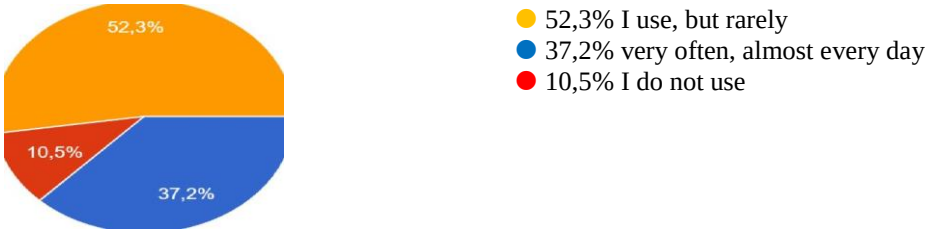

Figure 1. How often do you consume mass media content related to gaming technology? (e.g., video games, sports, gaming news, etc.)

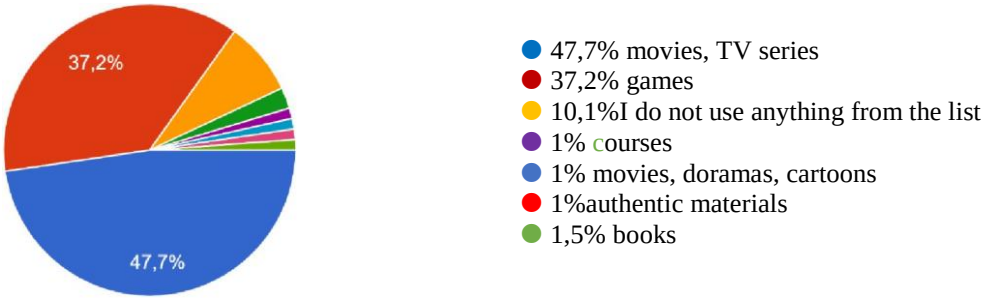

Figure 2. What types of gaming materials of mass medis (movies, TV series, games, etc.) do you prefer to use in learning English language and culture?

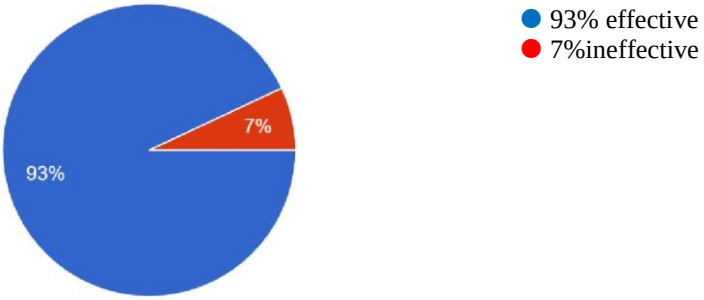

Figure 3. How do you evaluate the effectiveness of using gaming situations of media materials for learning languages?

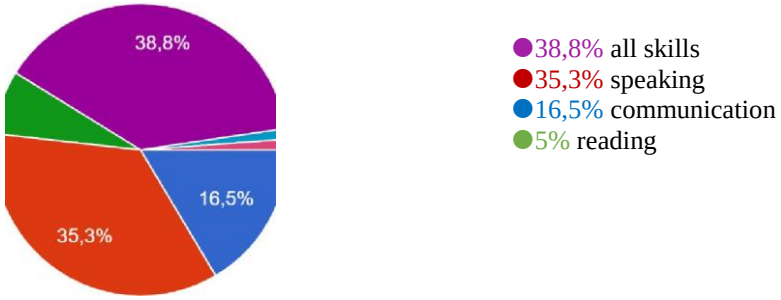

Figure 4. What skills (listening, reading, speaking, writing) do you think are particularly developed when using gaming situations of media materials?

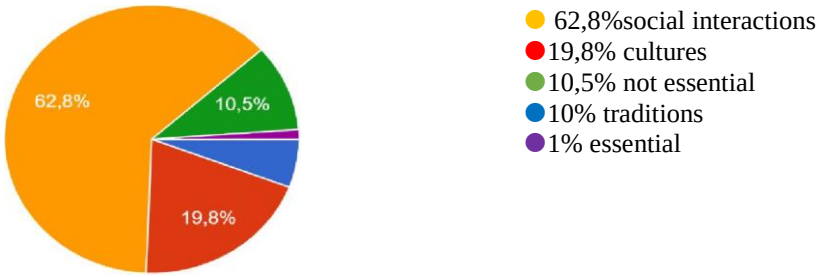

Figure 5. What aspects of culture (traditions, customs, social interactions, etc.) do you consider important in game situations presented in media materials?

Conclusion

Based on the questionnaire survey, it can be concluded that game technologies of mass media can be very useful in learning languages and in education in general as they help to make the learning process more interesting, desirable, motivating and effective. 52.3% of 88 teachers use media game elements in their lessons, 36.9% use online platforms, 47.7% recommend movies in English, 93% of teachers rated the application of media game materials highly effective, 39% rated the effectiveness of improving all skills through media materials in learning English. There is a list of popular gaming technologies that can be used when learning English:

1. Word Games: Word games such as crosswords, scanwords, riddles and anagram games help develop vocabulary and improve word knowledge.
2. Mnemonic Games: Mnemonic games help you memorize new words or phrases by making associations or creating fun stories related to those words.
3. Role Playing: Role playing allows students to practice speaking skills using real or fictional situations.
4. Listening games: Listening and understanding of English speech can be developed through audio games, podcasts or dialog games where students have to listen and answer questions.
5. Grammar games: Many games develop grammar skills such as sentence formation, correct use of tenses, subject-verb agreement, etc.
6. Computer games and apps: There are many educational computer games and mobile apps that help you learn English through interactive tasks, puzzles and tests. A computer game is a computer program used to organize gameplay, communicate with partners in the game, or act as a partner to practice speaking . Computer business game puts forward imitation-practical tasks to the participants, promotes the development of intelligence and solving practical problems on the basis of the theory of preferences (Narkulova ,2010).
7. Reading games: Reading games such as quizzes, crossword puzzles, or games related to the text being read help develop reading skills and English comprehension.
8. Writing games: Various games such as making stories, writing letters or essays help to develop writing skills and competent presentation of thoughts.

These are just a few examples of game elements that can be used when learning English. Games make the learning process interesting, allow students to actively participate and motivate them to apply new language skills in practical situations. Thus, the questionnaire data shows that the use of media game materials very often give effectiveness and improve all skills: speaking, reading, writing and listening, which is very important in the development of personality.

The main principle of gaming technologies is to ensure the receipt of constant, measurable feedback from students, providing the opportunity to openly correct errors, as a result, rapid mastery of all functional learning capabilities and step-by-step immersion in the learning process. Another method of gamification is to create a story, a learning outcome, that accompanies the gamification process. This helps to create a sense of belonging, contribution to a common cause, and interest in achieving some imaginary goals. We can say that education is already partly gamified. So, for example, at the university you completed the exercises and assignments in class correctly - you received a good grade, you made a number of mistakes, you didn't complete your homework, you don't answer during the class - you earned a bad mark. And also at the end of each academic year, the level of knowledge is checked and the transition to another "level or stopping in place (losing)." Portraits of the best "gamers" look proudly from the honor board. The best players don't stop there; they move to an even higher level. After all, any lesson can be turned into a game and a real celebration can be arranged. Game technologies of mass media in online education have a number of advantages:
-encourage creativity;
- help to find meaning in monotonous everyday study;
- increase the level and quality of knowledge;
- develop cooperation skills, allow you to gain positive experience of teamwork;
- help to experience failures less painfully than in the traditional form of training;
- establish a high level of motivation for results;
- create a comfortable atmosphere for all students, regardless of their level of knowledge.

Below we will give examples from my practice of using gaming technologies of mass media at different stages of the educational process:

1) Before going through new material, you can test students using online Quizziz on the topic of the lesson. This technology has ready-made questions-games that can interest the audience and help start the lesson in an exciting way. You can also create your own quiz by writing down and registering questions on the site. Currently, there are a lot of free online educational services that allow you to conduct quizzes or allow you to use ready-made quizzes. With the help of such ready-made, free online quizzes, increase the level of student involvement in the learning process.
2) When summarizing and repeating a block of studied topics, you can use an online game-competition. An online game-competition is the subject of research into the pedagogy of online games, which in turn is part of media pedagogy or media education (Dobychina, 2014). To conduct such games, I select games in advance that require testing students' knowledge, like Kahoot. Kahoot is a popular learning platform for quizzes, test creation, and educational games. This gaming platform is more convenient to use as a mobile application, so it is very suitable for students who have mobile phones with an Internet connection.
3) Consolidation of the studied material can also be carried out with elements of the game technologies. For example, you can run a mini quiz. Quizzes are one of the most common eLearning templates for many online courses. All topics and stages of the material covered are put up for discussion. For example, if I have a beginner group, then I use this platform to test knowledge https://www.gamestolearnenglish.com/reveal/. The students' task is to complete as many tasks as possible. Games to learn English is the easiest to use and multifunctional game where all the functions of gaming activities are included. There are games that develop speaking skills, improve knowledge of English grammar, games to fill out vocabulary and develop students' logical thinking.

Innovative technologies in lessons teach students to organize their activities, the ability to think, competent and meaningful reading, the ability to cooperate and get the result of learning on their own. Game-based media situations vary from traditional educational games and non-game-based e-learning in that they use the motivational techniques of entertainment games to achieve their educational goals. The techniques of such technologies give students the opportunity to express their point of view on the topic being studied freely, without fear of making mistakes and being corrected, to record all statements, expand their vocabulary and use the acquired knowledge in life. Many students like to work independently: use e-libraries and check their knowledge by online tests, because they get more of the necessary knowledge and use that skills in their life. Thus, they quite often use some kind of story and parasocial relationship between the player and a non-player characterto begin the learning process. As the great psychologist Vysotsky wrote, play leads to development. If we want to teach lessons comprehensively and harmoniously, it is necessary to apply game elements of media, because it gives us the opportunity to observe how students apply their knowledge and skills in practice and in their life.

Recommendations

Thus, in the context of digitalization, the role of the media technologies in the development and terms of education processes is enormous, since the media has a new task: to show the importance of values for the successful formation of a new reality, to contribute to the development of an adequate culture, to form the values and norms that underlie the social transformation of society and language. So, the technologies of mass media are one of the powerful tools with which you can influence the values of the past and present.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Innovation as an Organisational Competitiveness Factor in Project Start-Up Decisions

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Abstract: Innovation has become a leading buzzword in recent years. However, innovation is not just a concept, it is a series of activities that can move an economy in resource scarcity through stagnation and hard times, offering new solutions, products and processes. For organisations, whether small or large, it is essential to adopt an innovative approach and mindset in order to thrive in the future. Innovation is very important for increasing competitiveness, which is primarily captured at the level of organisations. It is also important how innovation and the drive to innovate is embedded in the daily life of organisations. In our study, we aim to examine how innovation and its impact are reflected in project start-up decisions, using the examples of Hungarian and Slovakian enterprises. We want to answer the question of how innovation is prioritised in a project start-up decision with respect to different organisational characteristics, which, broadly interpreted, can actively influence the international standing and competitiveness not only of an organisation but also of a region or even a country.

Keywords: Innovation, Project start-up, Economic engineering

Introduction

Innovation has long been a major focus for economic and social development. Academic research and practical experience, backed up by the results of each other, clearly show that innovation is one of the most important parameters of competitiveness, especially in an era of globalisation and technological progress. Competitiveness, as a determinant of the market position of organisations, is inseparable from the ability of organisations to innovate quickly and effectively, to respond to changing circumstances and to identify and exploit market opportunities. This paper focuses on project initiation as a key decision for organisational innovation and competitiveness. The research examines Hungarian and Slovakian enterprises to explore how the drive to innovate can be demonstrated at this critical stage and what impact it has on the long-term performance of organisations.

Literature Review

The first step in the literature review is to define the concept of innovation. Looking at a wide range of literature, we can find many definitions. In this study, we use the Oslo Manual's formulation, "innovation is the process of introducing new or significantly improved products, processes, new marketing methods, or new organisational approaches" (Oslo Manual, 2018). In the literature, the relationship between competitiveness and innovation is discussed by several authors, highlighting that innovative companies are more likely to outperform in international markets (Vladi et al, 2022; Varga, 2023a).

Innovation projects are engines of change (Vasa et al., 2023). The low success rate of such projects is well known, hence the general "fail, fail again, fail better" perception in this field. We learn from failure, but it is best to prepare for success. Identifying the technological, marketing, commercial and managerial readiness of projects can be an important parameter for launching projects. These aspects will be useful in managing projects and increasing the chances of project success. (Cseminschi et al., 2024)

Two textbooks published last year reflect the growing interest in innovation, the wider application of innovation methodology and the need to develop an innovation mindset. Gabriella Cserháti's book 2023 emphasises that the success of innovative ideas and initiatives depends on how they are implemented. Success depends, among other things, on the choice of project management tools and the extent to which the characteristics of innovation implementation are placed in a broader context (Cserháti, 2023)

Theories and models used in project generation and start-up are fundamental and highly dependent on organisational strategy. To use these models, it is very important to understand innovation activities, how they can influence the long-term competitiveness of organisations and how they can help to improve market positioning (Varga, 2023b; Varga, 2023c). Project selection and launching should be an important part of the corporate innovation strategy or portfolio management, which determines the direction of subsequent activities and market success. (Mascellaro, 2021)

The analysis of the impact of innovation characteristics has shown that market orientation in both product and service innovation patterns contributes significantly to the impact performance of an innovation project, measured in terms of its intermediate benefits for the firm. However, this has little impact on its market success. The impact can be measured in terms of revenue and profit performance (Kwaku, 1996).

Surprisingly, the results do not support the hypothesis that market orientation will have a greater impact on service innovation performance than on product innovation performance. Lack of knowledge of project management best practices and strategic project management processes, as well as lack of organizational structures and skilled project management professionals, may be the main factors that affect the adoption of strategic project management. (Ugonna et al., 2021)

Last but not least, the financing side is also a very important factor in the decision to launch these projects. The decision to finance innovative projects is influenced by a number of factors that vary from one organisation to another. Most owners and managers make their decisions when evaluating innovative projects, relying on traditional methods of calculating performance indicators and considering the innovative project as an investment. These traditional methods are, for example, the calculation of net discounted income, the internal rate of return, the payback period of the project, the profitability ratio and other indicators. When using these methods, the focus on financial indicators overshadows professional considerations such as the qualitative impact of the introduction and use of innovations (Mutovkina, 2023).

A review of the literature highlights the complex and multifaceted relationship between innovation and project launch decisions, and why understanding and correctly managing these elements is of paramount importance for any organisation in order to increase competitiveness.

Material and Method

The results presented in this study are partial results of quantitative research among Hungarian and Slovak enterprises. The research was based on a pre-tested standardised questionnaire and the data were collected through an online survey, in both cases using an arbitrary sampling technique. The survey measured the perceptions of SMEs in the two countries along the lines of factors that strengthen competitiveness. We wanted to examine factors such as a project approach, green thinking, CSR activities, digitalisation or even agility. For the Hungarian sample 427 and for the Slovak sample 181 questionnaires were processed, in both cases the population was defined as registered enterprises in the respective country. Limitations of the research include the local value of the results due to arbitrary sampling. The research provides an excellent basis for further research to follow and monitor the changes of our time. The results presented in this study reflect the opinions of the groups based on the size of the enterprises that filled in the questionnaire on the statements made. Respondents were asked to express their opinions on project start-up and project content using a four-point Likert scale, which is presented in the results section of this study. Our conclusions were drawn using analysis of variance, significance calculation and basic statistical methods. The composition of the sample is shown in the figure below.

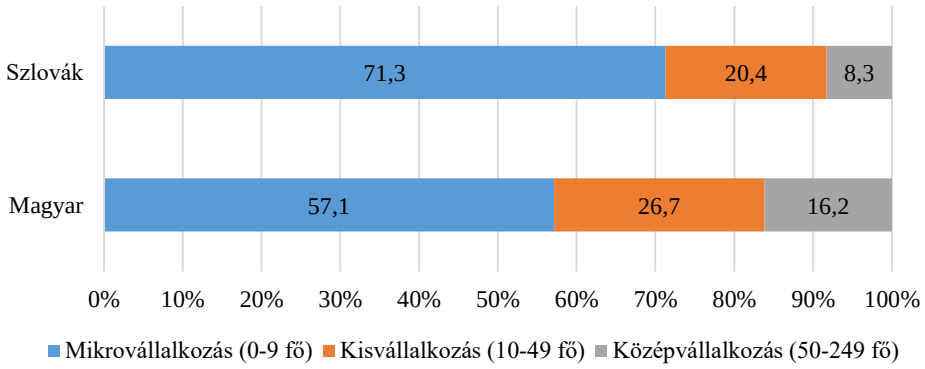

Figure 1. Distribution of the Hungarian and Slovak sample by size of enterprises
Source: own research, 2023, N Hungarian = 427, N Slovakian = 181

Results

We conducted research on the internal motivations of Hungarian and Slovak enterprises to start projects, how they search for funding and to what extent they adopt an innovative approach when deciding to start a project. Overall, on a four-point scale, the four statements assessed show that the scores did not rise above 3 in any of the four cases. It can also be seen that Hungarian and Slovak enterprises have roughly the same opinion on the above project start-up conditions. The statements with the highest average value include that enterprises in both countries start their projects in a way that tries to be most demand-driven and that tries to apply an innovative approach in their decisions. What is surprising, however, is that innovative approaches scored higher on average according to the opinions of enterprises in both countries, but innovative project start-up scored less highly. The least agreed with the statement that enterprises start a project for which there is funding available. This is certainly an effective and welcome endeavour, as most of the countries that have changed their systems have for a long time been characterised by a high level of project start-ups for which funding was available.

Table 1. Mean and variance of responses of Hungarian and Slovak enterprises on project start-up decisions

	Hungarian		Slovakian	
	Average	St. Dev.	Average	St. Dev.
The projects we launch are always driven by demand.	2,817	1,335	2,818	1,356
We launch projects for which we can find funding.	1,721	1,124	1,901	1,248
We try to apply an innovative approach to our projects.	2,707	1,220	2,818	1,327
We try to launch innovative projects.	2,464	1,265	2,591	1,345

Source: own research, 2023, N Hungarian = 427, N Slovakian = 181

Table 2. Hungarian entrepreneurs' views and the relationship between size category

		Sum of Squares	df	Mean Square	F	Sig.
The projects we launch are always driven by demand.	Between Groups	8,855	2	4,427	2,500	0,083
	Within Groups	750,897	424	1,771		
	Total	759,752	426			
We launch projects for which we can find funding.	Between Groups	8,429	2	4,214	3,375	0,035
	Within Groups	529,407	424	1,249		
	Total	537,836	426			
We try to apply an innovative approach to our projects.	Between Groups	13,521	2	6,760	4,617	0,010
	Within Groups	620,887	424	1,464		
	Total	634,407	426			
We try to launch innovative projects.	Between Groups	14,897	2	7,448	4,733	0,009
	Within Groups	667,290	424	1,574		
	Total	682,187	426			

Source: own research, 2023, N Hungarian = 427

We also looked at the influence of the size of the business on the perception of project start-up issues in Table 1. To this end, an analysis of variance was carried out, and the significance values indicate that three out of four statements are influenced by the size of the enterprise. In only one case did we not see a significant correlation between the perception of the statement and the size of the enterprise, namely in the case that the projects launched by enterprises are driven by demand. All this suggests that the decision to take an innovative approach or to launch a project based on a grant is definitely influenced by the size of the enterprise.

We also looked at how the average values for the perception of the claims for the above size categories evolve in Table 2. It can be seen that the primary needs-based approach to business-initiated projects is most prevalent in medium-sized enterprises and least so in micro-enterprises. The statement that projects should be launched along the lines of tenders is most typical of small enterprises and again least agreed with by micro enterprises. Although this is surprising because it is micro enterprises that are most in need of external funding compared to their larger counterparts. The emergence of an innovative approach in projects was again the highest average for small enterprises and, unsurprisingly, the launching of innovative projects was the highest for medium-sized enterprises.

Table 3. Opinion of Hungarian entrepreneurs by size category

		Average	St. dev.
The projects we launch are always driven by demand.	Micro-enterprise (0-9 persons)	2,693	1,391
	Small enterprise (10-49 persons)	2,982	1,241
	Medium enterprise (50-249 persons)	2,986	1,254
	Total	2,817	1,335
We launch projects for which we can find funding.	Micro-enterprise (0-9 persons)	1,607	1,162
	Small enterprise (10-49 persons)	1,930	1,019
	Medium enterprise (50-249 persons)	1,783	1,110
	Total	1,721	1,124
We try to apply an innovative approach to our projects.	Micro-enterprise (0-9 persons)	2,553	1,296
	Small enterprise (10-49 persons)	2,921	1,114
	Medium enterprise (50-249 persons)	2,899	1,031
	Total	2,707	1,220
We try to launch innovative projects.	Micro-enterprise (0-9 persons)	2,303	1,308
	Small enterprise (10-49 persons)	2,649	1,197
	Medium enterprise (50-249 persons)	2,725	1,149
	Total	2,464	1,265

Source: own research, 2023, N Hungarian = 427

We were also curious to see whether size had an impact on the perception of claims in Slovak businesses. In the present case, we found that there was no significant correlation between any of the statements, i.e. the responses of Slovak enterprises were not influenced by the size category of the respondent.

Table 4. Slovak entrepreneurs' opinions and the relationship between size category

		Sum of Squares	df	Mean Square	F	Sig.
The projects we launch are always driven by demand.	Between Groups	1,569	2	0,785	0,424	0,655
	Within Groups	329,414	178	1,851		
	Total	330,983	180			
We launch projects for which we can find funding.	Between Groups	0,288	2	0,144	0,092	0,913
	Within Groups	279,922	178	1,573		
	Total	280,210	180			
We try to apply an innovative approach to our projects.	Between Groups	3,588	2	1,794	1,019	0,363
	Within Groups	313,396	178	1,761		
	Total	316,983	180			
We try to launch innovative projects.	Between Groups	9,360	2	4,680	2,633	0,075
	Within Groups	316,386	178	1,777		
	Total	325,746	180			

Source: own research, 2023, N Slovakian=181

In the present case, we have also examined how the average values of the claims within each category evolve. We found that the Slovak sample is less heterogeneous in this respect than the Hungarian sample. For the first four statements, that the applications are motivated by needs, application sources and that the projects are clearly based on an innovative approach, small enterprises showed the highest average values in all cases. However, as in the present case, the launching of innovative projects was highest for medium-sized enterprises.

Table 5. Opinions of Slovak entrepreneurs by size category

		Average	St. Dev.
The projects we launch are always driven by demand.	Micro-enterprise (0-9 persons)	2,775	1,410
	Small enterprise (10-49 persons)	3,000	1,179
	Medium enterprise (50-249 persons)	2,733	1,335
	Total	2,818	1,356
We launch projects for which we can find funding.	Micro-enterprise (0-9 persons)	1,876	1,206
	Small enterprise (10-49 persons)	1,973	1,258
	Medium enterprise (50-249 persons)	1,933	1,624
	Total	1,901	1,248
We try to apply an innovative approach to our projects.	Micro-enterprise (0-9 persons)	2,729	1,356
	Small enterprise (10-49 persons)	3,054	1,177
	Medium enterprise (50-249 persons)	3,000	1,414
	Total	2,818	1,327
We try to launch innovative projects.	Micro-enterprise (0-9 persons)	2,473	1,398
	Small enterprise (10-49 persons)	2,730	1,262
	Medium enterprise (50-249 persons)	3,267	0,799
	Total	2,591	1,345

Source: own research, 2023, N Slovakian = 181

Conclusions

The results of the research show that businesses in the two countries have broadly the same mindset when it comes to project start-up decisions. It became clear that they attach importance to innovation and an innovative approach to their projects. However, in terms of innovation, it is clear, as has been proven by a number of studies, that it is the companies in the largest size category that are at the forefront. What was surprising, however, was that it was not the smallest companies that agreed with these statements in the largest proportion in terms of funding. This shows that size was the most important factor in the mindset of Hungarian businesses. The same was not the case for Slovak enterprises. It can also be seen that in the Hungarian sample, which had a much larger number of items, we saw a much more heterogeneous picture within each size category than we saw in the Slovak sample. Based on the results of the survey, we can conclude that enterprises, whether Hungarian or Slovak, have increasingly recognised the importance of innovation. In this respect, the enterprises with the largest number of employees should be considered as relevant and should be accepted as a model. It is therefore very important that these companies share their approach and knowledge as widely as possible with their smaller counterparts in order to ensure future competitiveness for both countries.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Chatbot Development: Framework, Platform, and Assessment Metrics

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Abstract: It can be difficult for developers to select the best solution for their projects due to the abundance of chatbot development platforms and frameworks. This paper explores the selection of frameworks and platforms for designing chatbots, based on criteria from numerous scientific articles. The introduction covers the axes and sections of the paper, including frameworks, platforms, metrics, and paper details. The second section reviews previous studies on the topic, examining frameworks and platforms used, metrics, and other details. An expansion of software-related services devoted to chatbot development has resulted from the necessity for these services to be produced in large quantities quickly and effectively. The third section examines the latest frameworks and platforms, various sources of articles and scientific research published in prestigious international databases. Large corporations compete with one another and offer comprehensive chatbot development platforms include Google, Microsoft, Amazon, and IBM. We also talk about chatbot platform and measures of evaluation framework while showcasing successful industrial practices. The fourth section proposes methodologies for choosing frameworks or platforms based on findings from numerous scientific research, master's and doctoral theseis, and important scientific books by prominent authors. The fifth section discusses the criteria for measuring chatbot efficiency and the best frameworks and platforms according to these metrics. Scholars, developers, and businesses are given recommendations that point to potential areas for further research and development in this rapidly evolving section. The final section presents the conclusions, listing details and section mentioned in the paper, and a list of references, including about a hundred references from prestigious scientific articles. This scientific paper provides individuals, groups, and large and small companies with mental and intellectual enlightenment, helping them make decisions on their chatbot designing by choosing the most appropriate frameworks and platforms.

Keywords: Conversational agents, Natural language processing (NLP), Chatbot

Introduction

Recently, the world has witnessed a wide spread of chatbots in various fields of work, due to their ease of use 24/7 without getting tired or bored. chatbots respond to the questions and inquiries of users and provide suggestions and solutions to them. This is done by understanding natural languages (NLU) and processing them using natural language processing (NLP). There are also many varied platforms and frameworks available for building and designing chatbots suit to various specialization fields in the labor market (Abd-Alrazaq, 2020) Companies noticed the effectiveness of the chatbot, its ease of use, and the satisfaction of clients and customers

with its performance, which prompted them to competition to develop platforms and frameworks for developing chatbots. Thus, it became important to carefully choose between these platforms and frameworks for building a chatbot and integrating it with applications (Suhaili, 2021) The rate of increase in online conversations with chatbots over the past few years has attracted the attention of artificial intelligence (AI) and machine learning (ML) developers, as well as the diversity of its areas of use in health, education, entertainment, customer support, etc., in addition to the possibility of integrating it with other applications such as Siri, Messenger, Watson, etc. (Radziwill, 2017). In light of the rapid emergence of chatbots, the search for criteria for evaluating it has become an urgent issue, and there are no accurate metrics for evaluating its performance. Existing studies primarily focus on technical aspects, lacking human or business perspectives and exploring motivators (Io, 2017). Although there is a lot of research on chatbot development and design, there is still a big knowledge vacuum about user motivation (Brandtzaeg, 2017). Goal-oriented dialogue systems have previously been evaluated using TRAINS, PARADISE, SASSI, and MIMIC. PARADISE is the most popular framework for evaluating chatbots; it measures subjective aspects including user happiness, clarity, and ease of use (Venkatesh, 2018). In this regard, developing a methodical process for assessing and contrasting various chatbot frameworks and platforms becomes essential. By using evaluation criteria in an organized manner, chatbot development experts can make accurate decisions that are consistent with their goals (Gupta, 2022). This study attempts to offer recommendations on the ideal framework or platform for developing chatbots by incorporating knowledge from the literature already in existence and industry best practices. We will cover the many assessment metrics and criteria that developers should take into account as well as the important elements that affect platform selection through a thorough analysis of pertinent research articles, case studies, and industry reports. In order to choose the most appropriate platforms and frameworks, we examined these proposed methodologies to supply programmers and developers with wide insights that will help them create a chatbot and facilitate their decision-making process in choosing the best and most appropriate platform or framework for building and designing their chatbot. Using a methodical search of the Scopus, Elsevier ,Web of Science, IEEE, and Science Direct platforms, the study examined current chatbot assessment measures with an emphasis on the computer science, telecommunications, education, and engineering domains. Papers addressing chatbot assessment, evaluation measures, and quality factors were deemed pertinent. A combination of qualitative and quantitative measurements were found when prior research on chatbot evaluation was refined. The majority of evaluation metrics, which were based mostly on user satisfaction surveys, lacked quantitative components. In Hung (2009) assessed LifeLike's efficacy and naturalness using the PARADISE technique, paying particular attention to efficiency and quality costs in dialog performance. The functioning of commercial chatbots, including their appearance, implementation, speech synthesis, knowledge base, conversational skills, context sensitivity, personality, customisation choices, and user rating, was examined in Kuligowska, (2015). The study concentrated on quality factors and was subjective. A paradigm for assessing chatbots based on user involvement, topic coverage, consistency, content variety, and conversation depth was presented by Venkatesh (2018) to objectively evaluate chatbot performance, the metrics were combined. Using user feedback as a baseline, the approach's validity was confirmed by the significant correlation observed between the suggested measures and user evaluations. In Chakrabarti (2013) experts evaluated the conversational agents, factual accuracy, information sufficiency, manner, and relation. In [(Jwalapuram, (2017, September))] Grice's Maxims were employed to assess the conversations and rated chatbot conversations using a Likert scale. In Shawar (2007) using qualitative methods to assess the efficacy, quality, and user satisfaction of conversations by analyze the relationship between user input and chatbot responses. In Cahn, (2017) and Hussein et al. (2020) the study assesses chatbot performance from multiple angles, including information retrieval, user experience, linguistics, Using user feedback.

Chatbot Framework and Platform

There are two kinds of tools for creating chatbots: frameworks and platforms. Frameworks provide developers greater control and freedom when building chatbots from scratch by offering tools, libraries, and standards. Developers that have the resources and programming abilities to oversee the complete development process can use them. Conversely, platforms provide a whole ecosystem for creating, implementing, and overseeing chatbots without requiring a lot of coding knowledge or technical know-how. They provide pre-built templates, chat platform connections, and user-friendly interfaces. Development is made easier by the fact that platforms frequently come with NLP, analytics, and deployment options pre-installed. On the other hand, compared to using frameworks directly, users can have less customization and freedom. The decision between a framework and a platform is based on particular needs and level of experience. Developers can create and implement chatbots more effectively by using a chatbot framework, which is a collection of guidelines and tools.

Table 1. Platforms and frameworks

Platform	Features	Suitablefor	Pricing
Chtfuel	A/B testing, AI/ML, alerts/notifications, auto-responders, automated publishing, automated scheduling, and campaign management are all provided by Chatfuel.	Chatfuel's user interface is simple to use, and can quickly build up a chatbot using it. The fact that each chatbot flow is exclusive to a single channel and cannot be duplicated across channels is the only negative could detect.	Enterprise plans start at $300 and provide customized plans, priority support, and a dedicated bot building specialist. Business plans start at $14.39 and include 500 monthly talks plus $0.03 additional conversations each interaction.
anychat	Popular for building and administering chatbots on Facebook Messenger, ManyChat provides capabilities including broadcasting, audience segmentation, custom design, and connectivity with marketing tools.	Creating bots for sales, support, and marketing is possible with ManyChat, a top Facebook Messenger marketing solution. ManyChat gives all the growth tools needed to turn anyone into a subscriber, so you can easily expand the Messenger audience.	Manychat has a range of business options, which include bespoke features, specialized automation specialists, sophisticated Pro features beginning at $15/mo, and free basic capabilities.
I.B.M	Central repository for enterprise vocabulary that helps users with governance initiatives, asset comprehension, compliance, and Working With IT Teams.	Enhancing decision-making confidence for businesses by providing accurate, consistent, and complete information definition and organization.	With a committed use account or subscription upgrade, the service provides discounted rates on over 350 products, a 30-day credit, and free access to over 40 services. pay-as-you-go options are also available.
Google-Dialog-Flow	With features like a visual flow builder and omnichannel implementation, dialogflow expedites the creation of generative aı agents, cutting down on development time and enhancing conversational capabilities.	Use text virtual agents to quickly and accurately respond to common inquiries and provide specific information while interacting with customers on their preferred platform at any time and from any location.	Monthly pricing for dialogflow is determined by edition and number of requests. a $600 credit is given to new customers for a risk-free trial that lasts for a year.)
Azure AI Bot Service	With power virtual agents, developers can build conversational aı bots without writing any code thanks to a fully hosted low-code platform.	With the least amount of code modifications, the aı system generates conversational interactions for clients by combining natural language, discourse, and vision.	The cost of the azure AI Bot service is determined by how many messages are sent over premium channels (standard channels are free).

Amazon-Lex	Rich insights and dashboards are provided by amazon lex, an aı service that creates, develops, tests, and launches conversational interfaces. ıt also integrates With AWS Lambda.	Scalable, safe, and easy to use, amazon lex works with aws lambda to solve deep learning issues such as language comprehension and speech recognition.	Amazon lex is a service that offers voice and text conversational interfaces for applications, processing up to 10,000 text requests per month without any upfront commitment or minimum fee.
R.A.S.A	AI/machine learning software is appropriate for developers and pre-configured bots because it can modify behavior based on data, assist in intent recognition, and process natural language for contextual guidance.	Millions Of Developers Use Rasa open source, rasa x, and rasa enterprise to create conversational aı applications for small teams and large enterprises alike.	Rasa Io plus and pro plans offer customizable features for small to mid-sized businesses, simplifying newsletter management and saving time with varying pricing.
WIT. AI	Multimodal interaction across multiple platforms is made possible by the platform, which facilitates the development, testing, and deployment of free, open, and extensible natural language experiences.	Signing Up, creating a wit app, improving detection, querying it, adding new intents, and adding entities to capture more data are all possible with Facebook.	Wit is available for free, even for business use. thus, our terms apply to both private and public wit apps, which are free.
PANDORA-BOT	A comprehensive artificial intelligence software for businesses and startups, pandorabots offers complete Windows Solutions, İncluding Chatbots And Multilingual Features.	With its easy-to-use platform, pandorabots makes it possible to quickly deploy chatbots and virtual assistants without requiring complex infrastructure management.	The $199/month pro plan offers live training, email, chat, phone support, an unlimited message limit, chat widget Access, API Access, Development Sandbox, And Third-Party Channels.
BOT-PRESS	Use multiple conversations, css, and react to customize the gui messages that your bot sends. you can host on aws s3 or bpfs, share files via shareable links, and set and delete conversations privately.	Botpress offers an easy-to-use interface for creating chatbots, with pre-built themes and plugins that make customization and functionality enhancement simple.	No cost with restrictions, obtain $5 credit every month for aı spend, five bots, two thousand incoming messages or events per month, three partners, five thousand table rows, one hundred
SAP-CONVERSATIONAL-AI	Make use of our cutting-edge natural language processing technology to interpret text inputs, enhance important information, and construct flexible bots that can speak different languages. you can configure triggers, parameters, and responses right within the bot-builder.	Using Cutting-Edge NLP technology and low-code features for quicker development, the platform offers an intuitive user interface for training, developing, testing, connecting, and monitoring chatbots integrated into sap and third-party solutions.	Model Of Pricing: Free, Trial Offer: Obtainable

Google Gemini AI	Google created Google Gemini AI, formerly known as Bard, as an AI chatbot tool to mimic human discussions using machine learning and natural language processing.	Because Google Gemini takes strong privacy and confidentiality precautions, such as severing communications from users' accounts before reviewers can access them, it is safe.	For individuals 18 years of age and older who have a personal Google Account or Google Workspace account with admin access allowed, Google Bard AI, now known as Gemini, is available for free.

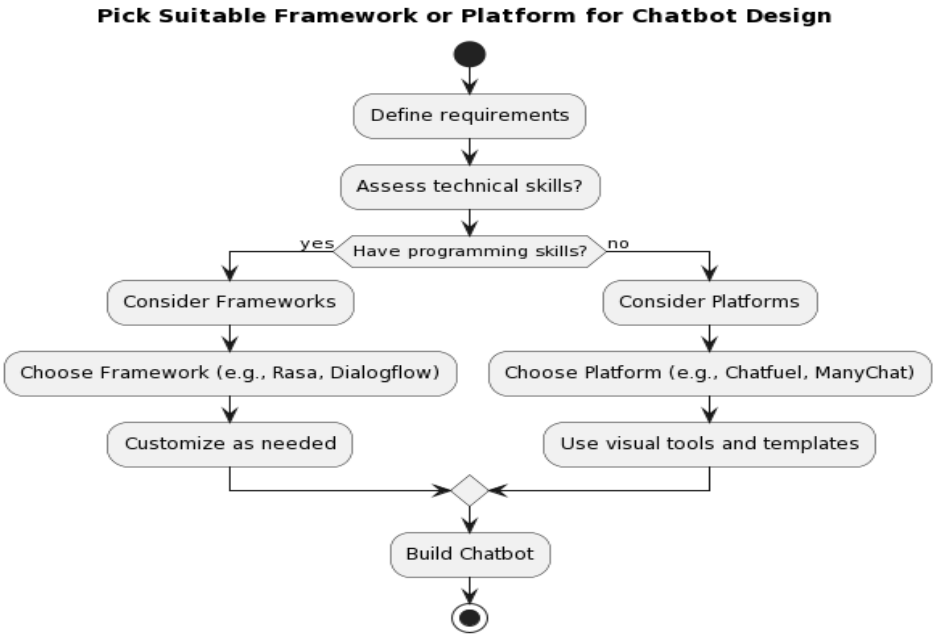

Figure 1. Path for picking up the framework or platform.

These frameworks provide developers with defined techniques and reusable code for basic tasks, freeing them up to concentrate on personalizing the chatbot's behavior and connecting it with certain applications. Microsoft Bot Framework, Google's Dialogflow, and Rasa are popular frameworks (Wei, 2018). Chatbot frameworks and platforms are distinct tools for developing and deploying chatbots. Frameworks offer a foundation for customizing chatbots, requiring coding expertise, while platforms offer an end-to-end solution with a user-friendly interface and pre-built components, making them suitable for individuals with varying technical expertise (Framework., 2019). Microsoft Bot Framework is an AI chatbot framework made for communicating and interacting with customers. It can be taught with current conversations and Azure cognitive services, and it connects with well-known Microsoft programs like Cortana and Office 365. With help of the free and open-source (NLP) API Wit.ai, companies may develop voice- and text-based chatbots. It extracts useful information using machine learning methods and supports multiple languages. Google owns Dialog Flow, a system that translates speech into text to digitize corporate operations and save time and money. It has special voice navigation functions. It enables automatic human-computer interaction through speech-to-text and natural language dialogues (Thorat, 2020). Neural networks (NN) are used in the DeepQA project I.B.M. Watson to provide organically processed responses. It is widely used in healthcare facilities to diagnose possible illnesses and prescribe appropriate care and medications. These frameworks are made to function as dynamic dialogue-flowing question-answering platforms that let organizations get information and crucial data. With the help of the AIaaS platform Pandorabots, companies can easily create, implement, and refine chatbots. To process human language organically, it makes use of the Artificial Intelligence Modelling Language (AIML) and the (A.L.I.C.E) Artificial Linguistic Internet Computer Entity. Pandorabots includes SDKs for Java, Node.js, Python, Ruby, PHP, and Go and supports GIFs and static images. Voice interfaces, eCommerce, customer support, and marketing have all made use of it (Følstad, (2021)). Botpress is a chatbot available under two licenses that provides enterprises with a modular blueprint to add new features to pre-existing code frames. Businesses can use their choice cloud hosting service and create chatbots locally with its three-step installation method. More than 7,000 developers use the Botkit platform, which includes integrated LUIS.ai (NLU).

Numerous plugins, open source libraries, a visual builder for conversations, integrated analytics and statistics, and a free edition are all available. A sophisticated collection of open-source machine learning tools called RASA Stack can be used to build assistants and chatbots. Among its characteristics are conversational functions, interactive and supervised (ML), and (NLU) (Pérez-Soler, (2020, October)). From the table1 below: there are several chatbot systems and frameworks on the market, each with unique features, cost structures, and intended user bases. Several well-liked choices are Amazon Lex, Microsoft Bot Framework, I.B.M Watson-Assistant, Google-Cloud's Dialog-flow, and Facebook-Wit.ai. Building conversational interfaces is made easy with Dialogflow, a free platform that provides natural language comprehension, messaging platform integration, and simple deployment. Pay-as-you-go Amazon Lex is a service that can build conversational interfaces based on voice and text that can be integrated with messaging apps and AWS services. Although the Microsoft Bot Framework is free, using Azure services and resources for the creation and implementation of bots may cost money. An AI-powered platform called IBM Watson Assistant is used to create, train, and use conversational bots on a variety of platforms.

Proposed Methodologies

The combination of AI-driven skills with chatbot frameworks is what will define chatbots in the future. (AI) chatbot frameworks, such as those for (ML), (NLU), and contextual understanding, are making it possible for chatbots to react more human-like and comprehend user inputs more precisely (Makatchev, 2010). Through enhanced personalization, adaptability, and dynamic dialogue management, this connection offers a more smooth and intuitive user experience. In order to prove concepts using appropriate frameworks, it is preferable to create prototypes in order to evaluate their applicability. It is also preferable to make modifications to the suggestions and knowledge collected in the stages of testing the prototypes. The success of a chatbot depends on evaluating frameworks and platforms (ElGibreen, 2020). For companies, frameworks and platforms have become extremely important because they help in developing advanced chatbots in all fields. Choosing the most appropriate among the frameworks and platforms depends on the needs of the company or institution and provides many specifications to achieve the required goals (Qaffas, 2019; Al-Khazraji, 2023). There are a number of criteria through which the best framework and platform for developing a chatbot can be determined, including cost, accuracy, ease of use, and compatibility with other applications (Denecke, 2020). We designed a comparison table above to highlight the most prominent comparisons between the most important frameworks and distinct platforms in developing chatbots. The optimal option is determined by the technical capabilities, financial restrictions, and project needs.

Chatbot Metrics

One of the important issues in evaluating the performance of a chatbot is user comments, ratings, and opinion polls (Balaji, 2019). When a chatbot's responses are accurate to a certain level, this is considered an important metric, and this is done using one of these metrics (F1 score), (recall), and (precision) (Goodman, (2023)). As is the case with humans, clear understanding and accurate interpretation are also important in a chatbot through understanding connotations, intentions, and entities. This is done by (NLU) and is considered a measure of the extent of understanding (Cañizares, 2022). When the user interacts, continues the conversation, and prolongs the dialogue with the chatbot, this is considered an important measure and is called the (Engagement metrics) (Schuetzler, 2020). When a chatbot is asked to perform a specific task and it completes it, the extent of completion, accuracy of completion, speed of completion, and other considerations related to this task, such as the error rate and success rate, are all considered a evaluate of the success chatbot (Schumaker, 2007). There are responses from a chatbot that require personalization ,so the extent of the chatbot’s flexibility in personalizating answers and adapting and being flexible with them is an important metric for a chatbot (Abd-Alrazaq,2020). Classification of some chatbot features based on quality, efficiency, and satisfaction in an analytical hierarchy process that has been proposed in order to evaluate chatbot performance. (Radziwill, 2017). User input and chatbot responses were evaluated using the correction rate and response satisfaction criteria to evaluate mixed dialogue systems and pure dialogue systems (Schumaker, 2007). To evaluate features such as human support, language diversity, command integrity through the use of helper commands such as cancellation, typos, key keywords and synonyms, as well as usage and response times, all of these are presented as criteria to evaluate the quality of the chatbot. (Pereira, 2018). Using a question or command that is already known to be answered to test a chatbot's responsiveness was presented as a criterion for measuring the efficiency of a chatbot. Assessors tallied mistakes and examined students' proficiency in grammar, spelling, and vocabulary. The acceptability of the responses was graded from both the grammatical and semantic perspectives (Coniam, 2014). Five categories were found in Brandtzaeg and Følstad's research on people's reasons for utilizing chatbots:

productivity, amusement, social/relational, novelty/curiosity, and other reasons. According to the study, users expect social and enjoyable interactions, while productivity was identified as the primary motivator. They also underlined the necessity of more research and the need for chatbots to offer useful and practical information (Brandtzaeg, 2017). In his 2017 study, Zamora looked at how people expected and perceived chatbots. With the chatbot, participants discussed their habits, observations, and experiences. The study discovered that a small vocabulary impedes communication and that delicate subjects should not be covered. Emotional needs were stated as the top priority, while privacy concerns around improper data handling were voiced (Zamora, 2017). Assessing chatbot effectiveness and important metrics indicators including job completion rates, customer satisfaction scores, and user engagement are crucial for gauging the efficacy of a chatbot when analyzing its performance. For more information see Table 2: Chatbot Metrics. It is crucial to comprehend how to calculate these metrics and analyze the information in order to consistently enhance and optimize chatbot functionality (Peras,2018). In the ever-evolving chatbot development ecosystem is essential to building chatbots that provide users with meaningful and value interactions. Developers can make well-informed decisions that result in the production of more efficient and user-friendly chatbots by studying comparative assessments of platforms and tools and comprehension of the evolution of chatbot capabilities. For chatbot deployment ,it's critical to take into account the chatbot deploying aspect like Facebook Messenger, WhatsApp, Slack, and Telegram that developers may decide which one is best for their particular chatbot project (Nuruzzaman, 2018).

Table 2. Chatbot metrics

Sorting by Category	Metrics	Articles
Metric with an automatic basis	F1-Score	(Zhang, 2018; Bashir, 2018; Alshammari, 2022; Nuruzzaman, 2020),
	ROUGE	(Omoregbe, 2020; Zhang, 2018; Kapočiūtė-Dzikienė, 2020; Hori, 2019).
	Accuracy	(Boussakssou, 2022;Peng, 2020; Wael, 2021;Wijaya, 2020; Niculescu, 2020; Grosuleac, 2020; Alshammari,2022)
	Recall	(Mai, 2021; Omoregbe, 2020; Zhang et al.,2018)
	Precision	(Boussakssou, 2022; Peng, 2020; Wael, 2021;Wijaya, 2020; Niculescu, 2020; Grosuleac, 2020; Alshammari, 2022; Mai, 2021; Omoregbe , 2020; Zhang et al., 2018)
	BLEU	(Yang, 2018; Aleedy, 2019; Palasundram, 2019; Alshareef, 2020; Kim, 2020;Tran, 2019;Zhou, 2020;Kim et al.,2019),
	PPL	(Song, 2021; Zhang et al., 2020; Wu, 2018)
	MRR, MAP, and P@1	(Prassanna, 2020; Liu, 2020; Candra, 2019)
	Skip thoughts cosine similarity, BOW and greedy matching scores, vector extreme cosine similarity, embedding average cosine similarity	(Mai, 2021; Omoregbe, 2020; Zhang et al.,2018)
	Other	(Hu, 2018; Sajjapanroj, 2020; Mohialden, 2021; Mavridis, 2011)
NA		(Roca, 2020; Zahour, 2020;Ranavare, 2020; Alotaibi, 2020; Kasinathan, 2020;Vanjani, 2019)
Metric based on human	H: User Satisfaction	(Hijjawi, 2014; Noori, 2014; Sweidan, 2021; Octavany, 2020;El Hefny, 2021;Al-Ajmi, 2021; Chete, 2020; Oguntosin, 2021; Mageira, 2022)

To create meaningful and interesting interactions, it is essential to understand user preferences and satisfaction levels. As is the case in all other applications, the development of a chatbot will necessarily make it important to choose platforms or frameworks for its design based on their advantages and disadvantages, taking into account the rapid development in (NLU) (Dagkoulis, 2022). There are many metrics that measure the coherence and fluency of the responses generated, and among these measures is the (F1 Score), which combines recall, accuracy, and the confusion measure. (Yuwono, 2019). In order to evaluate the quality of the text created by the chatbot in terms of comparing response units and text references, a metric called (ROUGE) Recall-Oriented Understudy for Gisting is used (Duong,2022). To measure one of the forms of accuracy known (precision at K (P@K)) as the percentage of responses. To evaluate the effectiveness of retrieval systems, a special metric

called Mean Average Precision (MAP) is used (Gu, 2019). To rank relevant responses, a measure called the Mean Reciprocal Rank (MRR) is used to evaluate how well the retrieval system classifies relevant responses. These automated metrics offer insightful information on a range of topics related to chatbot behavior, such as response relevancy, correctness, completeness, and fluency (Singh, 2021). The methods used by different chatbot tactics differ, and metrics are essential to assessing their efficacy. While human-based metrics offer qualitative evaluations of user happiness and interaction quality, automatic-based analytics offer quantitative insights (Naous,2020).

Regarding to table 2 above, metrics that are based on automatic processes showen with related articles infront of each metric are essential for assessing chatbot performance in an automated manner. These metrics include the fluency and coherence of generated responses measured by the Perplexity measure, and the precision and recall measured by the (F1-Score). Additional metrics are (ROUGE), which evaluates the quality of generated text or summaries by analyzing the overlap between (n-grams), and (BLEU), which compares n-grams in machine-generated text to those in a reference answer. Information retrieval metrics like (MAP), Precision at K, and (MRR) are used to assess how well a retrieval system is working. These measures, which include response relevance, accuracy, completeness, and fluency, offer insightful information on chatbot behavior. They are essential for comparing alternative systems and statistically evaluating chatbot performance, offering insightful information on a range of chatbot behavior and Metric based on human, User Satisfaction.

Conclusion

This scientific paper discusses the selection of frameworks and platforms for designing chatbots, focusing on criteria that have been thoroughly examined through numerous scientific articles. The introduction covers the axes and section of the paper, including frameworks, platforms, metrics, and paper details. The second section reviews and delves into previous studies on the topic, examining frameworks and platforms used, metrics, and other details related to the research. The third section examining the latest frameworks and platforms, various sources of articles and scientific research published in prestigious international databases such as Scopus, Web Science, Clarvit, natural Science, and IEEE. The fourth section which are this article's base, proposes methodologies for choosing frameworks or platforms for designing a chatbot, based on our findings from numerous scientific research, master's and doctoral theseis, and important scientific books by prominent authors in the section. The fifth section discusses the criteria for measuring the efficiency of a chatbot, which are this article's core, and the best frameworks and platforms according to these metrics. The final section presents the conclusions, listing the details and section mentioned in this paper, explaining each section briefly and with great clarity. The paper concludes with a list of references, including More than a hundred references of the important articles that are related. This scientific paper provides individuals, groups, and large and small companies in the governmental, private, and mixed sectors with mental and intellectual enlightenment, helping them make decisions on their chatbot designing by choosing the most appropriate frameworks and platforms.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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A Fuzzy AHP Analysis of the Barriers to Digital Transformation in Turkish SMEs

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Abstract: In the era of the Fourth Industrial Revolution, digitalization emerges as a key driver reshaping societal norms and business models, particularly for Small and Medium-sized Enterprises (SMEs). This paper aims to identify and prioritize the barriers SMEs face in their digital transformation journey. Utilizing the fuzzy analytic hierarchy process, a method adept at handling the uncertainties and complexities in prioritizing barriers, this study identifies 26 sub-barriers grouped into five main categories through literature review and expert consultation. The analysis reveals organizational barriers as the most significant, suggesting the need for strategic planning to navigate digital transformation challenges. The research underscores the risk of a widening digital divide, where SMEs lagging in digital adoption may exacerbate employment and regional economic disparities. This study examines the digital transformation challenges of SMEs within Industry 4.0, with a focus on Turkey, providing new insights for strategic planning and policy-making to address these barriers.

Keywords: SME, Digital transformation, Fuzzy AHP

Introduction

The criticality of digital transformation for SMEs to achieve sustainable growth is paramount, particularly in the milieu of the Industry 4.0 revolution. This transformation is a cornerstone for business expansion, as noted by (Philbin et al., 2022). By embracing digital technologies, SMEs can expedite the development of sustainable products and services, cultivate an innovative culture, enhance user experiences, and engage more effectively with customers. This transition not only augments capital efficiency but also opens strategic avenues for market expansion (Chen et al., 2021). For SME managers striving to ensure their businesses' resilience and prosperity in competitive landscapes, adapting to digital transformation across all business operations emerges as an optimal strategy. Through digital transformation, businesses can reshape their organizational structures, amplify operational efficiency, enrich customer experiences, reinforce competitiveness, innovate business models, and reduce operating costs. SMEs, these advantages are crucial in the successful execution of digital transformation initiatives. They play a significant role in augmenting managerial effectiveness and in providing superior products and services to their customer base. Nonetheless, SMEs encounter several challenges, including capital limitations, difficulties in accessing skilled human resources, a dearth of competent ICT personnel, insufficient digital infrastructure platforms, and disparities in digital standards. Research underscores the necessity for SMEs to embrace digital transformation in a competitive milieu (Eller et al., 2020).

The digital transformation journey for SMEs is impeded by technological, organizational, human resource, customer-related, and environmental barriers. In this context, it is crucial to prioritize these barriers in the digital

transformation process, enabling SMEs to effectively allocate their limited resources. However, there is a discernible research gap concerning the prioritization of these barriers for SMEs undergoing digital transformation. This study employs the Fuzzy Analytic Hierarchy Process (FAHP) technique to identify and rank the barriers confronting SMEs in Turkey during the digital transformation process, thereby bridging existing research gaps and enhancing both theoretical and practical understanding of digital transformation. FAHP is a method employed to ascertain the most significant criteria in multi-criteria decision-making (MCDM) scenarios. This technique leverages fuzzy numbers in pairwise Analytic Hierarchy Process (AHP) comparisons, incorporating the perspectives of academics, digital transformation experts, and SMEs managers, thus enabling the precise articulation of subjective preferences. The prioritization process involves pairwise comparison of barriers, assisting SMEs in pre-emptively recognizing impediments to digital transformation.

This research is aimed at scrutinizing the identification and ranking of barriers in the digital transformation process of SMEs in developing countries. The introductory section, constituting the paper's onset, provides a comprehensive overview of the subject and is succeeded by a research framework. The third section delves into a detailed exposition of the FAHP approach. Subsequent to this, the fourth section systematically presents the research findings, followed by in-depth discussions in the fifth section. The paper culminates with a conclusion summarizing the results and providing an overarching evaluation of the study.

Research Framework

In the ambit of their developmental strategies, nations in the developing world have gleaned pivotal insights from the sequence of industrial revolutions commencing in the early 18th century, spanning from Industry 1.0 through to Industry 4.0. This progression delineates a transition from the advent of steam power, through the advent of electrical energy, to the emergence of electronics and computer technologies, culminating in the advent of cutting-edge technologies such as digitalization, the Internet of Things, and Artificial Intelligence. These sequential industrial revolutions have been instrumental in the metamorphosis of business processes, yielding substantial enhancements in production efficiency and quality.

Figure 1. Industry 4.0 keywords

For SMEs in developing nations, these technological shifts are imperative for securing competitive edges and fostering sustainable growth. The developmental blueprints of these countries incorporate policies and

mechanisms designed to facilitate the SMEs' acclimation to these digital transformation processes, thereby broadening their access to novel business domains and technological proficiencies. This stratagem is deemed a vital catalyst in hastening the economic advancement of developing countries and augmenting the prominence of SMEs in the global economic arena.

Within the context of national development strategies, a paramount driver of the transition towards Industry 4.0 is recognized as the enhancement of awareness. Consequently, a thorough exploration of nations' engagement with and consciousness of industrial revolutions assumes significance. The ramifications of Industry 4.0, particularly for SMEs, are regarded as an integral aspect of the technical evolutions and innovations delineated in scholarly discourses. During the transition phase to Industry 4.0, variegated levels of awareness and expectations of adaptation among SMEs in both developed and developing countries are observable (Table 1).. For SMEs in the developing world, this heightened awareness is especially crucial in terms of their adaptation to digital transformation processes and the cultivation of technological capabilities. Hence, differing degrees of awareness are posited as a critical determinant impacting the efficacy of SMEs in the digital transformation trajectory.

In this vein, a comprehensive literature review focused on Industry 4.0 was undertaken to ascertain these varying levels of awareness. This review, spanning the period from 2010 to 2023 and utilizing the Web of Science database, facilitated the identification of the most prevalently employed keywords in conjunction with Industry 4.0. Subsequently, these keywords were systematically organized into eight distinct clusters and further subdivided into 37 sub-clusters, providing a nuanced understanding of the thematic concentration within this domain.

Table 1. Development plans of developing countries

Country	Plan timeframe	Country	Plan timeframe	Country	Plan timeframe
Africa		Asia		Middle East	
Angola	2018-22	Bangladesh	2020-25	Algeria	2013-30
Benin	2018-25	Bhutan	2018-23	Bahrain	2017-20
Botswana	2017-23	Brunei	2018-23	Egypt	2020-30
Burkina Faso	2016-20	China	2021-35	Lebanon	2016-40
Burundi	2018-27	India	2012-17	Oman	2021-25
Chad	2017-21	Laos	2021-25	Palestine	2021-23
Congo	2019-23	Malaysia	2021-25	Qatar	2018-22
Ethiopia	2021-30	Myanmar	2018-30	Iraq	2018-22
Ghana	2022-25	Pakistan	2013-18	Saudi Arabia	2018-30
Guinea	2016-20	Papua New Guinea	2008-50	Tunisia	2022-25
Guinea-Bissau	2020-23	Philippine	2023-28	Latin America	
Kenya	2018-22	Thailand	2023-27	Argentina	2023-25
Lesotho	2018-23	Timor Leste	2011-30	Barbados	2013-20
Liberia	2018-23	Vietnam	2015-35	Belize	2010-30
Madagascar	2019-23	Europe		Bolivia	2021-25
Malawi	2017-22	Albania	2015-20	Chile	2014-18
Mali	2019-23	Armenia	2014-25	Colombia	2018-20
Mozambique	2020-24	Azerbaijan	2022-26	Costa Rica	2023-26
Namibia	2017-22	Belarus	2018-25	Dominica	2020-30
Nigeria	2021-25	Bosnia	2021-27	Ecuador	2023-27
Rwanda	2017-24	Estonia	2018-20	El Salvador	2014-19
R. of Congo	2018-22	Georgia	2014-20	Guatemala	2021-24
Sierra Leone	2019-23	Kazakhstan	2018-25	Haiti	2018-30
Somaliland	2023-27	Kosovo	2016-21	Honduras	2010-38
South Africa	2012-30	Kyrgyzstan	2018-26	Jamaica	2018-21
South Sudan	2021-24	Lithuania	2011-30	Mexico	2019-24
Swaziland	2019-22	Moldova	2018-30	Nicaragua	2019-23
Tanzania	2021-26	Mongolia	2016-30	Panama	2019-24
Togo	2018-22	Tajikistan	2021-25	Peru	2016-21
Uganda	2015-20	Turkey	2019-23	Tobago	2020-30
Zambia	2022-26	Ukraine	2017-30	Venezuela	2020-23
Zimbabwe	2021-25				

In this study, the method of document analysis, a fundamental approach in qualitative analysis, was employed to scrutinize information derived from the national development plans of 92 countries. This research necessitated a meticulous examination of the concepts related to the characteristics of Industry 4.0, as outlined in these nations' national development strategies. The most recent iterations of these development plans were considered, with each country's plan being directly obtained from the relevant official web portals.

The analytical process involved the use of MaxQda 2020, a software package specifically designed for qualitative data analysis, to code features related to Industry 4.0. During this analytical phase, primary codes were established, followed by the addition of corresponding sub-codes that aligned with each main code. The process of analyzing each country's development plans entailed aligning the same or closely related expressions with predetermined codes. The emerging codes and sub-codes related to Industry 4.0 are illustrated in Figure 1. The frequencies and percentages obtained from this analytical scan are also presented, providing a measurable perspective on the data. The coding of concepts in the development plans was meticulously conducted at various levels including paragraphs, sentences, and words, resulting in the identification of 8 primary codes and 37 sub-codes. Following the coding of the national development plans, a word cloud visually representing the characteristics of Industry 4.0 compiled from these documents was created. The concluding sections of the findings depict the codes of the sub-codes and their emergence frequencies in a comprehensive graphic format, thereby offering a detailed overview of the prevalence and significance of Industry 4.0 features within the context of national development strategies.

The national development plans of 92 countries underwent a comprehensive analysis. Within this context, the 25 most frequently occurring words pertaining to the concept of Industry 4.0 were identified. These words have been prominently displayed in a word cloud, as depicted in Figure 2.

Figure 2. Industry 4.0 code cloud

Frequency and percentage values of the first 5 words are also shown (Table 2). The word cloud was created by taking into account the number of repetitions in the development plans.

Table 2. Word frequency distributions of Industry 4.0 features

Keyword	Frequency (f)	Percentage (%)
Digitalization	70	10,7
Digital Technology	59	9,0
Digital Transformation	56	8,6
Internet of Things	51	7,8
Artificial Intelligence	50	7,7

The code cloud analysis shows that the term "digitalization" is the most prominent and used term among the Industry 4.0 concepts. The terms "digital technology", "digital transformation", "internet of things" and "artificial intelligence" are also listed as important concepts respectively. The total frequency of the codes discussed in the study was determined as 653. According to the code frequencies, "Bangladesh" 93, "'Malaysia" 58, "Philippine" 52, "China" 44 and "Azerbaijan" 36 are among the prominent countries, while "Turkey" appears 28 times. The digitalization focuses in the national development plans of countries can be associated with various dimensions such as cultural, economic, communication and international competition and the

importance of these factors can be emphasized. In particular, the impact of these findings on the digital transformation processes of SMEs can be decisive in terms of their technology adaptation, innovation capacities and their position in the international competitive environment. By adopting these digital transformation foci in national development plans, SMEs can become more competitive and innovative in both local and global markets. The study then proceeds within the framework of digital transformation, which ranks third in the development plans of nations.

Digitalization

Digitalization is conceptualized as leveraging digital technologies and data to enhance efficiencies, evolve, refine, and revolutionize business processes, thereby fostering a digital-centric business model where digital information is fundamental (Schallmo & Williams, 2018). According to (Digitalization and Digitization – Culture Digitally, 2014), digitalization means "the integration of digital or computer technology by a business, industry, country, etc., or the expansion of its use in business processes". Although the importance of the concept of digitalization is increasing day by day and accepted by businesses, it can be stated that businesses cannot easily integrate and face difficulties against the change process that the digital transformation process will bring (Parviainen et al., 2022). This transformation poses distinct hurdles for manufacturing SMEs, which must either align with larger corporations or risk exclusion from the evolving digital framework (SMEs - European Commission, n.d.). Digitalization opens significant avenues for SMEs to penetrate new markets, yet the journey towards digital transformation is complex, characterized by barriers that impede manufacturing SMEs in their digital adoption strategies. The integration of digital technologies in business models, product offerings, and service delivery within cloud-based systems heralds innovative prospects for service innovation (Zheng et al., 2018). Emerging digital technologies, including mobility, social media, and smart devices, are reshaping customer engagement, internal business operations, and value creation processes (Henriette et al., 2015; Pagoropoulos et al., 2017). Digitalization fosters value-creation structures, catalyzing the reformation of existing business models and the development of new ones (Pagoropoulos et al., 2017; Vendrell-Herrero et al., 2017). Furthermore, the synergy of services and digital technologies introduces novel capabilities, such as enhancing process efficiency, enriching managerial decision-making through comprehensive and rapid data, forging robust customer relationships, adding value to products, personalizing offerings, and creating shared value (Paschou et al., 2018). With the digital revolution, the concepts of digitalization and digital transformation have undoubtedly become a trending topic in recent years. In fact, it is obvious that the concept of transformation, which is much older, is more talked about today (Alcácer et al., 2016; Sommer et al., 2017; Tekic & Koroteev, 2019). The main reason for this is the recent developments affecting information technologies such as electronic data processing, personal computers, communication technologies, internet and social media. Big data, artificial intelligence and information technologies have also heralded the arrival of a new era in information technologies, leading to the emergence of common words such as digitalization and digital transformation (Downes & Nunes, 2013). Thus, it is evident that digital transformation is pervasive, impacting all organizations, with many businesses still grappling to adapt to this paradigm shift. The permanence and ubiquity of information, knowledge, and processing capabilities, coupled with the growing interconnectedness of people, objects, devices, and systems, are transforming the operational landscapes of individuals, businesses, and societies.

Digital Transformation

Digital transformation is not about a single technology, but about major changes based on a "combination of information, computing, communication and connectivity technologies" (Bharadwaj et al., 2013), i.e. a "combination of advanced technologies" that integrate physical and digital systems (SMEs - European Commission, n.d.). Today's digitalization trend has radically changed the business processes of companies by pressuring them to integrate and incorporate digital technologies into their operations (Zangiacomi et al., 2020). Digital technologies such as IoT, Cloud Computing and Big Data and Analytics (Paschou et al., 2018), especially applied in manufacturing, bring significant changes to traditional manufacturing systems where inter-company connectivity (Mueller et al., 2017) and process integration between different stakeholders in the supply chain (Khan & Turowski, 2016) are realized, thus improving the overall efficiency of the company. The changes brought by Industry 4.0 are mainly focused on information technologies (Lasi et al., 2014), digital technologies of this nature are enablers of a digital industrial transformation, often referred to as the fourth industrial revolution or Industry 4.0. The implementation of Industry 4.0 leads to process optimization, resulting in improved operations for the entire organization. This is recognized as the main advantage of supporting the decision to implement Industry 4.0 (Sony & Naik, 2020).

Small and Medium-Sized Enterprises (SMEs)

An additional focal point of the literature review encompasses SMEs, a distinct category of organizational entities. Since its inception in 2011, Industry 4.0 has been at the forefront of industrial digital transformation, exploring innovative methods to interconnect devices and systems, thereby yielding novel data insights, facilitating the customization of products, and advancing technological independence. In this milieu, the digital transformation, as influenced by Industry 4.0, is becoming increasingly significant across various sectors. This is particularly pertinent in Europe, where it is imperative to ensure that SMEs, which constitute 99% of businesses, are not marginalized from these evolving opportunities. (Grooss et al., 2022). The definition of SMEs is not a universally accepted standard worldwide. These definitions vary depending on various factors such as economic data and differences in the distribution of enterprises across countries. SMEs are generally enterprises with a limited number of employees and a limited amount of income. Such enterprises are recognized as an important source of economic growth and employment. SMEs are recognized for their distinct advantages, including adaptability, innovation, and their substantial contribution to local economies, as elucidated by (Management Association, 2013). These enterprises represent a considerable segment of the global business landscape, encompassing over 95% of businesses (Malesios et al., 2020). Their role is particularly vital in supporting the supply chains of larger corporations. The European Commission has categorized SMEs based on employee count, distinguishing small-sized enterprises (employing fewer than 50 individuals) from medium-sized ones (with fewer than 250 employees). (Zaied & Mohmed, 2021) note that both formal and informal SMEs collectively contribute between 60% and 70% to the Gross Domestic Product. In the realm of open innovation processes, while larger firms often prioritize research and development, especially in the discovery phase, SMEs tend to focus more intently on commercialization aspects (Van Hemert et al., 2013). Nevertheless, SMEs frequently grapple with challenges such as constrained resources, complicating their capacity to innovate and compete effectively (Carias et al., 2020). The dynamic and heterogeneous nature of SMEs necessitates a variety of support mechanisms to navigate their specific challenges and harness their potential for sustainable economic development. In the Turkish context, SMEs constitute a majority of businesses, providing approximately 66% of employment and playing a pivotal role in the economy, significantly contributing to import and export rates (Aydin & Yildiz, 2023). However, the operational efficiency and competitiveness of Turkish SMEs are often lower compared to many European counterparts. This disparity stems from factors such as difficulties in accessing finance, growth challenges, struggles with technology adaptation, innovation lags, and deficiencies in institutional regulation. The literature of recent years has extensively discussed SMEs, particularly within economic domains. Yet, specific challenges inhibiting SMEs from actively participating in the economic process- like resource limitations, absence of formal planning, and financing hurdles (Klewitz & Hansen, 2014)- warrant further scholarly attention. Additionally, SMEs encounter various barriers in the digital transformation journey. Addressing these barriers and proposing solutions is critical for the economic development of nations, emphasizing the need for a focused discourse in this area.

Barriers to Digital Service Provision for SMEs

The implementation of digital transformation is articulated as a multifaceted process fraught with numerous impediments, complicating the successful progression of related initiatives. Presently, numerous enterprises continue to grapple with realizing the full potential of their digital transformation endeavors, hindered by a spectrum of barriers (Vogelsang et al., 2019). For this reason, identifying barriers and understanding their basic structure and origins is an important step in combating them. Although the importance of digitalization is well known, companies often struggle to understand the potential impacts and benefits of digitalization. According to (Henriette et al., 2015), a digital transformation project involves the application of digital capabilities to support business model transformations that affect entire organizations, especially operational processes, resources, internal and external users. Initially, the foundational technologies enabling the provision of digital services encompass the Internet of Things (IoT), big data and analytics, cloud computing, cybersecurity, augmented reality, advanced manufacturing solutions, additive manufacturing, simulation, and artificial intelligence. These technologies are characterized by their heterogeneous and intricate compositions (Paschou et al., 2018). The fact that SMEs are financially limited and do not currently have technical resources creates an barrier to easy adoption and implementation of digital technologies (Mittal et al., 2018). Barriers to digital transformation need to be well defined and necessary precautions must be taken. As a result of the literature review, it was concluded that there are many studies on the barriers to digital transformation. These studies were carried out to identify barriers and can be listed as follows: (Ahmed et al., 2022; Chatterjee et al., 2022; Cichosz et al., 2020; Jones et al., 2021; Kutnjak, 2021; Lammers et al., 2019; Raj et al., 2020; Scuotto et al., 2021; Troise et al., 2022). There are three most basic studies conducted specifically in Turkey regarding digital barriers. These studies can be

listed as follows; (Bolat & Temur, 2019; Demirbas et al., 2011; Mutluturk et al., 2021). In the study conducted by (Demirbas et al., 2011), the barriers faced by SMEs operating in Turkey were examined. In this context, 224 SMEs were examined empirically and as a result of the research, it was concluded that the lack of government incentives and research and development policy is the most critical barrier encountered within the scope of change and transformation in Turkey. In another research conducted, the relationships between the possible barriers that industrial development in Turkey will encounter with the data obtained from the literature using the ISM method and a survey conducted with 14 experts in the sector were investigated. As a result of the research, it was concluded that lack of vision is the most fundamental deficiency and affects other factors (Bolat & Temur, 2019). Table 3 includes selected studies conducted in the manufacturing and service sectors on the barriers and success factors of digital transformation.

Table 3. The hierarchical structure of barriers and sub-barriers

Barriers	Sub-barriers	References
Technical/ technological barriers (B1)	Digital tools are both diverse and complex (B11) Limited financial resources of SMEs (B12) Lack of a stable and reliable technical infrastructure (B13) Product incompatibility with tech transformation (B14) Difficulties in selecting and implementing the right technology (B15) Lack of integration (incompatibility between different systems) (B16)	(Kane et al., 2015)
Organizational barriers (B2)	Decision makers' resistance to digital change and risk aversion (B21) Employees' reluctance or indifference to change (B22) Lack of experimentation and iteration process (B23) Coping with uncertainty and constant change (B24) Reluctance to outsource (B25) Failure to support relevant training of employees (B26) Lack of time (B27) Lack of cooperation between departments (B28) Lack of strategy (B29)	(Kane et al., 2015; Vogelsang et al., 2018, 2019)
Human resources barriers (B3)	Lack of employees with digital competence (B31) Fear of job loss (B32) Loss of control (B33)	(Vogelsang et al., 2018, 2019)
Customer-related barriers (B4)	Unclear customer needs (B41) Ineffective customer communication of digital benefits (B42) Customers closed to innovation (B43) Privacy and security breaches (B44)	(Plekhanov et al., 2023)
Environmental barriers (B5)	Lack of standards and laws (B51) Industrial purchasing culture and relationships (B52) Inadequate brand image (B53) Lack of investors (B54)	(Töytäri et al., 2017)

Digital transformation must be underpinned by a robust strategic framework. The efficacy of digital technologies does not reside in the technologies themselves but in how firms integrate them to reformulate business processes and accrue advantages (Kane et al., 2015). Digital transformation entails integrating digital technologies to modify fundamental business operations, products, services, processes, organizational structures, and managerial concepts (Matt et al., 2015). Digitization of service processes amplifies the factors involved in value creation, elevating the complexity of products and escalating the requirements for resources and competencies essential for their creation and support. This shift often necessitates novel competencies, resources, and collaborations, demanding an innovation management approach that synergizes traditional research and development services with information technology systems, contemporary management systems, and robust customer service (Lerch & Gotsch, 2015).

Digitalization represents a profound shift, yet the cultural resistance to change and transformation, or the indifference to its necessity, is cited as a significant cultural barrier; this aspect is often overlooked or underestimated by companies (Von Leipzig et al., 2017). Alterations in service delivery frequently imply substantial and radical cultural transformations within SMEs (Dubruc et al., 2014; Peillon et al., 2018). Transitioning to digital structures in service delivery is a complex endeavor for manufacturing SMEs, with digitalization introducing an additional layer of complexity and deepening the cultural shift required.

In the context of digital transformation, the literature highlights issues related to qualifications and skills. (Lerch & Gotsch, 2015), identify the absence of sufficiently qualified personnel within organizations as a primary

impediment to the digitalization of services during the development and delivery of digital business processes. Digitalization considerably heightens the complexity, abstraction, and problem-solving skills required of all employees. Furthermore, those involved in direct service provision must possess technical competencies encompassing engineering, mechatronics, and information technology. Digital competence, defined as the effective utilization of digital technology, is deemed essential for the evolution of digital service delivery and the overarching process of digitalization (Süße et al., 2018). A deficiency in digital competencies poses a significant challenge for SMEs. (Coreynen et al., 2017) also highlight the need for acquiring new sales competencies or developing customer interface skills as potential barriers in digital servitization.

Klein et al., (2018) have identified several primary obstacles in the realm of digital transformation, which include the uncertainty in ascertaining customer needs, the vagueness in articulating value propositions, and the challenges associated with conveying the benefits of digital transformation to customers.. Another critical barrier can be listed as customers' fear of losing control over information, that is, privacy violations, concern about security and security of access to corporate systems (Klein et al., 2018). Additionally, Raja et al. (2017) point out customer proximity as a managerial uncertainty in pursuing service-oriented growth strategies. While businesses gain from and require customer insights to develop complex service offerings, there is often reluctance from customers to provide the necessary information for these insights.

Research Methodology

Research Framework

The aim of this study is to evaluate the relative importance of barriers to digital transformation using the FAHP methodology. The use of the FAHP approach offers several advantages:

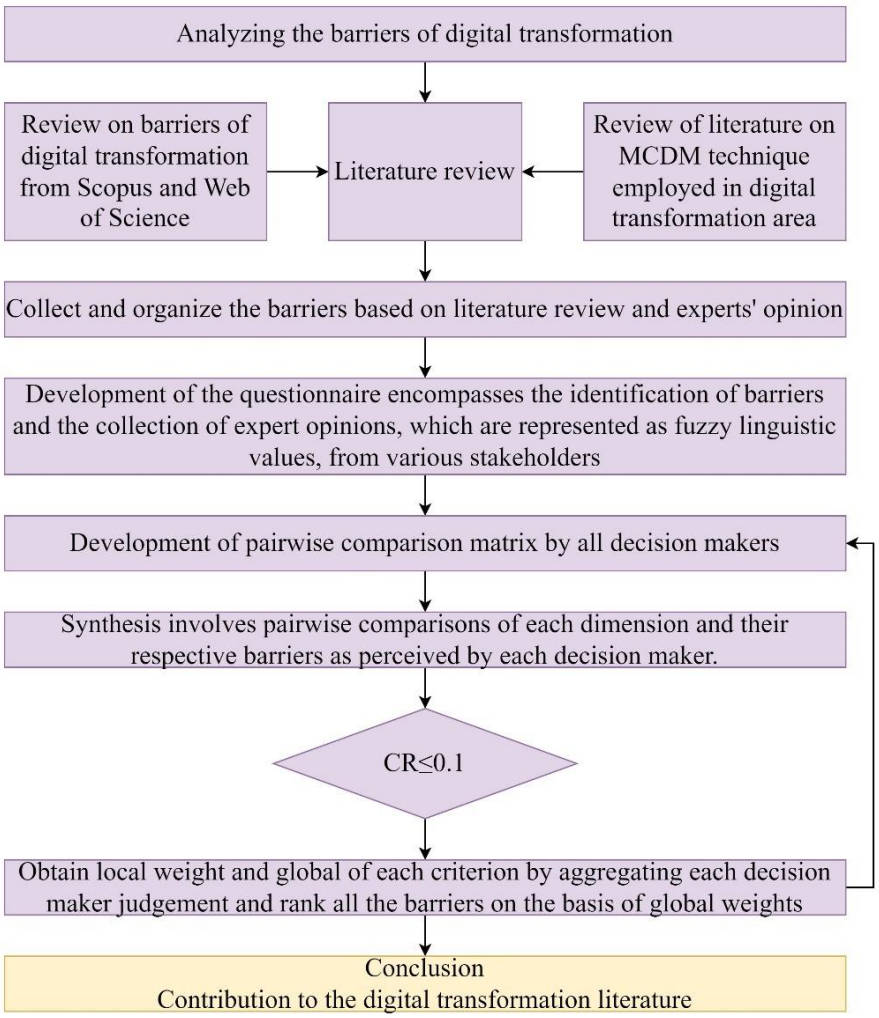

Figure 3. Research framework

- Fuzzy numbers, due to their inherently dispersed structures, are preferred tools in understanding human judgment. These numbers are suitable for modeling ambiguity and uncertainty in decision-making processes.
- The use of fuzzy numbers provides decision-makers with the freedom to estimate their preferences and to evaluate these estimates in a flexible manner. This is particularly useful in complex decision-making processes, as it allows for the consideration of various probabilities and scenarios.
- The fuzzy numbers approach can effectively handle uncertain data; human emotions and preferences are inherently unpredictable and uncertain. In modeling such uncertainties, fuzzy set theory, as an extension of the analytic hierarchy process, can be integrated into pairwise comparisons. This integration ensures a more realistic and accurate representation of decision-making processes.

This study, integrating literature findings with expert opinions, seeks to identify the primary barriers to the adoption of digital transformation. In the next step, we discuss and analyze these barriers with various field specialists. Subsequently, we determine the relative weights and global weights of each dimension using the FAHP. Figure 3 presents the proposed research framework employed for this study.

Fuzzy Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP), originally proposed by (Saaty, 1987), is a widely used method for solving Multiple Criteria Decision Making (MCDM) problems. However, the conventional AHP may not accurately capture human cognitive processes, particularly in situations where problems are not fully defined or where solving them involves uncertain data, often referred to as "fuzzy" problems. Recognizing this limitation, (Van Laarhoven & Pedrycz, 1983) addressed the issue by incorporating the concept of "fuzzy theory" into AHP assessments.

The introduction of "fuzzy AHP" enables the resolution of uncertain and fuzzy problems, providing a framework to rank excluded factors based on their weight ratios. This adaptation enhances the applicability of AHP in scenarios characterized by incomplete problem definitions and uncertainty. The integration of fuzzy theory into AHP contributes to a more realistic representation of decision-making processes, especially when dealing with complex and ambiguous decision environments.

The extent analysis fuzzy AHP method

In this study, (Chang, 1996) extent analysis method was employed due to its widespread usage and its efficiency, requiring fewer operations compared to alternative methods. The rationale behind selecting Chang's extent analysis method lies in its prevalent use and operational simplicity, making it a pragmatic choice for our study. The following are the systematic steps involved in the application of this method

Let $X = \{x_1, x_2, \dots, x_n\}$ be an object set, and $U = \{u_1, u_2, \dots, u_m\}$ be a goal set. According to the extended analysis method, g_i values are generated for each object, considering each target individually. Thus, for each object, m extended analysis values can be obtained as follows.

$$M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m \qquad i = 1, 2, \dots, n \tag{1}$$

where all values of $M_{g_i}^j (\, j = 1, 2, \dots, m)$ are triangular fuzzy numbers. The steps of Chang's extended analysis are given below.

The fuzzy pairwise comparison matrix $\tilde{A} = [\tilde{a}_{ij}]$ is set as follows:

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & (1,1,1) \end{bmatrix} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & (1,1,1) & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \dots & (1,1,1) \end{bmatrix} \tag{2}$$

Step 1. The value of the fuzzy synthetic degree with respect to the ith object is calculated using (Eq. 3).

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} \tag{3}$$

To obtain $\sum_{j=1}^{m} M_{g_i}^{j}$ perform the fuzzy addition operation of m extent analysis values for a specific matrix. This operation is essential for comprehensively assessing the performance of the matrix under a given criterion or parameter.

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{4}$$

To obtain $\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1}$ perform the fuzzy addition of $M_{g_i}^{j}(j = 1, 2, \ldots, m)$ values such that

$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right)$ and then compute the inverse of the vector

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{g_i}^{j}\right]^{-1} = \left(\left(\sum_{j=1}^{m} l_j\right)^{-1}, \left(\sum_{j=1}^{m} m_j\right)^{-1}, \left(\sum_{j=1}^{m} u_j\right)^{-1}\right) \tag{5}$$

Step 2. $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ degree of probability:

$$V(M_2 \geq M_1) = \sup_{y \geq x}\left[min(\mu_{M_1}(x), \mu_{M_2}(y)\right] \tag{6}$$

In the context of the FAHP, after establishing a pairwise matrix predicated on the prioritization among criteria utilizing triangular fuzzy numbers and their inverse counterparts, the methodology advances to the computation of composite scores for each alternative relative to these criteria. These composite scores are articulated as fuzzy values, encapsulating the efficacy of each alternative. This process of aggregation takes into account the fuzzy assessments contributed by various decision maker and the inherent fuzziness in the weights of the criteria. Consequently, the degree of possibility (*V*) is ascertained through the application of (Eq. 6) and (Eq. 7).

$$V(M_2 \geq M_1) = hgt(M_2 \cap M_1) = \begin{cases} 1 & if\ m_2 \geq m_1 \\ 0 & if\ l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \tag{7}$$

d, μ_{M_1} and μ_{M_2} between the highest intersection point is the ordinate of D.

weight vector for k≠i ; k=1,2,…,n

$$W' = \left(d'(A_1), d'(A_1), \ldots, d'(A_n)\right)^T \tag{8}$$

Step 3. The normalized weight vectors are

$$W = \left(d\,(A_1), d\,(A_1), \ldots, d\,(A_n)\right)^T \tag{9}$$

where W is a non-fuzzy number. Table 4 shows the meaning of linguistic expressions in the form of fuzzy numbers (Kannan et al., 2013). Although precise data may not suffice for modeling real-world scenarios in Multi-Criteria Decision Making (MCDM), this study implements linguistic variables to specifically define the grades of a criterion, thereby facilitating decision makers' subjective assessment using fuzzy numbers. A

linguistic variable is a variable that employs natural language to describe the degree of value, and the type of expressions used for comparing each criterion is illustrated in Table 4.

Table 4. Linguistic scales and fuzzy scales for importance

Linguistic scale for importance Criterion i and Criterion j	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Ci and Cj are equally strong	(1, 1, 1)	(1, 1, 1)
Ci is slightly more moderately strong than Cj	(2, 3, 4)	(1/4, 1/3, 1/2)
Ci is strongly more important than Cj	(4, 5, 6)	(1/6, 1/5, 1/4)
Ci is very strongly more important than Cj	(6, 7, 8)	(1/8, 1/7, 1/6)
Ci is extremely more important than Cj	(9, 9, 9)	(1/9, 1/9, 1/9)
Intermediate values	(1, 2, 3)	(1/3, 1/2, 1)
	(3, 4, 5)	(1/5, 1/4, 1/3)
	(5, 6, 7)	(1/7, 1/6, 1/5)
	(7, 8, 9)	(1/9, 1/8, 1/7)

Fuzzy Analytical Hierarchy Process (AHP)

Turkey is renowned for its rich historical and cultural heritage, serving as a pivotal bridge between the East and the West. Economically, the country is characterized by a dynamic structure predominantly reliant on SMEs. In recent years, these enterprises have accelerated their digital transformation by adopting technology more effectively. Advancements in areas such as e-commerce, digital marketing, and online business processes have enhanced their competitiveness in both local and global markets. This progression in digital transformation plays a crucial role in Turkey's economic growth, and is anticipated to continue its upward trajectory in the future.

Application and Results

This section is dedicated to the presentation of the numerical outcomes. In the study, the FAHP methodology was employed for expert assessments, and all computations were conducted using an Excel spreadsheet. Details regarding the experts involved are provided in Table 5.

Table 5. Profile of the Ten Decision-Making Experts

Code	Gender	Age	Education Level	Experience (Years)	Job Title	Job Responsibility
E1	Male	34	PhD in operation research	>7	Research Assistant	Managing the budget university.
E2	Female	30	PhD in business	>7	Research Assistant	Marketing research
E3	Male	34	Computer engineering	>6	Manager of software development	In charge of all software development decisions.
E4	Male	35	Computer engineering	>6	Manager of software development	Responsible for R&D and new software development.
E5	Female	35	Master's in Businesses	>5	Manager of company	Director of company
E6	Male	32	Master's in electronic engineering	>9	Project manager	Managing the engineering team and new projects
E7	Female	42	PhD in management information systems	>15	Academic	Responsible for projects and academic studies
E8	Male	33	PhD in financier	>5	Academician	Accounting and finance specialist
E9	Male	38	Master's in Industrial Engineer	>10	Manager of company	Director of company
E10	Male	37	Assist. prof. dr	>10	Academician	Marketing research

Table 6. Comparison matrix of the barriers

	B_1	B_2	B_3	B_4	B_5
B_1	(1, 1, 1)	(1.162, 1.356, 1.597)	(0.856, 0.992, 1.149)	(0.736, 0.904, 1.149)	(1.516, 1.871, 2.259)
B_2	(0.626, 0.738, 0.860)	(1, 1, 1)	(1.149, 1.301, 1.490)	(1.886, 2.253, 2.595)	(1.282, 1.778, 2.392)
B_3	(0.871, 1.009, 1.168)	(0.671, 0.769, 0.871)	(1, 1, 1)	(1.267, 1.513, 1.762)	(1.672, 2.141, 2.595)
B_4	(0.871, 1.107, 1.358)	(0.385, 0.444, 0.536)	(0.568, 0.661, 0.789)	(1, 1, 1)	(0.669, 0.823, 0.972)
B_5	(0.443, 0.535, 0.660)	(0.418, 0.563, 0.780)	(0.385, 0.467, 0.598)	(1.029, 1.215, 1.431)	(1, 1, 1)

Table 7. Comparison matrix of the sub-barriers within "Technical/technological barriers" (B1)

	B_{11}	B_{12}	B_{13}	B_{14}	B_{15}	B_{16}
B_{11}	(1, 1, 1)	(0.430, 0.521, 0.660)	(0.789, 0.896, 1.054)	(0.707, 0.803, 0.933)	(0.634, 0.763, 0.933)	(0.616, 0.719, 0.871)
B_{12}	(1.516, 1.918, 2.325)	(1, 1, 1)	(1.182, 1.552, 1.943)	(1.414, 1.763, 2.083)	(1.000, 1.205, 1.414)	(1.072, 1.390, 1.741)
B_{13}	(0.949, 1.116, 1.267)	(0.515, 0.644, 0.846)	(1, 1, 1)	(1.149, 1.344, 1.516)	(0.616, 0.695, 0.812)	(0.475, 0.549, 0.652)
B_{14}	(1.072, 1.246, 1.414)	(0.480, 0.567, 0.707)	(0.660, 0.744, 0.871)	(1, 1, 1)	(0.707, 0.803, 0.933)	(0.545, 0.617, 0.707)
B_{15}	(1.072, 1.311, 1.578)	(0.707, 0.830, 1.000)	(1.231, 1.438, 1.625)	(1.072, 1.246, 1.414)	(1, 1, 1)	(0.699, 0.763, 0.846)
B_{16}	(1.149, 1.390, 1.625)	(0.574, 0.719, 0.933)	(1.534, 1.823, 2.107)	(1.414, 1.621, 1.835)	(1.182, 1.311, 1.431)	(1, 1, 1)

Table 8.Comparison matrix of the sub-barriers within "Organizational barriers" (B2)

	B_{21}	B_{22}	B_{23}	B_{24}	B_{25}	B_{26}	B_{27}	B_{28}	B_{29}
B_{21}	(1, 1, 1)	(1.072, 1.255, 1.431)	(1.072, 1.311, 1.578)	(1.625, 2.019, 2.421)	(1.149, 1.334, 1.534)	(0.728, 0.888, 1.072)	(1.943, 2.273, 2.595)	(2.024, 2.690, 3.383)	(0.461, 0.544, 0.660)
B_{22}	(0.699, 0.797, 0.933)	(1, 1, 1)	(0.860, 1.061, 1.282)	(0.634, 0.782, 0.960)	(0.591, 0.757, 1.012)	(0.836, 0.958, 1.116)	(0.771, 0.903, 1.041)	(0.461, 0.535, 0.634)	(0.469, 0.567, 0.671)
B_{23}	(0.634, 0.763, 0.933)	(0.780, 0.943, 1.162)	(1, 1, 1)	(1.358, 1.633, 1.888)	(0.933, 1.052, 1.196)	(0.679, 0.803, 0.972)	(0.480, 0.549, 0.660)	(0.438, 0.521, 0.634)	(0.530, 0.612, 0.736)
B_{24}	(0.413, 0.495, 0.616)	(1.041, 1.278, 1.578)	(0.530, 0.612, 0.736)	(1, 1, 1)	(0.728, 0.803, 0.907)	(1.103, 1.311, 1.534)	(0.728, 0.896, 1.116)	(0.360, 0.444, 0.574)	(0.430, 0.521, 0.660)
B_{25}	(0.652, 0.750, 0.871)	(0.988, 1.321, 1.692)	(0.836, 0.950, 1.072)	(1.103, 1.246, 1.374)	(1, 1, 1)	(0.641, 0.803, 1.029)	(1.029, 1.390, 1.813)	(0.699, 0.903, 1.149)	(0.370, 0.471, 0.616)
B_{26}	(0.933, 1.126, 1.374)	(0.896, 1.043, 1.196)	(1.029, 1.246, 1.473)	(0.652, 0.763, 0.907)	(0.972, 1.246, 1.560)	(1, 1, 1)	(0.871, 0.943, 1.041)	(0.577, 0.725, 0.896)	(0.530, 0.649, 0.812)
B_{27}	(0.385, 0.440, 0.515)	(0.960, 1.108, 1.297)	(1.516, 1.823, 2.083)	(0.896, 1.116, 1.374)	(0.552, 0.719, 0.972)	(0.960, 1.061, 1.149)	(1, 1, 1)	(0.758, 0.896, 1.072)	(0.660, 0.757, 0.907)
B_{28}	(0.296, 0.372, 0.494)	(1.578, 1.871, 2.169)	(1.578, 1.918, 2.285)	(1.741, 2.253, 2.781)	(0.871, 1.108, 1.431)	(1.116, 1.380, 1.732)	(0.993, 1.116, 1.320)	(1, 1, 1)	(0.536, 0.644, 0.812)
B_{29}	(1.516, 1.838, 2.169)	(1.490, 1.764, 2.132)	(1.358, 1.633, 1.888)	(1.516, 1.918, 2.325)	(1.625, 2.125, 2.702)	(1.231, 1.540, 1.888)	(1.103, 1.321, 1.516)	(1.231, 1.552, 1.866)	(1, 1, 1)

Table 9. Comparison matrix of the sub-barriers within "Human resources barriers" (B3)

	B_{31}	B_{32}	B_{33}
B_{31}	(1, 1, 1)	(1.267, 1.732, 2.945)	(1.516, 2.158, 2.144)
B_{32}	(0.340, 0.577, 0.789)	(1, 1, 1)	(0.922, 1.125, 1.320)
B_{33}	(0.467, 0.463, 0.660)	(0.758, 0.889, 1.084)	(1, 1, 1)

Table 10. Comparison matrix of the sub-barriers within "Customer-related barriers" (B4)

	B_{41}	B_{42}	B_{43}	B_{44}
B_{41}	(1, 1, 1)	(1.966, 2.290, 2.595)	(0.341, 0.408, 0.509)	(0.552, 0.649, 0.780)
B_{42}	(0.385, 0.437, 0.509)	(1, 1, 1)	(0.687, 0.859, 1.103)	(1.000, 1.175, 1.374)
B_{43}	(1.966, 2.451, 2.930)	(0.907, 1.165, 1.455)	(1, 1, 1)	(1.149, 1.256, 1.374)
B_{44}	(1.282, 1.540, 1.813)	(0.728, 0.851, 1.000)	(0.728, 0.796, 0.871)	(1, 1, 1)

Table 11. Comparison matrix of the sub-barriers within "Environmental barriers" (B5)

	B_{51}	B_{52}	B_{53}	B_{54}
B_{51}	(1, 1, 1)	(1.116, 1.356, 1.625)	(1.041, 1.145, 1.282)	(0.907, 1.061, 1.282)
B_{52}	(0.616, 0.738, 0.896)	(1, 1, 1)	(1.217, 1.427, 1.625)	(0.803, 0.950, 1.090)
B_{53}	(0.780, 0.873, 0.960)	(0.616, 0.701, 0.822)	(1, 1, 1)	(0.509, 0.577, 0.679)
B_{54}	(0.780, 0.942, 1.103)	(0.917, 1.052, 1.246)	(1.473, 1.732, 1.966)	(1, 1, 1)

The FAHP was subsequently utilized to ascertain the weights of both factors and sub-factors. Illustratively, utilizing the pairwise comparison matrix of the factors presented in Table 6, the weights of the factors were meticulously computed. In the process of conducting comparative analyses, each sub-barriers was meticulously evaluated in relation to the higher-level barriers. This evaluation was performed by decision-makers operating at the corresponding level, resulting in the formulation of comparison matrices. Subsequently, these matrices were consolidated to form representative matrices, which are comprehensively presented in Tables 7-11. Using Eqs. (3) – (5), we determined TFN values of the six output indicators as follows:

$$S_{B_1} = (5.270, 6.122, 7.153) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.165, 0.223, 0.305)$$
$$S_{B_2} = (5.923, 7.069, 8.338) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.185, 0.258, 0.355)$$
$$S_{B_3} = (5.481, 6.432, 7.395) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.171, 0.234, 0.315)$$
$$S_{B_4} = (3.522, 4.034, 4.655) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.110, 0.147, 0.198)$$
$$S_{B_5} = (3.275, 3.779, 4.469) \otimes \left(\frac{1}{23.472}, \frac{1}{27.436}, \frac{1}{32.010}\right) = (0.102, 0.138, 0.190)$$

$$V(S_{B_1} \geq S_{B_2}) = V[(0.165, 0.223, 0.305) \geq (0.185, 0.258, 0.355)]$$

The values of SB_i were individually compared and the degree of possibility of $SB_j = (lj, mj, uj) \geq SB_i = (li, mi, ui)$ were subsequently determined using the equation (Eq. 7). Table 12 shows the values of $V(SB_i \geq SB_j)$.

Table 12. Degree of Posibility of $V(SB_i \geq SB_j)$ for the barrriers.

$V(S_{B_1} \geq S_{B_j})$	Value	$V(S_{B_2} \geq S_{B_j})$	Value	$V(S_{B_3} \geq S_{B_j})$	Value	$V(S_{B_4} \geq S_{B_j})$	Value	$V(S_{B_5} \geq S_{B_j})$	Value
$V(S_{B_1} \geq S_{B_2})$	0.776	$V(S_{B_2} \geq S_{B_1})$	1	$V(S_{B_3} \geq S_{B_1})$	1	$V(S_{B_4} \geq S_{B_1})$	0.307	$V(S_{B_5} \geq S_{B_1})$	0.232
$V(S_{B_1} \geq S_{B_3})$	0.922	$V(S_{B_2} \geq S_{B_3})$	1	$V(S_{B_3} \geq S_{B_2})$	0.848	$V(S_{B_4} \geq S_{B_2})$	0.107	$V(S_{B_5} \geq S_{B_2})$	0.043
$V(S_{B_1} \geq S_{B_4})$	1	$V(S_{B_2} \geq S_{B_4})$	1	$V(S_{B_3} \geq S_{B_4})$	1	$V(S_{B_4} \geq S_{B_3})$	0.237	$V(S_{B_5} \geq S_{B_3})$	0.165
$V(S_{B_1} \geq S_{B_5})$	1	$V(S_{B_2} \geq S_{B_5})$	1	$V(S_{B_3} \geq S_{B_5})$	1	$V(S_{B_4} \geq S_{B_5})$	1	$V(S_{B_5} \geq S_{B_4})$	0.896

Afterwards, we determined the minimum degree of possibility $d'(i)$ of $V(SB_i \geq SB_j)$ for $i, j = 1, 2, \ldots, 6$ by using Eq. (6).

$d'(1) = \min V(S_{B_1} \geq S_{B_2}, S_{B_3}, S_{B_4}, S_{B_5}) = 0.776$
$d'(2) = \min V(S_{B_2} \geq S_{B_1}, S_{B_3}, S_{B_4}, S_{B_5}) = 1$
$d'(3) = \min V(S_{B_3} \geq S_{B_1}, S_{B_2}, S_{B_4}, S_{B_5}) = 0.848$
$d'(4) = \min V(S_{B_4} \geq S_{B_1}, S_{B_2}, S_{B_3}, S_{B_5}) = 0.107$
$d'(5) = \min V(S_{B_5} \geq S_{B_1}, S_{B_2}, S_{B_3}, S_{B_4}) = 0.043$

The weight vector was obtained by the use of Eq. (8)

$W' = (0.776, 1, 0.848, 0.107, 0.043)^T$

Normalized the weight vectors using Eq. (9) and obtained the relative weights of the five barriers,

$W = \left(W_{S_{B_1}}, W_{S_{B_2}}, W_{S_3}, W_{S_{B_4}}, W_{S_{B_5}}\right)^T$
$W = (0.280, 0.360, 0.306, 0.039, 0.015)^T$, where W is a non-fuzzy number.

Through a comparable calculation, the weight vectors $W_{B1\mathrm{j}}$, $W_{B2\mathrm{j}}$, $W_{B3\mathrm{j}}$, $W_{B4\mathrm{j}}$, $W_{B5\mathrm{j}}$ for sub-factors at the successive level were established. They are delineated below:

$(W_{B11}, W_{B12}, W_{B13}, W_{B14}, W_{B15}, W_{B16})^T = (0.005, 0.387, 0.072, 0.025, 0.199, 0.313)^T$
$(W_{B21}, W_{B22}, W_{B23}, W_{B24}, W_{B25}, W_{B26}, W_{B27}, W_{B28}, W_{B29})^T$

$= (0.248, 0.003, 0.027, 0.006, 0.084, 0.072, 0.077, 0.196, 0.288)^T$

$(W_{B31}, W_{B32}, W_{B33})^T = (0.789, 0.167, 0.044)^T$
$(W_{B41}, W_{B42}, W_{B43}, W_{B44})^T = (0.234, 0.026, 0.547, 0.193)^T$
$(W_{B51}, W_{B52}, W_{B53}, W_{B54})^T = (0.507, 0.384, 0.051, 0.547)^T$

Table 13. Final prioritization of barriers in context of digital transformation

Barriers	Weight (*Bi*)	Ranking	Sub-barriers	Weight (*Bij*)	Finalized Weight	Local Rank	Local Weight %	Global Rank	Global Weight %
			B_{11}	0.005	0.001	6	0,1%	23	
			B_{12}	0.387	0.108	1	10,8%	2	
B_1	0.280	3	B_{13}	0.072	0.020	4	2,0%	13	28,0%
			B_{14}	0.025	0.007	5	0,7%	20	
			B_{15}	0.199	0.056	3	5,6%	7	
			B_{16}	0.313	0.087	2	8,7%	5	
			B_{21}	0.248	0.089	2	8,9%	4	
			B_{22}	0.003	0.001	9	0,1%	25	
			B_{23}	0.027	0.010	7	1,0%	15	
			B_{24}	0.006	0.002	8	0,2%	22	
B_2	0.360	1	B_{25}	0.084	0.030	4	3,0%	9	36,0%
			B_{26}	0.072	0.026	6	2,6%	11	
			B_{27}	0.077	0.028	5	2,8%	10	
			B_{28}	0.196	0.071	3	7,1%	6	
			B_{29}	0.288	0.104	1	10,4%	3	
			B_{31}	0.789	0.241	1	24,1%	1	
B_3	0.306	2	B_{32}	0.167	0.051	2	5,1%	8	30,6%
			B_{33}	0.044	0.013	3	1,3%	14	
			B_{41}	0.234	0.009	2	0,9%	16	
B_4	0.039	4	B_{42}	0.026	0.001	4	0,1%	24	3,9%
			B_{43}	0.547	0.021	1	2,1%	12	
			B_{44}	0.193	0.007	3	0,7%	19	
			B_{51}	0.507	0.008	2	0,8%	18	
B_5	0.015	5	B_{52}	0.384	0.006	3	0,6%	21	2,3%
			B_{53}	0.051	0.001	4	0,1%	26	
			B_{54}	0.547	0.008	1	0,8%	17	

As part of the research, decision-makers conducted a comparative analysis of five primary barriers using a pairwise comparison questionnaire. Table 13 presents the weight coefficients assigned to the main barriers. When analyzing the coefficients associated with primary barriers, decision-makers identified "Technical/technological barriers" as the most significant barriers, yielding a value of 0.360. Subsequently, "Human resources barriers" ranked second at 0.306, followed by "Technical/technological barriers" again at 0.280. Other barriers, such as "Customer-related barriers" held a value of 0.039, while "Environmental barriers" were deemed less influential with a value of 0.015. In Table 13, among technical/technological barriers, the most crucial sub-barrier is identified as "Limited financial resources of SMEs." Within organizational barriers, "Lack of strategy" holds the highest significance. Among human resources barriers, "Lack of employees with digital competence" is identified as the most pivotal barrier. In terms of barriers related to customer-related barriers, "Customers closed to innovation" is deemed the most prominent, while within environmental barriers, "Lack of investors" is recognized as the foremost challenge.

Discussion

In order to effectively realize digital transformation, there may be critical factors in overcoming the barriers that SMEs may encounter. Integrating new technologies with existing systems can be difficult. In this case, it is necessary to use technology wisely, improve processes and increase efficiency by creating a flexible and compatible infrastructure. Digital transformation is often costly; Therefore, it is important for businesses to plan their budget carefully and consider costs. Getting support from external sources in this process can facilitate access to technical information and resources.

Barriers in the digital transformation process are not limited to technological advances, but also require changes in business culture and employee attitudes. For this reason, the importance of digital transformation should be emphasized to employees, training opportunities should be provided, flexible working environments should be created and innovative ideas should be encouraged. To create an environment that supports digital transformation in business culture, full support from the leadership level is required. Therefore, SME managers should understand the importance of this process, provide the necessary resources and create a strategic vision. Additionally, communicating effectively with employees, customers, and other stakeholders, soliciting feedback, and involving them at every stage of the process can increase acceptance and support the success of the process. SMEs' progress in their transformation processes step by step and starting with small steps instead of major changes can provide a more manageable digital transformation process.

Governments can take various measures to alleviate the difficulties of SMEs in digital transformation: Applications can be developed to increase the integration of engineering fields and informatics, software and technology disciplines in universities. They can provide tax advantages to encourage businesses to employ IT experts. Policies and supportive practices can be implemented to increase the number of not only male but also female IT specialists. Technology roadmaps can be presented for focus technology areas (cloud computing, big data, artificial intelligence, autonomous robots, etc.). Finally, to accelerate the digital transformation of SMEs, centers of excellence or similar structures can be created and research centers can be strengthened and supported in line with technology roadmaps. These suggestions can contribute to reducing the barriers that may arise during the digital transformation process.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Measurement of Tensile Strength on Engineering Polymers Used in Plastic Rail Terminal Parts

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Abstract: Engineering polymers are of great importance in plastic rail terminals used in electrical panels in many sectors. Polyamide is fatigue resistant with a low coefficient of friction and has high tensile strength, is the most important of these polymers. In this study, the mechanical properties of engineering polymers used in the production of these terminals under different ambient conditions will be investigated. Tensile test specimens were obtained by plastic injection molding to determine the optimum injection parameters for these properties. A plastic injection machine (Arburg) and metal mold were been conducted to plastic experiments. Taguchi L_8Experimental design was used to examine the parameters of cooling time, injection speed, mold temperature and runner type. From this study, it can be seen that runner gate way is most effective parameters among four parameters. As a result, the effect of runner gate ways used in plastic injection molds on tensile strength was investigated.

Keywords*:* Engineering polymers, Injection molding, Tensile test, Plastic rail terminals, Taguchi design

Introduction

Polymers are materials composed of large molecules. They can be found in pure form in nature or can be chemically produced in a laboratory environment. Today, they are used in many fields such as packaging, automotive, construction, electricity, electronics, medicine, textile and agriculture sectors. The expected mechanical properties vary according to these areas of use. Polymers are produced in standards suitable for the sector with different test methods (Ezdesir et al., 2006)

In all sectors, electrical connectors are used to provide electronic transmission. There are certain properties that these electrical connectors must have. Polyamides are one of the polymers used to provide them. Polyamides are synthetic polymers. In terms of mechanical properties, polyamide 66 (PA66) is used in plastic rail terminals. It maintains its electrical properties in a wide temperature range, which is an important condition in plastic rail terminals (Akyuz, 2006). Polyamides have high tensile strength and creep resistance. They are resistant to abrasion resistance, fatigue and repeated impact toughness. Polyamides are available in many varieties and can be produced with crushing additives, making them an important choice for recyclability (Yan et al., 2016). However, the ideal ratio of crushing ratio should be determined, otherwise mechanical properties may deteriorate. The melting point of polyamide polymer changes depending on the change in the number of carbon atoms. With the increase in the number of carbon atoms, the melting point decreases (Beaumont et al., 2002).

Mechanical and chemical properties of this polymer should be known for injection molding and production. The viscosity of polyamide is one of the most important properties for the injection molding process (Campo, 2008). The machines and molds used in the injection process must meet the conditions for the production of the relevant polymer. For this reason, many injection parameters come into play. Researchers have examined that cooling time, mold temperature and injection speed are critical injection parameters. They tested the changes in the strength of the parts produced in the light of these parameters (Farotti et al., 2017). Another group studied the variation of tensile strength with the help of fiber reinforcement (Yallew et al., 2020). Different composites were created using various filler materials and their tensile strengths were compared (Liu et al., 2004; Lingesh et al., 2017). In another study, although the optimum values of these parameters are determined from catalogs, they are mostly found by testing during the production process. Depending on the characteristics of the part mold used, the injection parameters selected may have a positive or negative effect on the quality of the resulting part. In order to determine these parameters, simulation programs can be used to have an idea about the parameters related to part and mold design (Mehatet et al., 2011).

In this study, the mechanical properties of PA66 polymer used in plastic rail terminals were investigated according to different injection parameters. These injection conditions are injection speed, mold temperature, cooling time and runner type. With the help of minitab program, tensile and impact test specimens were obtained according to Taguchi L8 experimental design (Minitab Statistical Software, 2007). By using Taguchi method, time and production cost were saved. Tensile tests were performed on the obtained specimens in accordance with ASTM D-638 Standards (2010). According to the test results, the optimum injection parameters were compared. According to the data obtained from this study, it can be said that the most effective parameter is the runner type.

Method and Materials

Fabrication of the Mold Parts

In this study, plastic mold design was carried out by determining the test specimens according to the standards in the injection mold of PA66 natural polymer material. Mold parts were produced on a CNC machine to inject the plastic specimen (Figure 1). Another feature of the plastic mold is that the runner inlets are interchangeable. With these mold features, it was designed to take specimens for tensile, bending and impact tests in the mold.

Figure 1. Design of plastic mold

Tensile test specimens were injected from the produced mold. There are differences between these specimens depending on the production parameters. In the light of these differences, many test specimens were produced. Many injection parameters and runner inlet types were used to ensure the diversity of the test specimens. By closing and opening the runners, different specimens were obtained with the same injection parameters.

Materials and Parameters

The properties of the raw material from which the specimens used in the tests were taken are given in Table 1. The trade name of the raw material used in this study is Zytel EFE1068 NC010T.

Table 1. Process conditions

Property	Units	Values
Melt temperature	℃	280 - 300
Mold temperature	℃	50 - 90
Density	g/cm^3	1.14
Drying temperature	℃	80

For the tests to be performed, the injection molding parameters of the specimens to be taken with polyamide 66 raw materials were determined. Many values were used to determine the most effective of these parameters. Apart from these injection parameters, runner types were created as single runner inlet and double runner inlet according to the runner types. Thus, the effect of the filling type of the raw material while forming the test was also examined. The tests were produced as horizontal plastic injection molding on an Arburg injection machine (Figure 2). It is a preferred plastic injection molding machine brand in the sector for many years.

Figure 2. Injection molding machine

The injection parameters used to inject the test specimen in this study are selected from the manufacturer's catalog and given in Table 2.

Table 2. Injection molding process parameters

Parameters	Units	Values
Melt temperature	℃	270 - 280 - 290
Cooling time	s	8 - 10 - 12
Injection time	s	1 - 2 - 3

Tensile Tests

In this study, the mechanical properties of PA66 material were tried to be determined by applying tensile strength test. The aim here is to prepare for the experiments to be carried out later. 8 specimens were subjected to tensile tests using different injection parameters. The tensile speed of the specimens in these tests was span rate 50 mm/min. Tensile tests were performed with a Time brand WDW series machine as shown in Figure 3.

Figure 3. Tensile compression testing machine

Results and Discussion

In this chapter, the results of tensile strength and elongation values obtained from 8 tests performed on plastic specimeninjected from injection molded PA66 material are analyzed and evaluated. The effect of the applied process parameters on the results is also discussed. Displacement was evaluated using an extensometer(Farotti et al., 2017). Table 3 shows the tensile strength and elongation values obtained from the tests. Tensile strength in test 1 are the highest. On the other hand, the tensile strength in specimen 6 are low. On the other hand, the lowest elongation are obtained in specimen 7, while the highest elongation value are obtained in specimen 8.This shows that by optimizing the injection process parameters, the mechanical properties are improved (Yallew et al., 2020).

Table 3. Results of tensile strengthandstrain

Number of tests	Tensile strength MPa	Elongation at yield %
1	77	24
2	76	10
3	75	20
4	74	14
5	73	8
6	73	16
7	72	7
8	76	26

In specimen 8, the reason for the highest elongation is the change in the runner gate type. The mechanical strength increased with the change in the flow direction with the runner gate type.

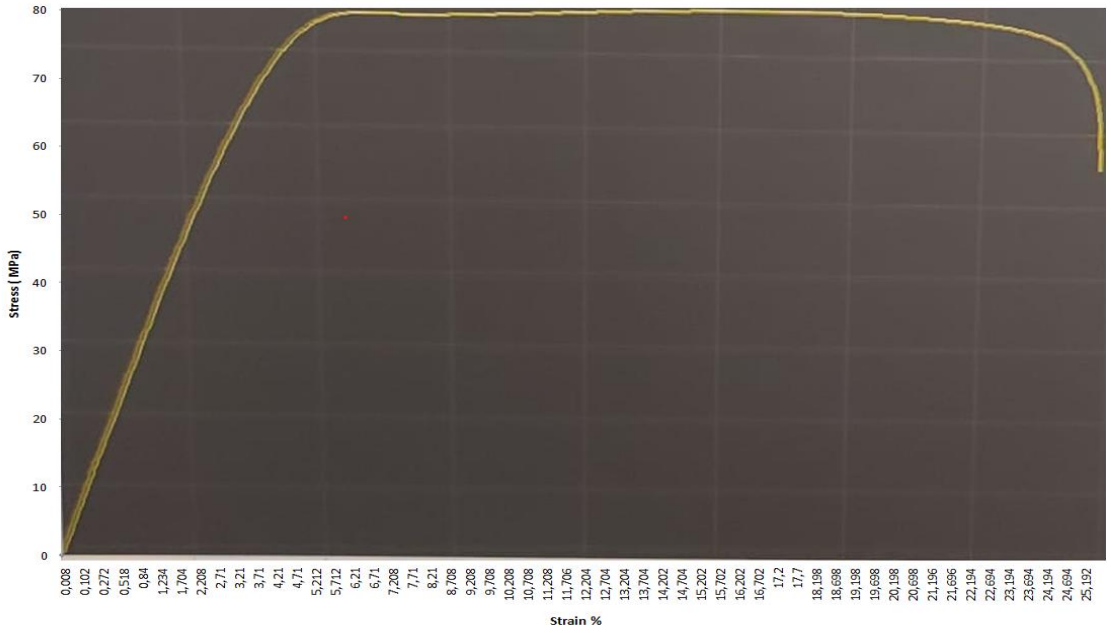

Figure 4. Tensile strengthwithstrain

Conclusions

In this study, the mechanical properties of PA66 polymer used in rail terminals were investigated. The results obtained as a result of tests performed on injected plastic specimens.

- The effect of the injection parameters selected during production is analyzed. Among these parameters, the runner gate type is found to be the most effective.
- In the tests performed without additives, strength change with injection parameters is observed. It is thought to increase the strength by using a certain amount of additives (Ogi et al., 2007).
- The use of the material as a recycling material would be expected to result in a reduction in mechanical properties. (Sen et al., 2020).
- This study has enabled to find the optimum values of the selected injection parameters during the production of PA66 polymer material.
- The PA66 polymer material has a higher strength when compared to high performance polymers. (Yılmaz, 2018)
- A range of three injection parameters has been used for the improvement of mechanical properties.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Assessment of Global Sustainable Competitiveness Index, Renewable Energy, and Climate Change Technologies in Realizing Environmental Sustainability: Evidence from Panel Quantile Regression

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Abstract: Environmental sustainability is important for addressing global challenges, as it encourages responsible practices that balance economic, social, and environmental factors. The Global Sustainable Competitiveness Index (GSCI) is a comprehensive measure used to assess the sustainability performance of countries or regions across various dimensions. It typically considers economic, environmental, and social factors to provide a holistic view of sustainability efforts. This study explores the relationship between the GSCI, renewable energy, climate change technologies, and carbon emissions (CO2). Therefore, this study aims to assess the role of sustainability in economic competitiveness and its impact on environmental outcomes. The study utilizes panel quantile regression to analyze the impacts of the GSCI, renewable energy, climate change technologies, and causal determinants on CO2 emissions in OECD countries from 2013 to 2022. We use a comprehensive dataset spanning multiple regions and years to analyze the association between GSCI scores and CO2 emissions levels. This study also employs the long-run estimate using the autoregressive distributed lag (ARDL) approach and panel causality tests. The results based on the panel quantile regression indicate a significant and causal relationship between renewable energy, climate change technologies, CO2 emissions, and causal factors. The GSI scores have a moderating and significant role in reductions in CO2 emissions. Finally, our findings shed light on the extent to which global sustainability initiatives correlate with reductions in carbon emissions and balance economic competitiveness with environmental concerns, providing valuable insights for policymakers, businesses, and researchers striving to address climate change and promote sustainable development on a global scale.

Keywords: Environmental sustainability, Climate change technologies, Renewable energy

Introduction

In the face of escalating environmental challenges such as climate change, resource depletion, and pollution, the imperative for sustainable development has become increasingly crucial. This importance stems from the recognition that unchecked environmental degradation poses profound risks to ecosystems, economies, and societies worldwide. One of the prominent challenges confronting the world today is the rise in carbon emissions stemming from the use of non-renewable energy sources, particularly fossil fuels. The extensive dependence on fossil fuels has led to a significant increase in global energy consumption and a simultaneous surge in carbon dioxide (CO2) emissions, as highlighted by Gershon et al. (2024) and Phadkantha and Tansuchat (2023) and Shah et al. (2023). This escalation presents a pressing threat of global warming, propelled by factors such as industrialization, urbanization, population growth, and shifts in lifestyle habits. Moreover, its impacts extend beyond environmental realms, exerting significant socioeconomic pressures and exacerbating existing inequalities.

The Global Sustainable Competitiveness Index (GSCI) emerges as a comprehensive framework for assessing nations' abilities to generate inclusive wealth while minimizing environmental harm, the GSCI provides a

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

nuanced understanding of the dynamics of sustainable competitiveness. By examining a range of indicators spanning natural capital, resource efficiency, social capital, innovation, governance, and economic sustainability, the index offers insights into the multifaceted dimensions of sustainability and competitiveness. The GSCI stands out as the most comprehensive and precise tool for assessing the competitiveness of nation-states and their prospects. It serves as a valuable gauge for creditors assessing country-specific risks, as well as for other stakeholders seeking to evaluate both risks and opportunities within particular sectors.

However, as the global community strives to address environmental challenges and transition towards a more sustainable future, it is essential to consider the role of renewable energy and climate change technologies in this endeavor. Renewable energy sources, such as solar, wind, hydroelectric, and biomass, offer cleaner and more sustainable alternatives to fossil fuels, with the potential to reduce greenhouse gas emissions, enhance energy security, and foster economic development. Similarly, advancements in climate change technologies, including carbon capture and storage, sustainable transportation solutions, and resilient infrastructure, hold promise in mitigating the impacts of climate change and building adaptive capacity.

In the existing literature of study, several investigations have demonstrated the significant role of renewable energy and green technology in mitigating carbon dioxide (CO2) emissions (Amarante et al., 2021; Bilal et al., 2022; Lin & Ma, 2022; Luo et al., 2021; Nguyen & Le, 2022; Wolde-Rufael & Weldemeskel, 2020). These studies consistently highlight that the use of renewable energy sources tends to decrease CO2 emissions, and also the advancement of green innovation lead to reduction of CO2 emissions. Furthermore, there are several studies has focused on the effects of climate change adaptation and mitigation on CO2 emission levels ((Kahn et al., 2021a, 2021b; Ladenburg et al., 2024; Nyiwul, 2021; Stock, 2020). On the other hand, a few studies indicate that promoting the development of green and low-carbon energy and green technologies holds promise for minimizing environmental harm and achieving carbon neutrality (Hao et al., 2021; Nguyen & Le, 2022; Zhao et al., 2020; Zhu et al., 2023). Additionally, a subset of studies suggests the role of renewable energy consumption, educational level, and economic growth on sustainable goals and decreasing the level of carbon emissions (Erdem et al., 2023; Espoir et al., 2022; Fukase, 2010; Khan, 2020; Magazzino et al., 2023; Naseem & Guang Ji, 2020; Tenaw, 2022; Zhang et al., 2023).

This study aims to investigate the potential impact of climate change technologies, the GSCI, renewable energy, education level, economic growth, and general technology diffusion on CO2 emissions in OECD countries spanning the period from 2013 to 2023 by employing the panel quantile regression approach. To the best of our knowledge, no prior study has comprehensively examined the role of the global sustainable competitiveness index with multiple factors in environmental sustainability within the context of OECD economies. The significance of employing this analytical framework lies in recognizing that environmental sustainability in OECD countries represents a pivotal area of study, given its intricate interplay between economic dynamics and environmental considerations.

The empirical findings of our study underscore the role of climate change technologies, the GSCI, general technology diffusion, and the use of renewable energy in the levels of CO2 emissions in the selected OECD countries. These results highlight the significance of pursuing environmental sustainability, with a particular emphasis on promoting renewable energy utilization and climate change technologies. Overall, our study contributes to advancing knowledge in the field of environmental sustainability by offering insights into the key drivers and mechanisms underlying CO2 emissions reduction efforts. This study proceeds with the data description and methodology is presented. Later, this study reports the empirical results and discussion. Lastly, this study ends with the conclusions and recommendations.

Data Description and Empirical Model

Data

This section provides the data and empirical model for 38 OECD over the period from 2013 to 2023. These countries and periods are chosen based on the data availability. Table 1 presents a compilation of data descriptions. The aim is to examine how the development of climate change technologies, renewable energy, and global sustainable competitiveness index affects carbon dioxide (CO2) emissions, taking into account multiple causal factors such as income level, education index, and general technology diffusion. In the realm of environmental economics, the EKC framework stands out as a pivotal empirical model for investigating renewable energy and environmentally friendly technology, as evidenced by studies conducted by (Chu et al.,

2023; Dong et al., 2018; Khoshnevis Yazdi & Shakouri, 2017; Li et al., 2022; Saidi & Omri, 2020; Voumik et al., 2022; Wang et al., 2022; Wolde-Rufael & Weldemeskel, 2020; Hassan et al., 2024).

This study also employs the EKC framework to assess how carbon emissions are affected by climate change, human capital, foreign direct investments, and research and development (R&D) expenditure, as in studies by (Habiba et al., 2022; Jiang et al., 2022; Li et al., 2023; Li & Shao, 2023; Obada et al., 2024; Wang et al., 2023, 2024; Zhang et al., 2022; Zhu et al., 2023).

Table 1. Data descriptions

Variable	Definition	Source
Carbon dioxide emissions (CO2)	CO2 emissions (metric tons per capita)	World Development Indicators (WDI)
Global Sustainable Competitiveness Index (GSCI)	Calculated by 6-dimensional model	World Bank, various UN agencies, the IMF.
Climate Change Technologies (CCT)	The sum of climate change adaptation and mitigation Technologies based on patent applications	Organization for Economic Co operation and Development (OECD) statistics
Economic Growth (GDP)	GDP per capita (current US$)	WDI
Education Index (EDU)	Average of expected years of schooling (of children) and means years of schooling (of adults)	Human Development Report of the UN.
Renewable Energy (GE)	Renewable energy share of renewable energy in total final energy consumption (%)	WDI
General Technology Diffusion (GTD)	The sum of environment-related technologies, climate change adaptation, and sustainable ocean economy, % all technologies (%)	OECD statistics

The GSCI evaluates both the competitiveness and sustainability of nations. Sustainable competitiveness refers to the capacity to create and uphold inclusive prosperity while safeguarding the ability to maintain or enhance current levels of prosperity in the future. Figure 1 shows the sustainable competitiveness model which encompasses natural capital, resource efficiency, social capital, intellectual & innovation capital, economic sustainability, and governance performance. This index relies entirely on quantitative metrics and considers 188 indicators sourced from reputable global data outlets such as the World Bank, various UN agencies, and the IMF.

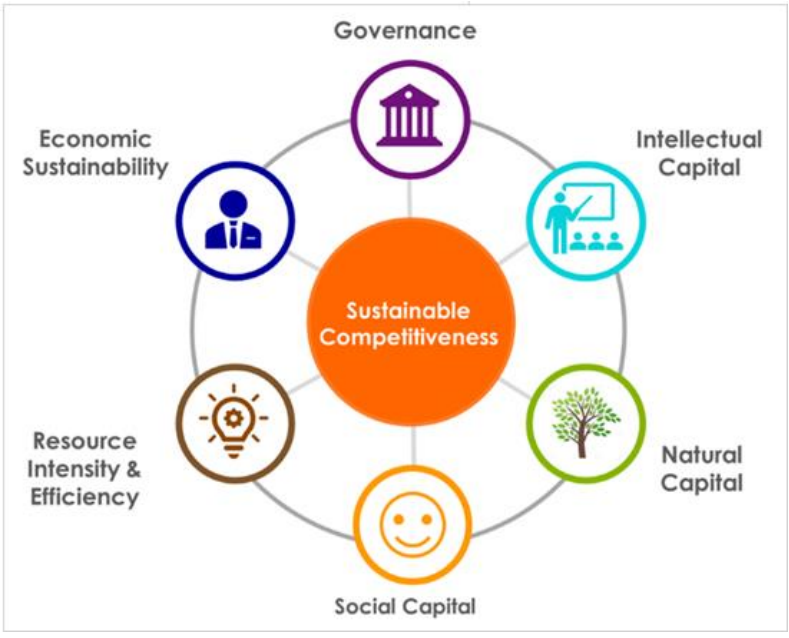

Figure 1. The sustainable competitiveness model

Figure 2 illustrates a plot of the average global sustainable competitiveness index across 38 OECD countries from 2013 to 2023. The global sustainable competitiveness index reaches a high level in Sweden, Finland, and Iceland in 2023.

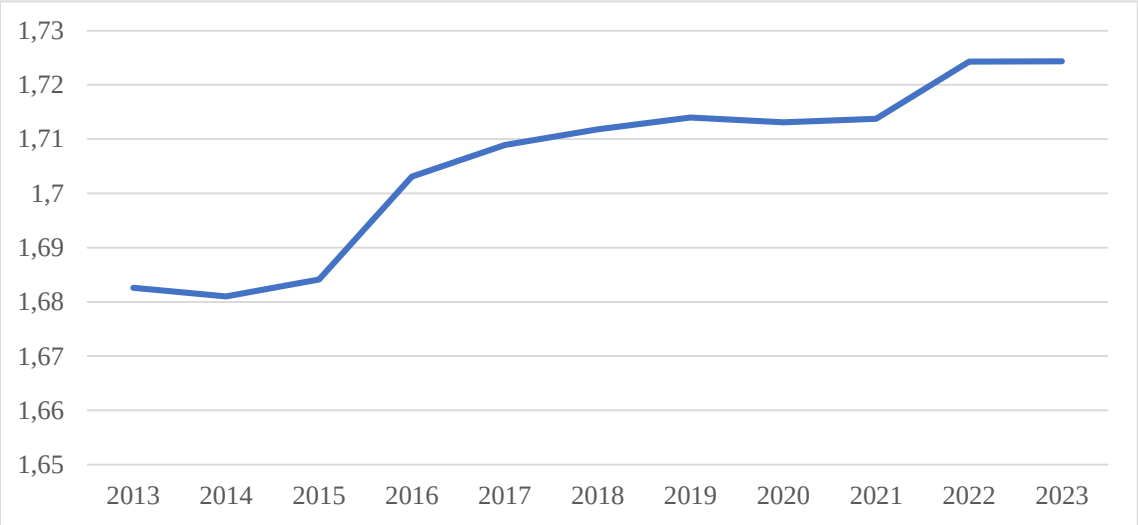

Figure 2. The global sustainable competitiveness ındex, 2013-2023**.**
Source: Author's own calculations.

Empirical Model

Previous literature has predominantly focused on investigating the influence of CO2 emissions on environmental sustainability. Several empirical studies (Chen et al., 2019; Mamkhezri & Khezri, 2023; Mitić et al., 2023; Mongo et al., 2021; Rahman et al., 2022; Sezgin et al., 2021; Shahzad et al., 2020; Tsimisaraka et al., 2023; Yao et al., 2020) aim to investigate the correlation between CO2 emissions and their potential repercussions on sustainable development objectives, encompassing environmental, social, and economic welfare over an extended period. To analyze the determinants affecting carbon emissions, this study employs a dynamic model. Herein, we introduce an empirical model aimed at scrutinizing the impacts of climate change technologies, renewable energy, and global sustainable competitiveness index, economic growth, education level, and general technology diffusion on CO2 emissions in 38 OECD countries.

The model is articulated as follows:

$$LCO_{it} = \beta_{it} + \alpha_{2i}LGSCI_{it} + \alpha_{3i}LGDP_{it} + \alpha_{4i}LCCT_{it} + \alpha_{5i}LEDU_{it} + \alpha_{6i}LRE_{it} + \alpha_{7i}LGD_{it} + \varepsilon_{it}$$

where LCO represents carbon emissions per capita, LGSCI denotes global sustainable competitiveness index, LGDP shows denotes per capita income level, LCCT is the climate change technologies, LEDU denotes education index, LRE represents renewable energy, and also LGD represents general technology diffusion. All variables are taken their natural logarithm level. The error term is denoted as ε_{it}, with *i* and *t* representing countries and time, respectively. This study constructs an empirical model by combining the form of the quantile approach as follows:

$$Q_{\tau}(LCO_{it}) = \beta_{\tau} + \alpha_{2\tau}LGSCI_{it} + \alpha_{3\tau}LGDP_{it} + \alpha_{4\tau}LCCT_{it} + \alpha_{5\tau}LEDU_{it} + \alpha_{6\tau}LRE_{it} + \alpha_{7\tau}LGD_{it} + \varepsilon_{it}$$

where the panel quantile regression is represented as *Q*, with the specific quantile point denoted by τ.

Table 2. Descriptive statistics and correlation matrix

Panel A: Descriptive Statistics							
	LCO2	**LGSCI**	**LGDP**	**LCCT**	**LEDU**	**LRE**	**LGD**
Observations (*n*)	418	418	418	418	418	418	418
Mean	0.805	1.705	4.553	0.777	2.032	1.248	3.678
Maximum	1.335	1.784	5.082	4.721	2.214	1.917	5.701
Minimum	0.226	1.594	3.811	0.011	1.802	0.459	2.167
Std. Dev.	0.237	0.037	0.221	0.854	0.063	0.303	0.891
Skewness	-0.259	-0.257	-0.751	1.931	0.615	-0.132	0.301
Kurtosis	3.04	2.610	4.234	6.312	4.277	3.01	2.466
Jarque–Bera	4.849	2.81	5.969	10.474	7.172	2.241	5.751
Probability	0.000	0.002	0.000	0.000	0.000	0.0125	0.000
Panel B: Correlation Matrix							
Probability	**LCO2**	**LGSCI**	**LGDP**	**LCCT**	**LEDU**	**LRE**	**LGD**
LCO2	1.000						
LGSCI	0.186*	1.000					
LGDP	0.591*	0.572*	1.0000				
LCCT	0.133*	-0.338*	-0.0937	1.000			
LEDU	0.238*	0.318*	0.3930*	-0.173*	1.000		
LRE	-0.268*	0.384*	-0.0787	-0.262*	0.2465*	1.000	
LGD	0.435*	0.120*	0.424*	0.215*	0.0430	-0.416*	1.000

Note: *Denote significance levels at 5%.

Table 2 provides a summary of descriptive statistics and the correlation matrix for all indicators. The results suggest that the variables do not follow a normal distribution. Climate change technologies exhibit the lowest mean value, while GDP per capita shows the highest annual mean. In a normal distribution, skewness is typically around zero and kurtosis is close to three or higher than three. However, the distribution of LCCT, LEDU, and LGD is positively skewed, whereas LCO, LGSCI, LGDP, and LRE are negatively skewed. Additionally, the series of LCO, LGDP, LCCT, LEDU, and LRE in the distribution display excess kurtosis, indicating a leptokurtic pattern, while the series of LGSCI and LGD show the low kurtosis, indicating a platykurtic.

Panel B of Table 2 presents the correlation estimates, revealing predominantly positive correlation coefficients among the variables. However, there are negative correlations observed between the variable pairs LCO and LRE, LGSCI and LCCT, LRE and LGDP, LCCT and LEDU, LCCT and LRE, LRE and LGD.

Empirical Results and Discussion

This study delves into the influence of climate change technologies, renewable energy, and global sustainable competitiveness index, economic growth, education level, and general technology diffusion on CO2 emissions. Prior to commencing the model estimation, preliminary analyses of panel data are carried out, including evaluations for cross-sectional dependency and stationarity. The outcomes of the cross-sectional dependency test are presented in Table 3. The results exhibit the findings from three cross-sectional dependence tests: Pesaran's (2021) test, Friedman's test, and Frees' test. The statistical significance of the test statistics for each variable indicates the presence of cross-sectional dependency. After assessing cross-sectional dependency, the analysis proceeds to conduct second-generation unit root tests.

Table 3. Cross-sectional dependence test

	CSD Tests		
Model*	**Pesaran CSD Test**	**Friedman CSD Test**	**Frees CSD Test**
Test statis.	6.849	40.689	4.907
Prob-value	0.000	0.000	0.000

Note: * represents the model of LCO=f (LGSCI, LGDP, LCCT, LEDU, LRE, LGD).

Acknowledging the presence of cross-sectional dependency, the outcomes of the second-generation unit root tests are presented in Table 4. To assess the stationarity of the variables, we conclude this analysis by utilizing

multiple panel unit root tests. These tests include Pesaran's (2007) cross-section-enhanced Im-Pesaran-Shin test and Pesaran's Augmented Dickey-Fuller test, denoted by the abbreviations CIPS and CADF, respectively. Remarkably, each test consistently confirms the presence of a unit root under both constant and trend specifications, except for LGDP, and LRE, which exhibit stationarity at the constant and trend level in both tests. Consequently, the results suggest that all series become stationary in their first differences. Based on these findings, we deduce that the variables in this study demonstrate a mixed order of integration.

Table 4. Panel unit root tests

Series	**Model**	**CIPS[a]**	**CIPS[b]**	**CADF [a]**	**CADF [b]**
LCO2	Constant	-2.011	-2.925***	-1.239	-3.001**
	Constant&Trend	-2.517	-2.863**	-2.895***	-3.082***
LGSCI	Constant	-2.283	-3.499***	-1.243	-2.610**
	Constant&Trend	-2.492	-4.012***	-1.383	-3.159***
LGDP	Constant	-3.105***	-2.638***	-2.557***	-2.298***
	Constant&Trend	-2.259	-2.620	-2.687**	-2.233**
LCCT	Constant	-2.039	-3.408***	-1.569	-2.714***
	Constant&Trend	-3.408*	-3.874***	-1.860	-2.085**
LEDU	Constant	-2.053	-2.523***	-2.474**	-2.086**
	Constant&Trend	-2.007	-2.448	-2.375	-2.366**
LRE	Constant	-2.265**	-2.888***	-2.334**	-2.500***
	Constant&Trend	-2.420	-3.074***	-2.566***	-3.360***
LGD	Constant	-2.195**	-3.092***	-2.267	-2.721***
	Constant&Trend	-2.714	-3.039***	-2.760	-2.386**

Note: a refers to unit root test model at level and b refers to unit root test model at first difference. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

After stationarity tests, Table 5 presents the results of the bootstrapped version of the Westerlund co-integration test for all panels, based on two sets of statistics. We reject the null hypothesis of no cointegration at a 5% significance level and with the support of 200 bootstrapping repetitions. This rejection suggests the existence of a long-term relationship between CO2 emissions and the determinants analyzed in this study.

Table 5. Panel cointegration tests

Statistic	**Value**	***p*-value**	**Robust *p*-value**
Gt	-2.2144	0.0134**	0.0000***
Ga	-3.0707	0.0011***	0.0000***
Pt	-3.6452	0.0001***	0.0000***
Pa	-2.9017	0.0012***	0.0020***

Note: ** and *** indicate significance at 5% and 1% level, respectively. No lag length is observed across 200 bootstrap repetitions.

In the same vein, this study proceeds to analyze the findings from the fixed-effect panel quantile regression. Table 6 showcases the results derived from panel quantile regression models at various quantiles, specifically at the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th quantiles. By employing nine quantiles, this study conducts the diverse impacts of LGSCI, LCCT, LRE, and other essential factors on CO2 emissions. The results of the panel quantile regression are interpreted by assessing how the coefficients of independent variables vary across different quantiles. Furthermore, this method allows for modeling the entire conditional distribution, offering a nuanced understanding of how independent variables affect the dependent variable across various quantiles. The panel quantile regression model effectively addresses hidden variations within each cross-section and explores distinct slope coefficients across different quantiles. Figure 3 also visually represents panel quantile regression models at the 10th, 20th, 30th, 40th, 50th, 60th, 70th, 80th, and 90th quantiles. showcasing specific variations of coefficients across quantiles.

As seen in Table 6, the effect of LGSCI on CO2 emissions is heterogeneous and significantly positive between the 40th and 60th quantiles. After the 70th quantile, its effect turns negative and insignificant. LGDP has a positive and significant impact on CO2 emissions at all quantiles. The positive impact is more robust at the 90th quantile. Similarly, the effect of LCCT is also positive and significant on CO2 emissions at all quantiles. The positive impact of LCCT is more robust at the 60th quantile. Furthermore, the impact of LEDU on CO2 emissions is heterogeneous at all quantiles. LEDU has positive and significant impacts, but its effects turn negative and insignificant at the 40th-60th-70th-80th and 90th quantiles. The effect is also more robust at the 10th quantile of LEDU.

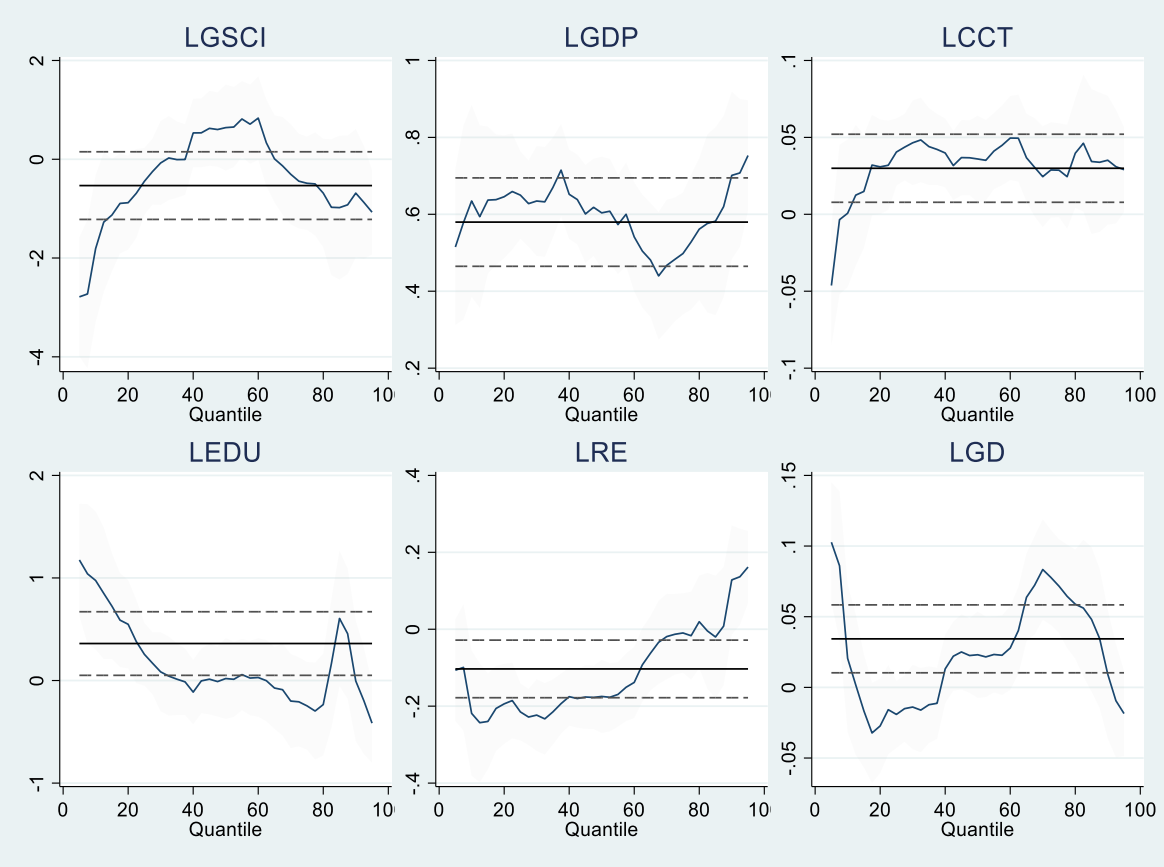

Figure 3. Change in panel quantile regressions coefficients of carbon emissions.
Source: Authors' elaborations

Moreover, the effect of LRE shows negative and significant effects on CO2 emissions from the 10th to the 70th, except for the 70th which is insignificant. Its effect turns positive at the 80th and 90th quantile. Likewise, the effect of LGD on CO2 emissions is negative at the 20th and the 30th quantiles. Its effect turns to positive at 10th and after 40th quantiles, and its significant from 60th to 80th quantile. The positive and significant impact of LGD is more robust at the 70th quantile.

Table 6. Panel quantile regression results

Variable	**Quantile Regression**								
	10th	**20th**	**30th**	**40th**	**50th**	**60th**	**70th**	**80th**	**90th**
C	-0.999**	-1.566**	-1.919**	-2.730***	-2.979***	-3.083***	-0.611	-0.234	-1.188
	(-0.87)	(-2.13)	(-2.92)	(-5.12)	(-4.43)	(-4.72)	(-0.78)	(-0.34)	(-1.19)
LGSCI	-1.808**	-0.879*	-0.075	0.532	0.641	0.833*	-0.304	-0.683	-0.685
	(-2.39)	(-1.82)	(-0.17)	(1.51)	(1.45)	(1.94)	(-0.59)	(-1.23)	(-1.04)
LGDP	0.634***	0.645***	0.634***	0.652***	0.603***	0.541***	0.467***	0.561***	0.701***
	(5.00)	(7.95)	(8.74)	(11.04)	(8.13)	(7.51)	(5.40)	(5.99)	(6.33)
LCCT	0.006	0.031**	0.046***	0.039***	0.035**	0.049***	0.024	0.039**	0.035
	(0.03)	(1.97)	(3.32)	(3.51)	(2.51)	(3.57)	(1.47)	(2.20)	(1.65)
LEDU	0.975***	0.548**	0.084	-0.113	0.019	0.029	-0.201	-0.2344	-0.0042
	(02.85)	(2.50)	(0.43)	(-0.71)	(0.10)	(0.15)	(-0.86)	(-0.93)	(-0.01)
LRE	-0.218***	-0.194***	-0.223***	-0.175***	-0.174***	-0.138***	-0.019	0.019	0.128*
	(-2.65)	(-3.67)	(-4.72)	(-4.55)	(-3.61)	(-2.94)	(-0.34)	(0.32)	(1.78)
LGD	0.021	-0.027	-0.014	0.013	0.023	0.027**	0.083***	0.058***	0.009
	(-0.78)	(-1.61)	(-0.92)	(1.06)	(1.49)	(1.85)	(4.61)	(3.00)	(-1.19)
Pseudo R^2	0.801	0.622	0.587	0.590	0.677	0.682	0.752	0.781	0.698
N	418	418	418	418	418	418	418	418	418

Note: This table shows the results of the panel quantile regression model driving factors on CO2 emissions. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively. The z statistics-values are represented in parentheses.

Following this, we employ the Dumitrescu and Hurlin (2012) Granger non-causality test to investigate the direction of causality, and the results are presented in Table 7.There is a bidirectional causality between LCO and LGSCI at all significance levels. It implies that a change in LGSCI can affect LCO, and similarly, a change in LCO can affect LGSCI. Likewise, there is also bidirectional causality between LCO and LGDP. It shows that a change in LGDP can affect LCO, and similarly, a change in LCO can affect LGDP.

Moreover, there is bidirectional causality between LCCT and LCO. This indicates that a change in LCCT can affect LCO, and similarly, a change in LCO can affect LCCT. Similarly, there is bidirectional causality between LEDU and LCO at all significance levels. This shows that a change in LEDU can affect LCO, and similarly, a change in LCO can affect LEDU. Lastly, there is bidirectional causality between LRE and LCO. It shows that a change in LRE can affect LCO, and similarly, a change in LCO can affect LRE. However, there is no causal relationship between LCO and LGD at any significance level. It implies that a change in LCO can not affect LGD, and similarly, a change in LGD can not affect LGD.

Table 7. Panel causality test results

Null Hypothesis	**W-Stat**	**Zbar-Stat**	**Probability**
LCO → **LGSCI**	1.9985	4.3525	0.0000
LGSCI → LCO	4.9611	7.8400	0.0000
LCO → **LGDP**	1.8574	3.7374	0.0002
LGDP → LCO	2.6848	7.3437	0.0000
LCO → L**CCT**	5.8766	9.8556	0.0000
LCCT → LCO	3.1637	3.8829	0.0001
LCO → **LEDU**	3.5123	4.6503	0.0000
LEDU → LCO	3.1142	3.4037	0.0005
LCO → **LRE**	2.5124	6.5925	0.0014
LRE → LCO	2.1526	5.0241	0.0000
LCO → **LGD**	1.1811	0.7893	0.4299
LGD → LCO	2.6253	7.0844	0.1221

Note: *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

Conclusion

The dynamic impacts of CO2 emissions have been examined concerning climate change technologies, the GSCI, renewable energy, general technology diffusion, education level, and economic growth. This study encompasses data from 38 OECD countries using panel data analysis. Utilizing the panel quantile regression model, the study findings reveal that the development and creation of climate change technologies exhibit positive effects on CO2 emissions across quantiles ranging from the 10th to the 90th percentile. On the contrary, the effect of renewable energy shows negative and significant on CO2 emissions from the 10th to the 70th quantiles. Additionally, there exists a negative correlation between the GSCI and CO2 emissions, except for the 40th and 60th quantiles. On the other hand, economic growth has a positive and significant impact on CO2 emissions at all quantiles.

The impact of education level on CO2 emissions is also heterogeneous at all quantiles. Education has positive and significant impacts at the 10th-20th and 30th quantiles, but its effects turn negative and insignificant at the 40th-60th-70th-80th and 90th quantiles. Lastly, the effect of general technology diffusion on CO2 emissions is negative at the 20th and the 30th quantiles. Its effect turns positive at the 10th and after the 40th quantiles.

Consequently, the adverse relationship between CO2 emissions and renewable energy use, the GSCI, and general technology diffusion suggests that the integration of environmentally sustainable technologies and the adoption of renewable energy sources are associated with favorable environmental outcomes, contributing to the mitigation of CO2 emissions released into the atmosphere.

On the other hand, we find that a positive relationship between CO2 emission and climate change technologies. This result could potentially indicate various factors at play, including the initial stages of technology deployment requiring significant energy inputs and resources, leading to temporary increases in emissions before the technologies mature and contribute to emissions reductions. Additionally, substitution effects may occur where new technologies displace older, less efficient ones, yet if the new technologies are not yet fully mature or widely adopted, they may not effectively reduce emissions. Indirect effects, such as changes in economic activity or consumer behavior spurred by technology development, could also contribute to increased

emissions in the short term. Moreover, feedback mechanisms, such as government policies or market dynamics inadvertently incentivizing carbon-intensive industries alongside technology development, could exacerbate emissions rather than mitigate them.

Moreover, we conclude that there is a long-term cointegration between CO2 emissions and the determinants analyzed in this study. Furthermore, according to Dumitrescu and Hurlin (2012) Granger non-causality test, there is no causal relationship between general technology diffusion and CO2 emissions at all significance levels. Also, there is there is bidirectional causality between all other pairs of variables at all significance levels.

Recommendations

According to the empirical findings of this study, there are several policy recommendations aimed at assisting governments and policymakers in advancing environmental sustainability within nations and aligning with the eco-friendly objectives of sustainable development. Firstly, governments and policymakers should actively foster the development and adoption of technologies and renewable energy sources as a means to mitigate high levels of CO2 emissions.

Secondly, policymakers are urged to explore strategies for diversifying economic growth to reduce reliance on sectors with significant carbon emissions. Encouraging the growth of sustainable and environmentally friendly industries can strike a balance between economic expansion and environmental preservation. Also, governments should improve the technologies and implementations of climate change technologies by decreasing the level of CO2 emissions and providing sustainable development goals.

Moreover, governments should prioritize the integration of sustainability criteria into economic policies and decision-making processes. This can be achieved by expanding the scope and coverage of the GSCI to include additional indicators related to environmental performance, such as carbon footprint, energy efficiency, and natural resource management. Policymakers should leverage the GSCI as a tool for assessing and monitoring progress towards environmental sustainability goals at both national and international levels Similarly, governments should prioritize investments in research, development, and commercialization of climate change technologies. This can be achieved through funding grants, establishing innovation hubs or centers of excellence, and fostering collaboration between academia, industry, and government agencies. Policymakers should also create a supportive regulatory environment that encourages the adoption and diffusion of climate change technologies, such as streamlined permitting processes or technology standards.

Policymakers should prioritize international collaboration and knowledge sharing to accelerate progress towards environmental sustainability. This can involve participation in global initiatives and agreements aimed at addressing climate change, promoting technology transfer and capacity building in developing countries, and sharing best practices and lessons learned from successful sustainability initiatives. Countries can leverage collective expertise and resources to achieve more significant and lasting impacts on environmental sustainability on a global scale.

Furthermore, suggestions for future research could involve conducting sector-specific examinations to discern the diverse effects of climate change technologies and renewable energy on CO2 emissions within distinct industries. This methodology has the potential to provide insights for tailored policies aimed at addressing sectors with the most significant carbon footprint.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

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Towards Net-Zero Emissions in OECD Countries: Forecasting AI by Machine Learning Methods

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Abstract: Achieving net-zero emissions is a paramount objective for Organisation for Economic Co-operation and Development (OECD) countries in combating climate change and fostering sustainable development. This study provides an overview of the strategies, opportunities, and challenges facing OECD countries in their transition towards achieving net-zero emissions. This study delineates the OECD's commitment to ambitious climate targets, including the overarching goal of achieving carbon neutrality by 2040. While some existing models provide reasonably accurate predictions of CO_2 emissions, the model presented in this study offer improved prediction capabilities for all OECD countries. This study successfully predicts historical emissions, current emissions, and future emissions from 1990 to 2022 using Machine Learning (ML) methodology. The study forecasts global CO_2 emissions for all OECD countries from 2022 to 2042 (near future) using prediction models using SARIMA (Seasonal Autoregressive Integrated Moving Average) based on ARIMA (Autoregressive Integrated Moving Average). The primary aim is to compare these models and identify the most effective one for predicting the transition to net-zero emissions for all OECD countries. These predictions highlight that policymakers should thoroughly evaluate the measures and strategies to promote a transition to net-zero emissions and reduce the levels of CO_2 emissions. Furthermore, it highlights the potential co-benefits of transitioning to a low-carbon economy, including improved air quality, enhanced energy security, and job creation.

Keywords: Environmental sustainability, Carbon emissions, Net-zero emissions, Machine learning (ML),

Introduction

One of the 21st century's biggest problems is global warming and related climate change, which is accepted by scientific circles to be human-induced. Climate change has a high potential to cause major environmental disasters, hunger, war, and thirst in the future. Therefore, it is very important for the whole world to analyze and plan the factors that trigger climate change. One of the most important factors that trigger change is greenhouse gases(Zhong & Haigh, 2013). This study aims to estimate CO_2 emissions from greenhouse gases that cause climate change. The assessment and estimation of CO_2 emissions is important for global warming (Florides & Christodoulides, 2009) and climate change (Solomon et al., 2009). The estimations are performed for OECD countries. The OECD is an international organization of 38 countries that brings together countries with market economies and democratic structures for economic cooperation. Its members are Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States. OECD countries generally have very large economies and require high amounts of energy due to their high living standards. According to 2022 data, OECD countries have 17% of the world population and 59% of GDP. At the same time, 54% of the world's total production is made by this group of countries Figure 1. Therefore, it is of vital importance to examine high CO_2 emitting countries such as the OECD. The CO_2 estimates obtained at the end of the study can be used in climate scenarios and can be used in policy-making

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

decisions and in the implementation of global climate protocols. Estimation of CO_2 emissions is important to quantify and tackle irreversible climate change (Solomon et al., 2009).

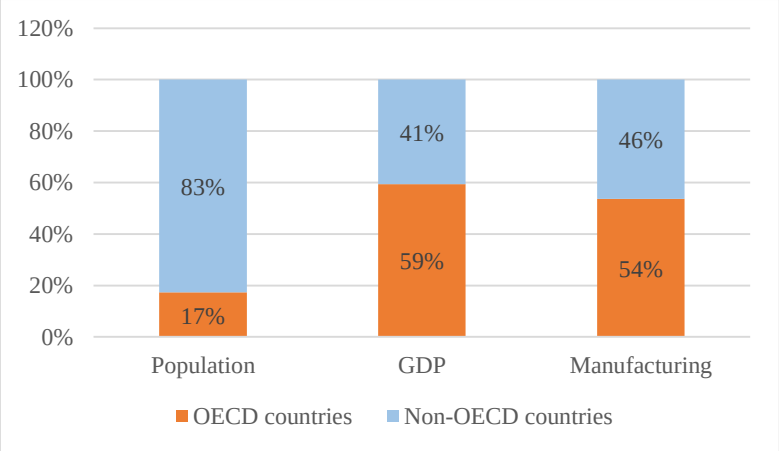

Figure 1. World and OECD economic outlook

Artificial intelligence studies are now used in classification, association and prediction for many different types of problems and produce successful results. Machine learning is a subset of artificial intelligence systems that make predictions by learning time-dependent historical data. In the literature, there are classical time series methods and statistical methods that estimate the CO_2 emissions of countries. Statistical time series methods are complex and model the change of data over time. While statistical models are mathematically complex and use many extra parameters, machine learning methods make more understandable predictions from the information they learn. In this study, the future CO_2 emissions of 38 countries were predicted by using machine learning method, which makes predictions by learning time-dependent historical data.

In this study, CO_2 emissions of 38 countries between 1990 and 2022 are used. 80% of the data is used for training and the remaining 20% is used for testing. Evaluation metrics are used when the prediction results need to be compared. Performance metrics are based on how close the predicted value in the test data is to the true value. The performance of the method is compared with statistical functions such as Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD), Root Mean Square Error (RMSE) and Mean Square Error (MSE).

In the literature, many studies have been conducted for CO_2 emission estimation. To date, there are some studies such as (Iania et al., 2022) that model the global CO_2 emission footprint. Most of the existing studies have a regional context, for example (Nyoni & Bonga, 2019) used the Box-Jenkins ARIMA approach on time series data on CO_2 emission in India from 1960 to 2017 and proposed five policy solutions to improve environmental conditions based on the forecasts. (Qian et al., 2020) studied CO_2 emission forecasting of Changxing county in China, while (Tanania et al., 2020) analyzed and predicted CO_2 emissions of India using dataset from 1995 to 2018. (Zuo et al., 2020), collected CO_2 emission data from different provinces of China and proposed an integrated model, LSTM-STRIPAT, to predict emissions in 2020. (Shabani et al., 2021) estimated local CO_2 emission in Iran using machine learning and neural network-based modeling. Furthermore, (Rolnick et al., 2023), provides a good overview of CO_2 emission and related issues but lacks in building a CO_2 emission model for a global situation. A number of modeling approaches have been attempted by various authors from different perspectives to estimate CO_2 emissions. (Kadam & Vijayumar, 2018) provides insight into a CO_2 emission estimation model using machine learning. A new hybrid model using combined principal component analysis (PCA) is built for China based on data from 1978 to 2014 (Sun & Sun, 2017). In addition, a forecasting model for CO_2 emissions in China based on multiple linear regression analysis is also studied (Libao et al., 2017).

The aim of this study is to model accurate CO_2 emission behavior for the past, present and near future. First, this study uses current data together with historical data. Second, it uses existing time series-based machine learning models to develop the CO_2 emission prediction model. The model selection process is different in that it obtains the best model and relevant parameters. The model developed based on the selected parameters becomes accurate (less prone to error). As a result, near-future forecasts become accurate when compared to the actual CO_2 emissions of that time. Initially, models based on the available time series were selected; the ML model optimization algorithm was developed, which selects the best model for each CO_2 data set in order to obtain the

best possible forecast. Finally, this study estimates the CO_2 emission footprint for 20 years (from 2023 to 2042) as an example.

Method

This paper uses data on CO_2 emissions of OECD countries for the period 1990-2022. Primary data are taken from this repository (Ritchie & Roser, 2024). The SARIMA model was used to develop forecasting models for the estimation of CO_2 emission behavior. The dependent variable in this study is the total amount of CO_2 emissions and the independent variable is the year. In this study, the data is divided into training data and test data; 80% of the CO_2 emission data is used for learning and 20% is used for testing. Training data were used in the CO_2 emission forecasting process of the model and test data were used to determine the accuracy of CO_2 emission forecasting. Data from December 1990 to December 2020 were considered as training data and data from December 2021 to December 2022 were used as test data for the model. A similar training-test separation was performed for each OECD country. Validation and comparison were then performed to evaluate our forecasting models and model results.

Machine Learning

Machine learning is based on creating algorithms based on data on a specific topic, updating the outputs as new data becomes available, and using statistical analysis to predict the results. There are many different types of algorithms under machine learning that enable computers to learn. Computers extract a model from the learned data using various functions and statistical methods and can predict, predict or classify new data according to this model. There are many different machine learning methods in the literature. These methods perform differently depending on the type of data. Therefore, it is difficult to say that one machine learning method is superior to others. There are three basic stages in machine learning. These are:

- Preparation of data: The first stage is the preparation of the right data, and the data must be prepared with great care in order to reach the right results. At this stage, the data is made ready for processing by finding outliers, normalizing the data, etc. Depending on the type of problems, both numerical and symbolic (nominal) data can be processed.
- Training: The second phase is to find the most appropriate model and train the data prepared in the first phase with this model. First, a machine learning method suitable for the problem is selected and the most appropriate model is created from the data by training. In order to find the appropriate model, as many models as possible should be built and tested. A part of the data in the training set is separated and the model is validated and it is decided whether the model is suitable or not.
- Test: The last stage is the performance test. For this, the model is tested using the model created with data other than the training data used to create the model. This data is called the test set. During the testing process, the performance of machine learning with the test set is measured with metrics such as accuracy rate, number of false positives, number of true positives.

Machine learning is used for classification, regression and clustering, but it is also frequently used for time-series analysis. Machine learning and time series try to make new predictions based on information from the past. This is a type of supervised learning in machine learning. In this study, time-series analysis was performed using SARIMA, a machine learning method known to give successful results.

ARIMA is an acronym that stands for autoregressive integrated moving average. Specifically, it is a model that uses the dependent relationship between an observation and a set of lagged observations, AR (autoregression), I (integrated), the use of differencing of raw observations and MA (moving average) to make the time series stationary. SARIMA, an extension of ARIMA, is known for its ability to incorporate seasonality into forecasts. SARIMA is a seasonal autoregressive integrated moving average with seasonality as well as trend. These algorithms are robust in handling both stationary and non-stationary time series data. Forecasting with ARIMA or SARIMA usually involves three main steps: specifying the temporal model, estimating the parameters and diagnostic checking. A standard notation is used for ARIMA (p, d, q), where parameters are replaced by integer values to quickly indicate the specific ARIMA model being used. Where p is the number of lagged observations included in the model, also called the lag order, d is the number by which the raw observations differ, also called the degree of differencing, and q is the size of the moving average window, SARIMA is represented as SARIMA (p, d, q) $(P, D, Q)^S$, where "P", "D" and "Q" correspond to the seasonal autoregressive, seasonal difference and seasonal moving average terms respectively. "S" denotes the seasonal parameter. The researcher

found that S=19 gives the best seasonality parameter during the ARIMA model optimization. As a result, the ARIMA model was transformed into SARIMA model and presented as SARIMAX. To evaluate the model, we use prediction metrics such as mean absolute percentage error (MAPE), mean square error (MSE), root mean square error (RMSE), and mean absolute deviation (MAD). To generate different models, the ARIMA algorithm was executed repeatedly using the optimization algorithm developed by the author.

Performance Metrics for Forecasts

After the predictions are made, it is necessary to quantify the prediction success of machine learning methods on the data set. Performance metrics have been developed for these purposes. Prediction metrics such as mean absolute percentage error (MAPE), mean square error (MSE), root mean square error (RMSE) and mean absolute deviation (MAD) are used to evaluate the model (Sammut & Webb, 2010). MAPE and MSE are the most commonly used functions for prediction performance evaluation. However, the presence of two other evaluation criteria in the study will enable future studies to compare the results with the results obtained. (Lewis, 1982) evaluated predictions with MAPE values below 10% as "very good". For the sake of simplicity and completeness, MAPE scores are presented in this article to compare with model accuracy. To generate different models, the ARIMA algorithm was executed repeatedly using the optimization algorithm developed by the author. After checking efficiency issues, the most efficient model was used.

$$MAPE = \frac{\sum_{t=1}^{n} |(y_t - \hat{y}_t)/y_t|}{n} 100 \tag{3.3}$$

$$MSE = \frac{\sum_{t=1}^{n} (y_t - \hat{y}_t)^2}{n} \tag{3.4}$$

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} |y_t - \hat{y}_t|}{n}} \tag{3.5}$$

$$MAD = \frac{\sum_{t=1}^{n} |y_t - \hat{y}_t|}{n} \tag{3.6}$$

Having successfully developed the model, it was time to create visual representations of the modeling results. Figure 2 is sufficient as evidence to validate the models presented in this paper. Figure 2 shows the forecast behavior of emissions for current (1990-2022) and future (2022 and beyond) years. The pink shades in Figure 2 are confidence intervals (upper and lower bounds of the forecasts). Furthermore, for a better understanding of the forecast values, Table 1 presents the modeling error and accuracy parameters found during model development.

Results and Discussion

A series of significant findings emerged from the forecast of near and far-future CO_2 emissions utilizing an exact model. Initial validation of the model was performed by comparing its predictions against observed data for the near future. Subsequently, projections were made for CO_2 emissions in the far future, yielding results summarized in Table 1. The model's efficacy in predicting near-future CO_2 emissions was assessed, providing empirical validation for its reliability. Notably, the model generated predictions for specific years in the near future, offering valuable insights that may bolster the development of models for forecasting distant future emissions. The forecasting models show a decreasing trend in CO_2 emissions over time and this trend is consistent with historical data showing seasonal variations. This observation is in line with previous forecasts and proves the reliability of the established models. Analysis of historical data, as shown in Figure 3, reveals a decrease in CO_2 emission rates in 2023, mirroring similar fluctuations in other years characterized by both increases and decreases. In contrast, the methodology used in this study exhibits remarkable precision in determining estimated CO_2emission values.

As a result, the developed models are less sensitive to errors. This agreement between the estimated CO_2 emission data and the accuracy metrics indicates a convergence, increasing confidence in the reliability of both the methodology and the estimated CO_2 emissions. Therefore, the methodological approach and the resulting CO_2 emission estimates deserve to be considered as accurate and reliable tools for future use.

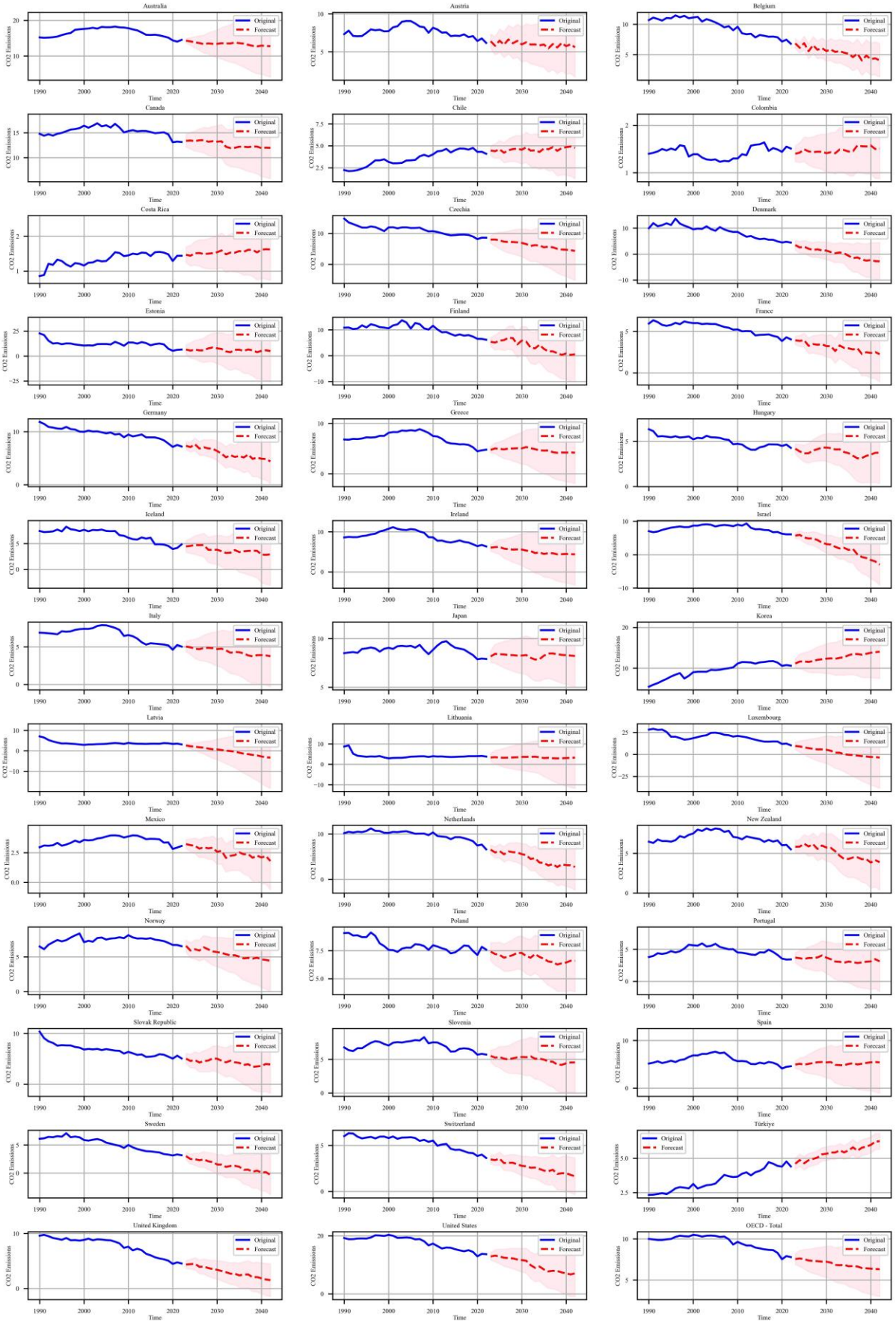

Figure 2. Emissions estimates for OECD countries

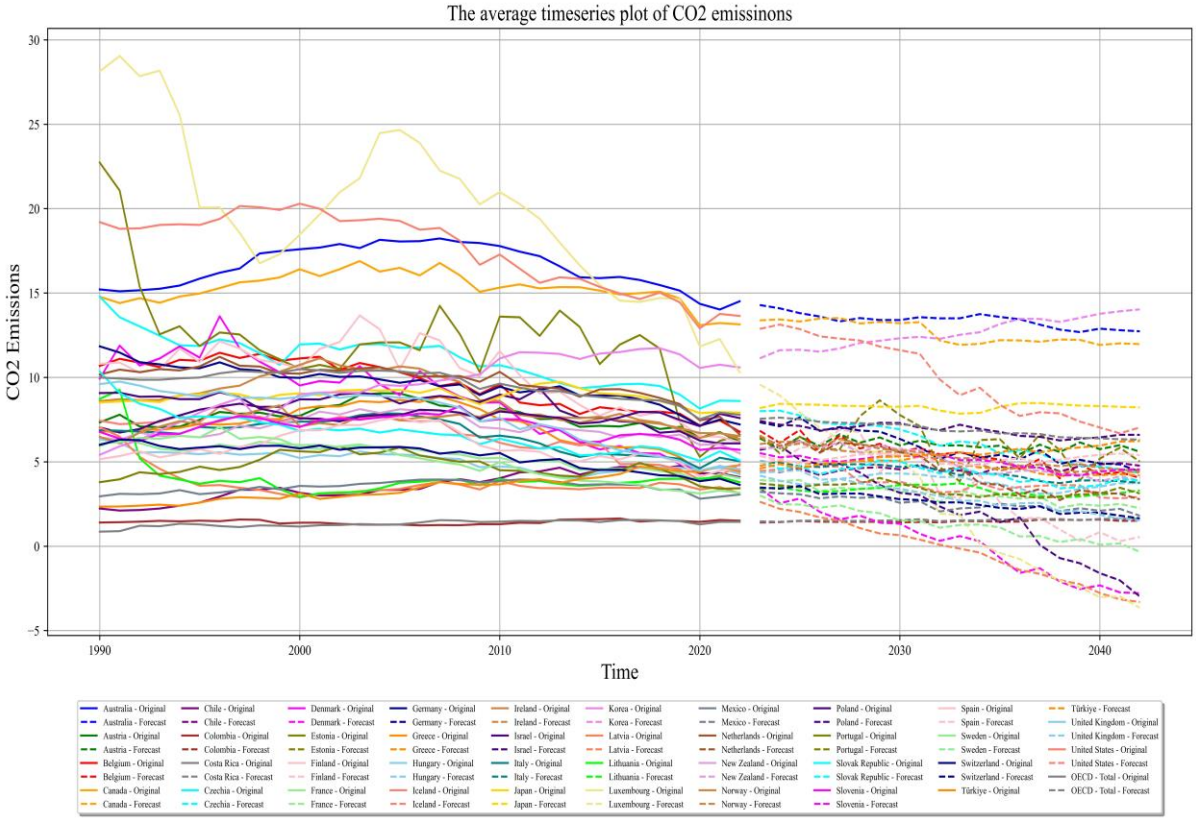

Figure 3. OECD countries emission estimates for 2023-2042

The forecasting model shows that CO_2 emissions have been decreasing over time except for some countries. This phenomenon can be seen in all time periods except for some countries as shown in Figure 3 of the 20-year forecast values of OECD countries. Minimizing CO_2 emissions should be considered by every nation. Looking at the OECD countries collectively, it is seen that the amount of CO_2 emissions has decreased. The situation is different for Turkey, Costa Rica and South Korea. In these three countries, the amount of CO_2 emissions is generally increasing until 2019 and it is seen in the study that this increase will continue in the coming years if CO_2 emissions are not directed to non-alternative energy sources.

All models in this article were developed in Python. The evaluation criterion values calculated by all models in this article are presented in Table 1. Taking into account seasonality and trends in the data, the SARIMA model provides a forecast consistent with the downward trend seen. The SARIMA model highlights the importance of considering seasonality in the forecasting context. Looking at the table results, a downward trend is predicted in the next twenty years compared to today, indicating that countries will undergo structural changes. The projected decrease is relatively significant and does not decrease for every country. This model implies that OECD countries will reach net zero emissions in the near future.

Conclusion

Carbon emissions, the greenhouse effect, climate change and devastating environmental problems have become the most important issues of today's world. If the increase in the amount of carbon dioxide in OECD countries and the world is not stopped or reduced, seasonal shifts, very high temperatures, floods and floods due to heavy rainfall will continue to increase. The underlying reason behind the increase in CO_2 emissions is the world's ever-increasing demand for energy. Apart from fossil fuels such as oil, natural gas and coal, the main sources of energy are nuclear energy, hydroelectric energy and sustainable energy. With the industrial revolution and the overuse of fossil fuels, CO_2 emissions, one of the most important greenhouse gases that cause climate change, have doubled in the last century. In addition to global warming, which is a very big problem, this increase in CO_2 emissions may cause much bigger problems such as water wars and migrations in the coming years. For these reasons, countries should make various plans to reduce their CO_2 emissions. Among these plans, countries should turn to renewable energy sources instead of using fossil fuels to reduce CO_2 emissions.

Table 1. OECD CO2 emission outlook to 2042

Countries/Years	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	MAPE	RMSE	MSE	MAD
Australia	14.29	14.09	13.81	13.61	13.32	13.51	13.40	13.40	13.57	13.50	13.50	13.75	13.58	13.44	13.12	12.83	12.68	12.89	12.80	12.73	18.96%	3.40	11.58	3.22
Austria	6.39	5.79	6.47	5.94	6.63	6.13	6.44	5.97	6.25	5.96	5.97	5.86	5.95	5.46	6.02	5.57	6.15	5.75	5.98	5.59	20.70%	1.79	3.21	1.64
Belgium	6.84	6.12	6.88	5.55	6.55	5.79	6.06	5.58	5.82	5.44	5.56	5.31	5.13	4.58	5.16	4.02	4.85	4.25	4.39	4.05	38.05%	3.36	11.29	3.31
Canada	13.38	13.43	13.31	13.48	13.51	13.19	13.29	13.21	13.27	12.18	11.93	11.99	12.20	12.19	12.11	12.24	12.22	11.92	12.01	11.97	16.72%	2.68	7.18	2.58
Chile	4.46	4.39	4.60	4.21	4.49	4.63	4.68	4.55	4.83	4.45	4.48	4.29	4.70	4.61	4.85	4.43	4.73	4.85	4.92	4.77	14.17%	0.66	0.44	0.52
Colombia	1.40	1.42	1.49	1.45	1.44	1.44	1.44	1.41	1.43	1.41	1.49	1.48	1.45	1.45	1.58	1.56	1.55	1.58	1.50	1.51	8.67%	0.13	0.02	0.12
Costa Rica	1.47	1.44	1.51	1.52	1.49	1.50	1.51	1.54	1.59	1.48	1.53	1.53	1.57	1.55	1.61	1.61	1.54	1.61	1.63	1.62	7.36%	0.13	0.02	0.10
Czechia	8.00	8.03	7.74	7.33	7.20	7.21	7.11	6.92	6.55	5.95	6.21	6.09	5.50	5.71	5.48	5.02	4.78	4.72	4.55	4.33	39.42%	3.99	15.91	3.97
Denmark	3.44	2.54	2.82	2.03	1.59	1.81	1.39	1.34	0.73	0.32	0.60	0.29	-0.69	-1.59	-1.31	-2.10	-2.54	-2.32	-2.74	-2.79	105.97%	7.05	49.70	7.02
Estonia	6.50	5.50	6.49	5.75	5.74	7.69	8.64	7.77	7.11	4.67	3.85	6.29	6.34	5.20	6.64	5.69	3.90	5.19	5.83	5.01	43.17%	5.79	33.55	5.20
Finland	5.35	5.07	5.80	6.02	6.90	6.76	4.35	5.83	5.45	3.09	2.83	4.22	2.60	1.66	1.67	0.98	0.32	0.83	0.29	0.55	65.82%	6.02	36.19	5.91
France	3.92	3.85	3.93	3.25	3.45	3.39	3.44	3.22	3.21	2.63	3.29	2.99	2.95	2.82	2.95	2.28	2.48	2.39	2.50	2.25	38.43%	1.91	3.65	1.89
Germany	7.34	7.10	7.63	6.83	7.06	6.85	6.79	6.36	5.86	5.16	5.57	5.25	5.41	5.14	5.69	4.88	5.12	4.90	4.85	4.41	33.91%	3.06	9.35	3.00
Greece	4.75	5.04	4.93	4.85	5.00	5.03	5.08	5.06	5.32	5.08	4.89	4.66	4.60	4.62	4.30	4.16	4.24	4.21	4.25	4.19	28.58%	2.43	5.92	2.12
Hungary	4.18	3.88	3.66	3.68	3.99	4.13	4.30	4.31	4.25	4.10	4.11	3.81	3.69	3.40	3.12	3.14	3.39	3.52	3.72	3.74	19.25%	1.09	1.18	0.94
Iceland	4.45	4.56	4.72	4.69	4.72	3.81	3.77	3.82	3.52	3.19	3.24	3.75	3.35	3.50	3.58	3.62	3.60	2.88	2.83	2.92	36.40%	2.33	5.44	2.22
Ireland	6.05	6.18	6.21	5.79	5.67	5.56	5.60	5.58	5.31	5.20	4.70	4.85	4.48	4.66	4.65	4.38	4.41	4.47	4.42	4.38	37.66%	3.29	10.85	3.18
Israel	5.70	5.94	5.13	4.85	4.87	4.37	3.62	3.16	3.03	2.35	1.84	2.05	1.42	1.69	0.07	-0.71	-1.01	-1.60	-2.02	-2.98	77.67%	6.09	37.04	5.83
Italy	5.03	4.93	4.74	4.69	4.83	4.86	4.82	4.70	4.75	4.52	4.21	4.31	4.28	4.12	3.85	3.73	3.89	3.90	3.85	3.75	28.18%	1.94	3.77	1.81
Japan	8.18	8.44	8.40	8.37	8.32	8.30	8.26	8.26	8.32	8.03	7.85	7.90	8.25	8.47	8.48	8.40	8.33	8.30	8.26	8.22	7.99%	0.88	0.78	0.73
Korea	11.13	11.61	11.64	11.52	11.72	12.04	12.17	12.32	12.40	12.29	12.52	12.68	13.16	13.47	13.46	13.29	13.52	13.77	13.91	14.03	18.43%	2.06	4.23	1.94
Latvia	2.63	2.21	2.02	1.71	1.52	1.07	0.75	0.65	0.39	0.08	-0.15	-0.38	-0.93	-1.41	-1.64	-2.01	-2.25	-2.77	-3.15	-3.31	107.40%	4.15	17.24	3.74
Lithuania	3.38	3.50	3.29	3.22	3.27	3.39	3.46	3.63	3.64	3.64	3.72	3.46	3.06	3.18	2.97	2.90	2.94	3.07	3.14	3.30	13.01%	0.60	0.36	0.50
Luxembourg	9.57	8.93	7.93	7.02	6.32	5.60	5.58	5.22	4.07	1.92	1.86	0.12	-0.40	-0.77	-1.44	-2.04	-2.44	-3.02	-2.98	-3.66	92.20%	15.80	249.70	15.76
Mexico	3.22	3.13	3.07	2.84	2.94	2.86	2.91	2.57	2.66	2.05	2.24	2.29	2.52	2.36	2.38	2.07	2.24	2.10	2.21	1.80	30.36%	1.15	1.32	1.10
Netherlands	6.55	5.94	6.25	5.53	6.15	6.00	5.93	5.57	5.34	4.50	4.67	3.72	3.63	3.07	3.38	2.73	3.31	3.16	3.11	2.77	51.52%	4.76	22.69	4.71
New Zealand	5.82	5.83	6.21	5.85	6.13	5.54	5.97	5.72	5.68	5.25	4.68	4.29	4.28	4.47	4.48	4.25	4.25	3.83	4.14	3.87	28.36%	2.01	4.05	1.97
Norway	6.55	5.90	6.08	5.90	6.36	6.06	5.78	5.67	5.56	5.37	5.20	5.22	5.01	4.77	4.84	4.74	4.87	4.64	4.55	4.43	27.99%	2.12	4.50	2.08
Poland	7.42	7.20	7.12	6.87	6.98	7.10	7.31	7.29	7.02	6.87	7.20	6.95	6.77	6.53	6.48	6.26	6.37	6.44	6.60	6.59	10.79%	0.92	0.85	0.84
Portugal	3.71	3.61	3.50	3.64	3.65	3.73	4.04	3.70	3.45	3.09	3.05	2.91	3.09	2.98	2.86	2.95	3.07	3.11	3.46	3.12	26.55%	1.39	1.94	1.27
SlovakRepublic	5.02	4.58	4.76	4.27	4.55	4.66	5.08	5.02	4.64	4.31	4.63	4.32	4.20	3.80	3.94	3.42	3.50	3.61	3.99	3.88	28.03%	1.75	3.05	1.69
Slovenia	5.51	5.26	5.35	5.10	5.00	5.15	5.30	5.35	5.32	5.45	5.09	5.11	4.97	4.70	4.65	4.24	4.18	4.41	4.53	4.55	28.16%	2.07	4.27	1.99
Spain	4.93	5.11	4.91	5.10	5.26	5.43	5.48	5.40	5.47	4.88	4.83	4.79	5.08	5.21	4.96	5.12	5.29	5.41	5.48	5.39	15.76%	1.31	1.72	0.99
Sweden	3.00	2.48	2.47	2.28	2.42	2.09	1.95	1.52	1.49	1.09	1.26	1.28	1.11	0.57	0.60	0.24	0.43	0.09	0.16	-0.34	72.61%	3.00	9.00	2.99
Switzerland	3.48	3.41	3.57	3.08	3.11	3.12	2.95	2.78	2.73	2.59	2.60	2.45	2.27	2.20	2.36	1.91	1.98	1.98	1.81	1.65	47.68%	2.33	5.43	2.32
Türkiye	4.60	4.86	4.63	4.85	4.94	5.05	5.28	5.32	5.41	5.41	5.57	5.42	5.56	5.79	5.54	5.76	5.85	5.95	6.20	6.23	38.42%	1.49	2.23	1.47
UnitedKingdom	4.35	4.43	4.50	3.94	3.98	3.72	3.53	3.40	3.18	2.97	2.70	2.69	2.39	2.54	2.56	2.06	2.08	1.85	1.64	1.52	56.60%	3.85	14.82	3.79
United States	12.87	13.13	12.86	12.43	12.30	12.19	11.83	11.61	11.39	9.88	8.94	9.39	8.37	7.72	7.94	7.87	7.38	7.03	6.69	7.03	39.78%	6.40	40.98	6.37
OECD - Total	7.55	7.62	7.52	7.37	7.31	7.29	7.23	7.22	7.12	6.84	6.80	6.84	6.67	6.69	6.64	6.46	6.42	6.38	6.34	6.32	24.23%	2.30	5.30	2.25

Accurate near real-time forecasting of CO_2 emissions of OECD countries is of great importance for governments' efforts to control and mitigate climate change. This paper focuses on evaluating the forecasting capabilities of the SARIMAX machine learning model for near real-time annual CO_2 emission forecasting of OECD countries. The study uses a series of real-time datasets of OECD countries covering the period from 1990 to 2022. Four evaluation criteria, namely MSE, RMSE, MAD and MAPE, are analyzed to identify the most appropriate model for future forecasts and to compare their forecasting performance. By building the ML model that takes into account the reduction of CO_2 emissions, some remarkable results are obtained that can help to understand CO_2 emissions among OECD countries. The study shows that the SARIMA (1, 1, 0, 19) model is not only stable but also the most appropriate model for forecasting the annual total CO_2 of OECD countries for the next 20 years. The model predicts that the total annual CO_2 emissions of OECD countries will average 9,310 t CO_2 by 2042. Whatever the estimate we obtain, it can practically reflect the actual CO_2 emission. This is an important warning signal, especially with regard to climate change and global warming. The results of this study are very important for the governments of OECD countries, especially when it comes to medium and long-term planning. Since global warming affects the world on a large scale, the study results can be applied to every country. The contribution of the study is to save human lives by controlling CO_2 emission.

Recommendations

This study presents a CO_2 emission prediction model based on a wealth of valuable information compiled from past data. The findings of this research enrich our understanding of CO_2 emission dynamics, aiding in the formulation of reduction policies and effectively monitoring emission trends. The ability to predict CO_2 emissions plays a crucial role in shaping reduction policies and evaluating their effectiveness.

The methodological framework and resulting solutions represent significant contributions to relevant research areas. Exciting opportunities for future research in CO_2 emission tracking are evident, with proposed policy recommendations for OECD countries including emission taxes, carbon taxes, and incentives for sustainable energy. These proposals stand out as effective strategies for reducing greenhouse gas emissions. While laying a valuable foundation for future research on CO_2 emissions, this study also provides practical guidance to policymakers and industries, contributing to the advancement of a sustainable future.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

Acknowledgements or Notes

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Enhancing Connected Vehicle Security: Innovations in Two-Factor Authentication

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Abstract: The automotive sector is undergoing profound changes with the advancement of technology, and connected vehicles represent one of the most notable examples. These vehicles, equipped with internet connectivity and communication capabilities with other devices, are becoming increasingly widespread. Consequently, they accumulate substantial amounts of data concerning drivers and their environments. However, this connectivity also brings about significant security concerns, particularly regarding the privacy and security of the metadata stored in these vehicles. Metadata encompasses diverse information about user activities, habits, location data, and personal preferences, making it an appealing target for potential attackers. Therefore, safeguarding the security of metadata in connected vehicles stands out as a primary concern for manufacturers. This study aims to surpass the two-factor authentication (2FA) systems developed to protect the metadata stored in connected vehicles. The system comprises two components: the Central Security Unit (CSU) and the AutoGuard (AG) mobile application. Integrated with the Remote Keyless Entry System (RKES), CSU initiates the 2FA process when the driver approaches the vehicle. Upon entering the second authentication factor (biometric, pattern, PIN code), successful authentication unlocks the vehicle doors via RKES, while failure prompts notification to the driver. To advance the 2FA system, a Bluetooth Low Energy (BLE)-based communication system has been integrated between CSU and AG. This integration enhances communication between the two, making it more secure and energy efficient. Furthermore, it enables data exchange without the need for a network connection, ensuring a seamless user experience. These innovative communication features transcend the 2FA system by rendering communication between CSU and AG more reliable and flexible. Additionally, by integrating the phone's location into the authentication system, AG functionality can enhance the accuracy of the 2FA system, potentially using the phone's location as an additional authentication factor.

Keywords: Metadata, Two-factor authentication, Connected vehicles, Vehicle security, Metadata, Bluetooth low energy

Introduction

In today's era, the automotive industry is progressively becoming more complex and dynamic. Technological advancements are fundamentally altering the expectations and needs of both drivers and passengers, thereby continuously incentivizing industrial actors to seek innovative solutions. At the core of this transformation lies the integration of digitization and connected devices, epitomized by the "connected vehicle" technology.The concept of connected vehicles represents an evolutionary leap from the traditional notion of automobiles, achieved through the amalgamation of advanced technologies such as inter-vehicle communication, cloud computing, artificial intelligence, and smart sensors. This technology aims to enhance the daily lives of drivers

and passengers by rendering them safer, more efficient, and more enjoyable. Vehicles are no longer mere modes of transportation but have evolved into intelligent devices.

These intelligent systems enable vehicles to perceive their surroundings and gather various data points, encompassing factors like traffic conditions, road status, weather conditions, and the locations of other vehicles. This information is analyzed and utilized in real-time to provide drivers with safer and more efficient driving experiences.However, the adoption and implementation of this innovative technology entail certain challenges. Concerns regarding security, data privacy, infrastructure compatibility, and regulatory compliance may hinder or delay the widespread adoption of connected vehicles. Therefore, it is imperative for industrial stakeholders to collaborate and develop solutions to overcome these challenges.

Connected vehicles represent one of the most significant advancements in today's automotive technology landscape. These vehicles continuously generate a wide range of data through various sensors, cameras, GPS, and other data collection devices. This data encompasses various parameters of the vehicle, including its position, speed, fuel consumption, engine performance, environmental conditions, and passenger behavior. The data accumulated in a vehicle due to connected functionalities typically constitutes metadata. Metadata essentially serves as a summary of information related to other data. For instance, the speed and location of a vehicle constitute fundamental information that forms the metadata of the vehicle. This metadata enables drivers and manufacturers to monitor vehicle performance, enhance safety measures, and plan for future journeys.An important aspect of metadata is its capacity to enhance the data collection and analysis capabilities of vehicles. These data can be utilized to evaluate vehicle performance, identify maintenance requirements, analyze driver behaviors, and even optimize traffic flow. Technologies such as big data analytics, artificial intelligence, and machine learning facilitate in-depth analysis of this metadata, enabling drivers and industrial stakeholders to make better decisions.

The privacy of metadata has become an increasingly significant concern in today's data-driven world. Smart vehicles like connected vehicles continuously generate a vast array of data through various sensors and communication technologies. This data encompasses various parameters of the vehicles, including their location, speed, travel route, fuel consumption, engine performance, and driver behaviors. However, there is a significant concern regarding the collection and utilization of this data, specifically pertaining to data privacy and security. The large volume of data collected from vehicles may contain sensitive information about the private lives of drivers and passengers. For example, a vehicle's travel route could disclose a driver's home or workplace address. Similarly, vehicle speed and driver behaviors could lead to inferences about a driver's personal preferences or health status.

Therefore, the privacy of metadata is of critical importance for the safety and privacy of drivers and passengers. Unauthorized access to this data, its malicious use, or exposure to cyberattacks could have serious consequences. For instance, data breaches could result in identity theft, cyber harassment, or compromise physical security. Hence, during the development and implementation of technologies like connected vehicles, data privacy and security should be paramount. Vehicle manufacturers and technology providers should adopt measures such as robust encryption methods, secure data storage infrastructure, and access controls. Additionally, it is important to establish mechanisms that provide users with greater control over the data collection and sharing processes. In conclusion, the privacy of metadata is an important consideration in the development and implementation of smart vehicle technologies like connected vehicles. Preserving data privacy is a fundamental requirement for ensuring the safety and privacy of drivers and passengers. Efforts in this regard are critical for the sustainability of future technological advancements.

This study focuses on the protection of metadata and the vehicles themselves in connected vehicles. The research aims to go beyond a proposed two-factor authentication system designed to safeguard both the vehicle and the hosted metadata. The two-factor authentication system comprises a Central Security Unit (CSU) and a mobile application called AutoGuard (AG). The CSU is integrated with the Remote Keyless Entry System (RKES) of the vehicle. RKES is one of the security and access control systems used in modern automobiles. This system enables the vehicle owner to lock and unlock the vehicle from a certain distance without the need for a physical key. RKES typically operates using a set of technological features integrated into a key card or key fob (Analog Devices, n.d.). At its essence, RKES is comprised of an assortment of sensors and communication modules responsible for managing the vehicle's doors and locks. These sensors are designed to detect the presence of the key within a specified proximity to the vehicle. Utilizing wireless technologies such as RFID (Radio-Frequency Identification) or similar protocols, the key establishes communication with the system (Shafiullah et al., 2022b).

RKES provides drivers with both convenience and security, enabling them to interact with their vehicle without the need for a physical key. Furthermore, by allowing operations to be executed without direct physical contact with the key, RKES helps mitigate the risk of car theft (Kaspin, 2023b). This system is progressively emerging as a significant element of contemporary automotive technology. The initiation of the 2FA process takes place as the remote-control key approaches the vehicle, triggering the CSU, which subsequently activates the second authentication factor. AG prompts the driver to input a valid security method, such as biometric data, pattern recognition, or a PIN code. Upon successful second authentication, AG grants authorization to the CSU, facilitating the unlocking of the vehicle doors by the RKES. In instances where the 2FA process fails, the CSU promptly notifies the driver through the AG interface. Therefore, the primary objective of this system is to safeguard the metadata stored in authorized users' vehicles and the vehicles themselves from unauthorized intruders (Karacali et al., 2023). Expanding on this concept, the 2FA process functions as a robust security protocol triggered by the proximity of the remote-control key to the vehicle. This unique methodology strengthens security measures by implementing a dual-layer verification system. Upon activation by the remote-control key, the sophisticated CSU seamlessly integrates with the vehicle's RKES, coordinating a synchronized authentication process.

The AG mobile application, an essential element of this security framework, serves as the conduit for the second authentication factor. It engages the driver, requesting the input of a valid security method, which may include biometric data for heightened personal identification, pattern recognition for a custom user-defined pattern, or a PIN code for an additional numerical layer of security. This multi-faceted approach ensures a robust defense against unauthorized access, necessitating not only possession of the remote-control key but also a personalized and verified security input from the authorized driver (Karacali et al., 2023). Following the successful conclusion of the second authentication, AG provides the requisite authorization to the CSU. This crucial interaction facilitates the RKES in unlocking the vehicle doors, seamlessly merging the security and access control functionalities. In the unfortunate event of an unsuccessful 2FA process, the CSU, functioning as the guardian of security, promptly alerts the driver through the AG interface. This transparent and immediate notification system ensures that the driver remains informed regarding any potential security breaches (Karacali et al., 2023). In addition to the SMTP-based communication system, a Bluetooth Low Energy (BLE) based communication system has been integrated into the connected vehicles to further enhance communication and provide a comprehensive security solution. This integration aims to make in-vehicle communication more secure and efficient while also improving user experience.

The integrated BLE communication system optimizes data exchange between the CSU and the AG, thereby enhancing security measures. BLE is known for its low energy consumption, ensuring reliable communication while preserving the vehicle's battery life. Moreover, this communication system does not require network connectivity, allowing for data exchange without reliance on external networks. This enables seamless data exchange and enhances user experience without the need for network access. The BLE communication system strengthens the connection between the CSU and AG, making data exchange more reliable and flexible. While ensuring low energy consumption, the system maintains robust security protocols, ensuring communication security and data integrity among users. Additionally, by facilitating effective data exchange in connected vehicles, the BLE communication system enhances security measures. Therefore, the integration of the BLE-based communication system improves communication reliability and efficiency in connected vehicles.

Materials

Raspberry Pi 5

Raspberry Pi 5, developed by the Raspberry Pi Foundation, represents the latest addition to the Raspberry Pi family. This miniature computer is a preferred platform by a wide user base and is utilized in various projects. Raspberry Pi 5 offers high performance, low power consumption, and a cost-effective solution. Looking at the technical specifications, Raspberry Pi 5 features a quad-core 64-bit ARM Cortex-A72 processor running at 1.8 GHz, providing robust processing capabilities (Raspberry Pi 5, 2023). Additionally, the device boasts an impressive memory capacity. Equipped with 8 GB LPDDR4 RAM, Raspberry Pi 5 enables smooth multitasking. In terms of connectivity options, Raspberry Pi 5 offers a diverse range of choices. The device is equipped with a Gigabit Ethernet port, dual-band Wi-Fi (802.11ac), and Bluetooth 5.0. These features facilitate easy connection to wireless networks and reliable data communication. Raspberry Pi 5 is equipped with Bluetooth Low Energy (BLE) capability, enabling the device to provide wireless communication with low power consumption (Raspberry Pi 5, 2023). BLE is an energy-efficient communication protocol, preserving battery life while ensuring reliable connectivity over long distances. The BLE feature of Raspberry Pi 5 makes it

an ideal choice for various IoT (Internet of Things) applications. This feature allows Raspberry Pi 5 to interact with environmental sensors, smart home devices, and other BLE-enabled devices. Furthermore, the BLE feature of Raspberry Pi 5 facilitates seamless integration with mobile applications. This allows users to control Raspberry Pi 5 with other smart devices such as smartphones or tablets, enhancing the device's flexibility of use (Raspberry Pi 5, 2023). In this study, an upgrade in hardware has been made beyond the previous study, replacing the Raspberry Pi 3B+ with the Raspberry Pi 5 platform (Karacali et al., 2023).

Raspbian Operating System

Raspbian, an operating system based on Debian and tailored for Raspberry Pi microcomputers, stands out for its adaptability and efficiency. This technical assessment delves into the core features that make Raspbian a preferred option among Raspberry Pi enthusiasts and developers (Raspberry Pi, 2023). Leveraging Debian's robust foundation known for its resilience and stability, Raspbian provides a dependable framework conducive to customizations catering to the specific needs of Raspberry Pi users (Raspberry Pi, 2023). By building upon Debian's reliability and robustness, Raspbian creates a Linux distribution finely tuned for Raspberry Pi, ensuring a stable platform for tailored adjustments. Engineered with the resource constraints of Raspberry Pi in mind, Raspbian is finely optimized for minimal power consumption and maximal performance, enhancing user experience and system responsiveness. Leveraging Debian's package management system, Raspbian streamlines the installation, updating, and maintenance of software packages, with a vast software repository offering access to a wide array of applications (Raspberry Pi 5, 2023). The preference for Raspbian as the operating system for the CSU stems from its compatibility with the versatile capabilities of the Raspberry Pi 5. As a Debian-based system, Raspbian builds upon a sturdy foundation, guaranteeing reliability, stability, and a flexible environment. The CSU's primary role is to proficiently administer and enforce security protocols in connected vehicles. Raspbian's alignment with the Raspberry Pi's resource constraints optimizes energy efficiency and fortifies the CSU's efficacy. Moreover, the Debian package management system facilitates seamless software updates, swift resolution of security vulnerabilities, and access to an extensive software repository, thereby bolstering the CSU's functionality. In summary, Raspbian emerges as an optimal choice for enhancing the security of connected vehicles, blending reliability, performance, and customization prospects for the CSU.

PyQt

PyQt emerges as a potent toolset for crafting desktop applications using Python as the core programming language. Serving as Python bindings for Qt, a prevalent cross-platform framework for application and UI development, PyQt seamlessly blends Python's simplicity with Qt's extensive capabilities. This amalgamation equips developers with a versatile arsenal for crafting intricate graphical user interfaces. Given PyQt's status as a Python library, it harmonizes seamlessly with the project's reliance on Python as the primary programming language, ensuring a smooth development journey while leveraging Python's readability and adaptability (Python Wiki, n.d.). PyQt was selected as the framework for the CSU application's development owing to its abundant features and user-friendly nature.

RC522 RFID NFC Module

The RFID RC522 module is an affordable and high-performance RFID device operating at 13.56 MHz. Its primary purpose is to enable efficient and extensive utilization of RFID technology (Handson Technology, n.d.). Compliant with ISO/IEC 14443 Type A standards, the RC522 communicates seamlessly with cards adhering to these standards. Capable of both reading and writing RFID tags, the RC522 module finds practical applications in access control systems, asset tracking, and identity authentication scenarios. Utilizing the SPI (Serial Peripheral Interface) protocol, the module ensures rapid and reliable data transmission when communicating with the microcontroller (MACFOS, n.d.). In this study, the RC522 module has been integrated with the Raspberry Pi 5 to serve as a simulation tool for the remote key.

Android Studio

Android Studio serves as the primary integrated development environment (IDE) specifically crafted for Android app development (Google, 2018). This feature-rich toolset, curated by Google, offers an extensive array of resources to streamline the app creation process, blending efficiency, flexibility, and robust

functionality into one cohesive platform. Android Studio's interface is designed with user-friendliness in mind, ensuring seamless navigation and accessibility to a wide range of tools within an organized workspace to bolster developer productivity (Google, 2018).

Within Android Studio, developers benefit from a sophisticated code editor proficient in multiple programming languages, notably Java and Kotlin for Android development. These capabilities empower developers with efficient coding experiences, including features like code completion, syntax highlighting, and real-time error detection (Google, 2018). The AG application's development journey heavily relied on Android Studio as the designated IDE, chosen for its official status and comprehensive toolkit tailored for Android app development (Google, 2018). By utilizing Android Studio, developers ensure smooth integration with the latest Android SDKs, APIs, and platform updates, guaranteeing optimal performance and access to cutting-edge features provided by the Android operating system.

Java was selected as the programming language for the AG application due to its platform independence and widespread adoption in Android development circles (Google, 2018). Aligning with Java's "write once, run anywhere" philosophy, this decision aims to ensure that the AG application delivers a consistent user experience across various devices and operating systems. Leveraging the extensive support and libraries within the Java ecosystem simplifies the development process, enhancing the reliability and scalability of the AG application (Google, 2018).

In essence, the development of the AG application relied on Android Studio as the preferred IDE, harnessing its official endorsement and robust feature set for Android app development. The integration of Java as the programming language underscores the commitment to platform independence and leverages the widespread community support within the Android development realm, culminating in the creation of a powerful and user-friendly AG application poised to deliver consistent experiences across diverse platforms.

Firebase

Firebase, a platform for mobile and web app development developed by Google, offers developers a wide range of cloud-based services to streamline the development process and improve user experience. With the goal of expediting application development and providing efficient application management tools, Firebase provides a comprehensive suite of tools and services to support various stages of the development lifecycle (Firebase, 2019). Central to Firebase is its Realtime Database, which is built on a NoSQL foundation and allows for the real-time synchronization of application data. This feature enables users to receive instant updates, thereby enhancing the overall user experience (Firebase, 2019). Additionally, Firebase Authentication ensures the security of user logins by offering secure authentication methods through different identity providers, including email and social media accounts. In the AG mobile application, Firebase has been employed for the authentication process to verify authorized drivers.

Simple Mail Transfer Protocol (SMTP)

SMTP serves as a communication standard utilized to send electronic mail across different servers. Essentially, SMTP facilitates the transmission of messages between email servers by following a defined set of rules and commands (Lepilkina, 2020). It establishes a connection between two servers to relay email data, terminating the connection once the transmission process concludes. SMTP ensures the proper formatting and accurate interpretation of transmitted data. Control commands are utilized by the sending server to verify the successful delivery of messages. Error codes and messages are employed by SMTP to report any transmission errors encountered. The operational mechanism of SMTP revolves around establishing a connection between sender and recipient servers, with the sending server transmitting email data through a series of commands and receiving responses from the destination server. Various checks are performed by the sending server to guarantee the precise delivery of messages (AWS, n.d.). Despite its widespread usage, SMTP is generally considered insecure due to its reliance on transmitting messages in plain text format between servers, often lacking encryption (AWS, n.d.). To enhance security, additional measures like Transport Layer Security (TLS) are commonly implemented for secure email transmission. In the research, communication between the CSU and AG is facilitated using the SMTP protocol.

Bluetooth Low Energy (BLE)

BLE is a communication protocol that forms a subset within wireless communication technologies. Fundamentally, it prioritizes energy efficiency by providing low power consumption, making it a suitable option for devices powered by batteries. BLE is commonly used to fulfill short-range communication needs, particularly in small-sized devices (Bluetooth, n.d.). Technically, BLE operates within the 2.4 GHz frequency band and supports low data rates tailored to specific application domains, enabling short communication distances (Bluetooth, n.d.). This optimization aims to minimize energy consumption while optimizing communication range and speed. BLE finds applications across various devices such as cellular devices, smart wearable technologies, health monitoring devices, and other smart objects. For data exchange and inter-device interaction, BLE utilizes the Generic Attribute Profile (GATT) protocol (Bluetooth Low Energy | Connectivity, n.d.). This protocol enables BLE devices to define their services, attributes, and relationships, thereby providing a standardized approach for data transfer and communication between devices. One of the significant advantages of BLE is its ability to provide long battery life by operating in low power modes. This ensures that battery-powered devices remain active for extended periods while consuming minimal energy (Mocrii et al., 2018). Additionally, the fast connection establishment process and low latency facilitate quick and efficient communication between devices. BLE based communication system was used between the CSU and the AG.

Method

This section delineates the developmental procedures involved in crafting the 2FA system. The system comprises two primary elements, namely CSU and AG, as depicted in Figure 1.

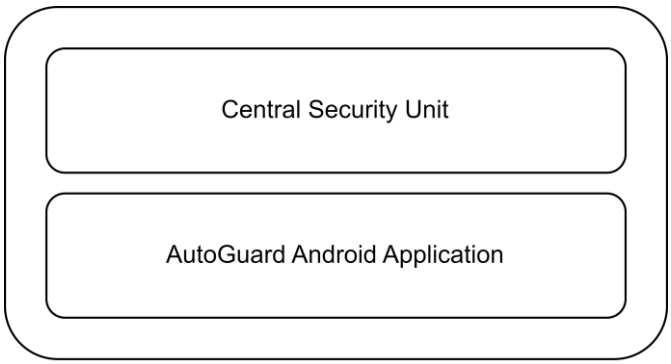

Figure 1. Two-factor authentication system main components

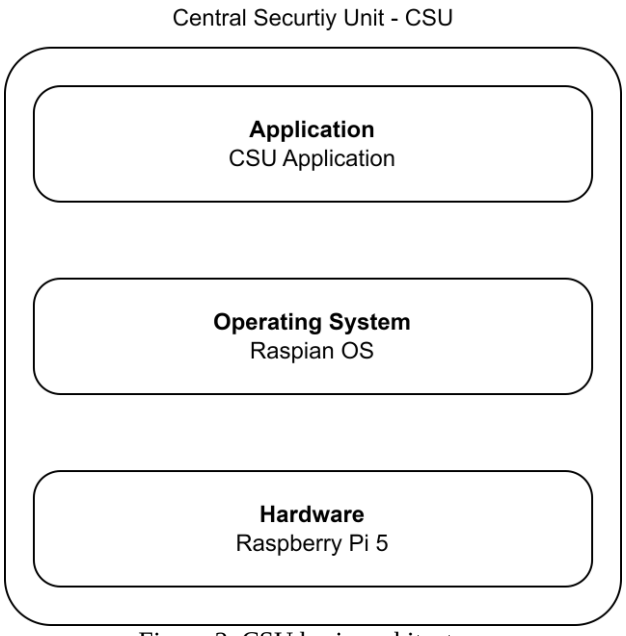

Figure 2. CSU basic architecture

CSU constitutes an embedded unit within the vehicle. Built upon the hardware foundation of the Raspberry Pi 5 platform, CSU operates on the Raspbian OS, initiating its boot process from an SD card. The architectural blueprint of CSU is illustrated in Figure 2. Development of the CSU application leverages PyQt within the Raspbian OS environment. This intricate setup underscores the robust integration of CSU within the vehicle infrastructure, ensuring seamless operation and compatibility with diverse hardware components.

CSU seamlessly integrates into the security framework of connected vehicles, serving as a vital component. The integration process entails a multi-step authentication procedure, starting with the initial verification via a physical key. The RKES system utilizes the physical key for initial authentication, detecting it through RFID or similar wireless technology upon proximity to the vehicle (Karacali et al., 2023). Once the remote key is successfully detected, RKES triggers CSU, initiating the first step of the verification process, as depicted in Figure 3.

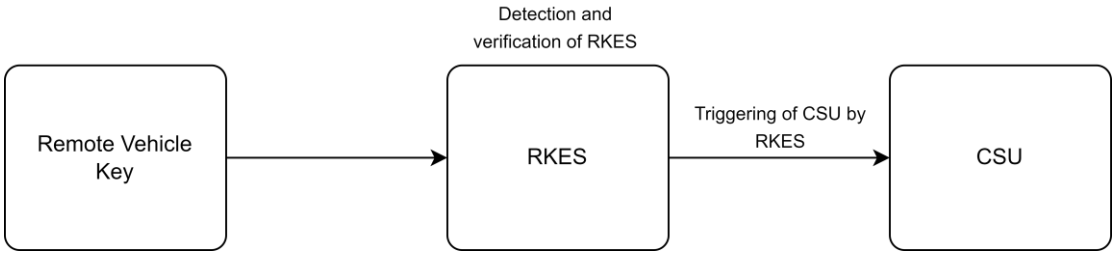

Figure 3. Remote vehicle key detection and triggering CSU

To simulate the process depicted in Figure 3, an RFID card was used instead of a remote key, with the RC522 RFID NFC module serving as the RFID reader integrated into the CSU hardware. This integration enabled smooth communication and accurate interpretation of RFID card signals for authentication initiation. The communication between the RC522 RFID NFC module occurs through the SPI protocol (Karacali et al., 2023). Once the hardware connections are established, the Raspbian operating system activates the SPI Protocol.

The CSU is integrated into a structure that performs the simulation of RKES. This structure involves the use of an RFID card to emulate an input provided to the vehicle's RKES system. By using the RFID card instead of a physical key, it mimics the functionality of a remote key detected by the RKES. Once triggered by the RKES, the CSU reads the RFID card and retrieves the identity information. The obtained identity information is then compared to the pre-defined authorized card identity. If the card's identity is successfully verified, this step is completed, and the first stage of the RKES authentication process is initiated (Karacali et al., 2023). Information regarding the success or failure of the authentication process is transmitted via SMTP and BLE. Therefore, the CSU initially checks internet connection and SMTP server connection to facilitate this communication.

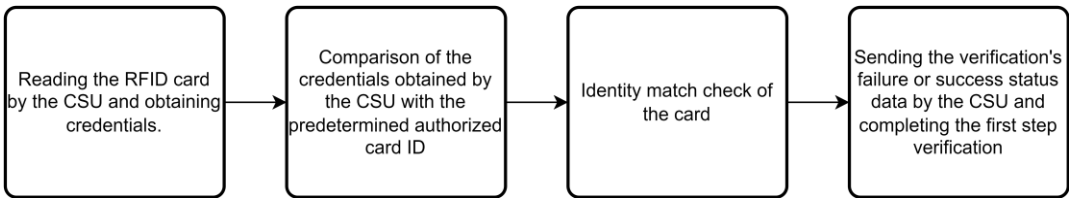

Figure 4. First authentication process block diagram

Following the completion of the initial verification step, the second stage is executed through the AG application. Developed using the Java programming language in Android Studio, the AG application requires authorized drivers to create a profile upon installation. During profile creation, various authentication methods, such as PIN, pattern schema, and biometric data (fingerprint and facial recognition), can be employed for password setting (Karacali et al., 2023). In the background, Firebase is utilized to ensure a secure authentication experience, allowing the vehicle to grant access exclusively to authorized users.

Firebase provides cloud-based services and tools for mobile and web app development. It securely manages user profiles and authentication for the AG app through Firebase Authentication. This service stores email addresses and passwords securely and supports various authentication methods. Firebase uses encryption to protect user credentials during transmission and storage, ensuring data confidentiality and integrity. Additionally, Firebase enables easy integration of biometric authentication, like fingerprint and facial recognition, in the AG app. Leveraging Firebase Authentication, the app ensures enhanced security and user experience with multiple

authentication options. In essence, Firebase strengthens the AG app's authentication system, ensuring secure and efficient user validation through various methods.

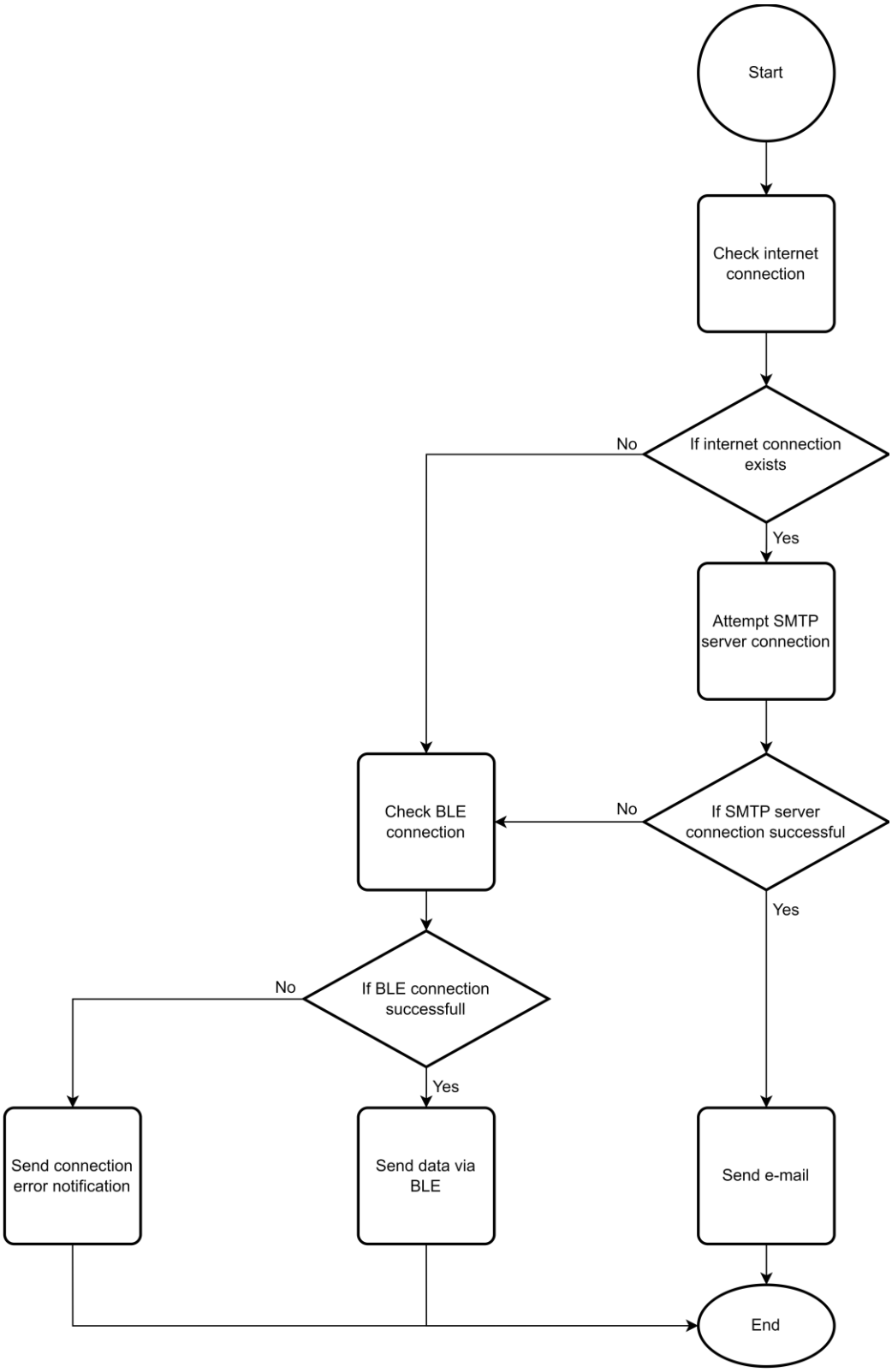

Figure 5. Basic connection control process

Upon successful completion of the profile creation process by the authorized driver, the AG application becomes operational. The registration interface of the AG application is depicted in Figure 6.

Figure 6. AG application registration form

In the case of an Internet connection CSU and AG communicate via SMTP. The AG application utilizes the Internet Message Access Protocol (IMAP) to receive emails sent by CSU. Retrieval of email content is accomplished through the Jsoup application. Subsequently, the extracted HTML content from the read email is parsed for further processing. To prevent application unresponsiveness during email reception, asynchronous programming with Java's CompletableFuture class is employed in the AG app. This ensures a responsive user interface by allowing multiple tasks to be managed simultaneously while waiting for email reception to complete.

In cases where the Internet connection is the culprit, CSU and AG communication is carried out via BLE. The registration procedure, leveraging the NFC capabilities of the phone, entails a multifaceted technical workflow designed to identify and synchronize with the MAC address of our vehicle, represented by the Raspberry Pi platform. This intricate process involves a series of protocol-specific operations to enable seamless communication between Bluetooth-enabled devices by initiating the establishment of an RFCOMM (Radio Frequency Communication) socket.

At its core, the process kicks off with the invocation of the "rfcomm" utility, a fundamental component of the Linux Bluetooth stack, tasked with managing RFCOMM channels. This utility is leveraged to initiate a communication session with the Bluetooth device, facilitating the negotiation of parameters and the establishment of a reliable data link. Subsequently, the registration process entails the transmission of initialization commands and parameters to the Bluetooth device, orchestrated through the RFCOMM channel. This includes configuring the Bluetooth interface of the Raspberry Pi to operate in a discoverable mode, enabling it to be detected and paired with the phone's NFC module. Upon successful establishment of the RFCOMM session and parameter negotiation, the next phase involves the exchange of authentication tokens and encryption keys between the phone and the Raspberry Pi. This step is critical for ensuring the integrity and confidentiality of the data exchanged during the registration process, mitigating potential security risks.

Furthermore, meticulous error handling mechanisms are incorporated throughout the process to detect and mitigate any anomalies or discrepancies encountered during the communication session. This includes robust error detection and correction algorithms to ensure reliable data transmission and seamless registration. In essence, the technical intricacies of the registration process underscore the meticulous orchestration of protocol-specific operations and communication protocols to seamlessly integrate the phone's NFC capabilities with the vehicle's Raspberry Pi platform, thereby facilitating a streamlined and efficient registration experience. In the CSU application, these operations are performed for data transfer over BLE.

In AG Java application BluetoothService module serves as the core component responsible for orchestrating all Bluetooth-related tasks within the system architecture. Primarily, its functionality revolves around the establishment and management of Bluetooth communication channels between the CSU and the paired mobile

device. Upon initialization, the BluetoothService initiates the creation of a Bluetooth socket, a pivotal interface facilitating bidirectional data exchange between the RPi and the mobile device. This socket remains receptive, awaiting signaling cues from the RPi to trigger subsequent actions. Upon receipt of a designated signal, typically denoted as 'True', the service promptly triggers a notification event on the mobile device, prompting user interaction.

Subsequently, user interaction with the notification triggers a seamless redirection to the designated BluetoothPassActivity page, where further actions, typically associated with authentication or data exchange, ensue. Central to the BluetoothService's operation is the establishment of a robust serial communication protocol between the RPi and the mobile device. This protocol ensures reliable and efficient data transmission, crucial for the integrity and responsiveness of the overall system. Additionally, the BluetoothService module incorporates a sophisticated mechanism for monitoring the mobile device's internet connectivity status. This feature enables the system to adapt its data transmission strategy dynamically based on the availability of internet access. In instances where the mobile device lacks internet connectivity, the BluetoothService seamlessly transitions to an alternative data transmission mode, utilizing the send_data function. The send_data function serves as a pivotal component within the BluetoothService, facilitating the transmission of data packets over the established Bluetooth connection. It encompasses a versatile set of functionalities, capable of handling diverse data transmission scenarios, including but not limited to the authentication process.

In essence, the BluetoothService module embodies the intricate interplay between hardware and software components, providing a robust foundation for seamless Bluetooth communication within the system architecture. After completing the verification step, the authorized driver receives a notification on their phone through the AG application. This notification prompts the user to proceed with the verification process by entering the application. Upon entering the AG application, the driver enters the password they have set, which is then authenticated by the application. Following successful verification of the password, the AG application sends a data packet to the CSU indicating the outcome of the verification process. This data packet is received and processed by the CSU. If the verification is successful, the RKES (Remote Keyless Entry System) is activated, allowing the driver to lock or unlock the vehicle. During this process, data communication between the AG application and the CSU is conducted either via SMTP or BLE. SMTP facilitates data transmission via email, while BLE enables wireless communication with low energy consumption. Both communication protocols ensure secure and reliable data transmission. The AG application provides the driver with a user interface displaying the status of the vehicle's lock. This interface allows the driver to see whether the vehicle's lock is open or closed. Figures 7 and 8 illustrate screen captures from the AG application showing the vehicle's lock status, providing the driver with information about the vehicle's security.

Figure 7. AG application vehicle lock status form

Figure 8. AG application vehicle unlock status form

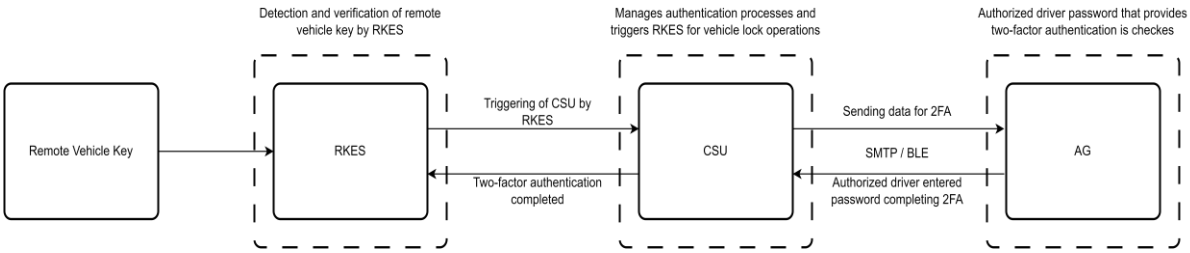

Figure 9. 2FA basic working principle block diagram

Results and Discussion

In the foreseeable future, there is an expected surge in the integration of connected vehicles into the automotive landscape. This surge is propelled by advancements in smart technologies, which are catalyzing the development of an array of connected features within the automotive sector. Internet-connected vehicles hold significant promise in augmenting safety, convenience, and operational efficiency by furnishing drivers with a diverse array of information and services at their fingertips. According to research findings, the sales of connected vehicles are forecasted to witness a substantial growth trajectory, surpassing 80 million units between 2017 and 2030 across key markets such as the United States, Europe, and China, as depicted in Figure 10 (Zaffiro & Marone, 2019).

The rapid increase in the adoption of connected vehicles heralds a significant transformation in the automotive sector. With the advancement of smart technologies, connected vehicles now have the potential to offer drivers a wide range of information and services beyond being mere modes of transportation. Communication between vehicles generates substantial data related to driver habits, environmental conditions, and vehicle performance. Particularly, with vehicles being connected to the internet, this data volume has further escalated.

The widespread adoption of connected vehicles results in a notable increase in the volume of data collected and processed. This data, spanning from driver habits to environmental conditions, underscores the growing importance of data management and security strategies in the automotive industry. This wealth of data plays a crucial role in driving the demand for advanced features such as advanced driver-assistance systems, autonomous vehicles, and service-based mobility, thereby shaping the future of automotive technologies.

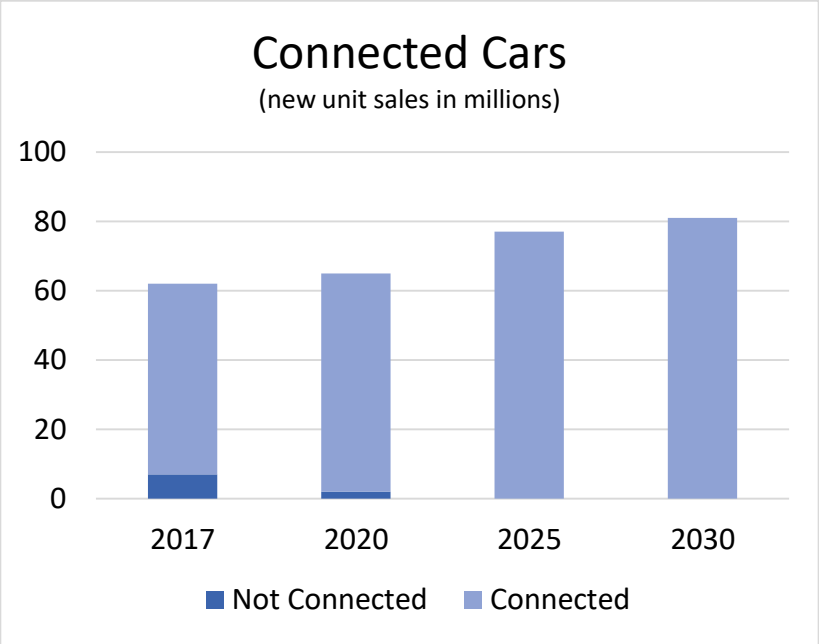

Figure 10. Connected cars sales forecast graphics

In this context, industry stakeholders need to develop strategies to effectively manage and securely utilize the growing data density. Issues such as data privacy, security, and compliance are of critical importance in the development and implementation of data-driven services in the automotive sector. Therefore, industry actors must meticulously work on data security policies and practices, developing strategies aligned with best practices in the field. This will not only ensure the security of existing customers but also support the development of future connected vehicle technologies.

In the contemporary landscape, the newly devised 2FA mechanism has introduced an additional layer of security within the domain of connected automotive systems. This innovative framework encompasses both the CSU and the corresponding mobile application known as AG, with a primary focus directed towards fortifying the protection of metadata. The core objective of this system revolves around bolstering the security infrastructure of connected vehicles, thereby thwarting any potential unauthorized access, courtesy of a robust secondary authentication mechanism coupled with the operational efficiency of a centralized security hub.

At its essence, this security framework is meticulously tailored to safeguard the intricate web of sensitive metadata housed within the interconnected automotive ecosystem. Employing a multifaceted approach, vehicles are fortified through an array of authentication methodologies tailored to the preferences of drivers. Biometric markers, intricate pattern recognition algorithms, and personalized PIN codes constitute the arsenal of protective measures skillfully deployed to deter any unauthorized entry attempts by individuals lacking proper authorization or ownership credentials.

The imperative nature of shielding this metadata cannot be overstated within the dynamic realm of cybersecurity threats, where the exponential surge in data volumes poses an imminent risk of perilous cyber incursions and breaches of individual privacy. As such, the comprehensive 2FA framework adopted by connected vehicles emerges as a formidable bulwark, ensuring the impregnable security of both drivers' and vehicle owners' data, thereby serving as a pivotal catalyst in fortifying the broader cybersecurity paradigm. The integration of BLE communication in the developed two-factor authentication (2FA) system for connected vehicles has yielded significant benefits and outcomes. By incorporating BLE into the communication framework between the CSU and the AG mobile application, several advantages have been realized.

Firstly, BLE-based communication has enhanced the security of data exchange between CSU and AG. BLE offers encryption capabilities, ensuring that transmitted data remains secure and protected from potential eavesdropping or interception by unauthorized parties. This heightened security is paramount in safeguarding the sensitive metadata stored in connected vehicles, addressing concerns regarding data privacy and integrity. Secondly, the integration of BLE has resulted in improved energy efficiency within the 2FA system. BLE technology is inherently designed to operate with minimal power consumption, optimizing energy usage and extending the battery life of devices such as smartphones used in conjunction with the AG application. This

energy-efficient communication mechanism ensures that the 2FA system remains operational for extended periods without significantly draining device batteries.

Moreover, BLE-based communication facilitates seamless data exchange between CSU and AG without the reliance on a network connection. This capability is particularly advantageous in scenarios where network connectivity may be limited or unavailable, such as remote or off-grid locations. By enabling offline communication, the 2FA system ensures uninterrupted functionality and maintains a seamless user experience regardless of network availability. Additionally, the integration of BLE communication enhances the reliability and flexibility of communication between CSU and AG. BLE technology offers robust connectivity even in congested or interference-prone environments, ensuring consistent and reliable data transmission between the two components of the 2FA system. This reliability enhances the overall performance and effectiveness of the system, contributing to its trustworthiness and usability.

In conclusion, the incorporation of BLE communication into the developed 2FA system for connected vehicles has yielded substantial benefits, including enhanced security, improved energy efficiency, offline functionality, and increased reliability. These advantages underscore the effectiveness and viability of BLE as a communication protocol in securing and managing metadata within connected automotive environments.

The 2FA system offers a reliable security solution not just for individuals but also for safeguarding corporate and commercial connected vehicles. Particularly useful in shared vehicle scenarios like rental fleets or corporate usage, it ensures only authorized drivers access vehicles, enhancing security during leasing and corporate usage. This benefits companies and rental firms by managing vehicles securely. Overall, the 2FA system enhances metadata security in connected vehicles, providing a robust defense against cyber threats and safeguarding valuable information and digital assets.

Conclusion

In the discussion section, a thorough assessment of the system's performance and potential improvements is provided. While the presented 2FA system effectively safeguards metadata in connected vehicles, future enhancements are essential to consider. Integrating AG features with location data emerges as a promising avenue for bolstering security. This integration could leverage real-time location information from the driver's phone to enhance authentication accuracy based on proximity. By utilizing location data, the system can more effectively discern the driver's presence near the vehicle, enhancing security measures. Furthermore, exploring novel authentication methods and encryption algorithms can further strengthen the system's resilience against potential attacks. These enhancements can elevate the security of connected vehicles and lay the groundwork for future improvements.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Review of Data Imputation Techniques in Time Series Data: Comparative Analysis

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Abstract: This review paper offers a thorough analysis of different data imputation methods that can be applied to time series data. Time series data is an essential element in various analytical and predictive models used in different domains. Time series data frequently experiences missing values as a result of diverse factors, such as system errors, human influences, or inherent gaps in data collection. The presence of these missing values significantly undermines the precision and dependability of models constructed using this data. This paper classifies imputation methods into basic and advanced techniques, providing a comprehensive examination of each. The simplicity and effectiveness of basic techniques, such as mean or median imputation and linear interpolation, are discussed in specific scenarios. The study investigates the efficacy of advanced techniques, such as ARIMA statistical models, K-Nearest Neighbors machine learning approaches, and Long Short-Term Memory networks deep learning techniques, in managing intricate and extensive time series datasets. The paper emphasizes a comparative approach, assessing each method's complexity, accuracy, and computational demands. The paper concludes by emphasizing the need for continuous innovation in imputation techniques to meet the growing complexity of time series data across various domains. It advocates for a collaborative approach that combines domain expertise with advanced data science methods to develop tailored, efficient, and accurate imputation strategies.

Keywords: Time Series, Data Imputation, Machine Learning, Deep Learning, Computational complexity

Introduction

Time series data, which consists of sequential measurements taken over time, is a crucial component of analysis in diverse scientific and commercial domains. The data sets, observed at consecutive time intervals, are essential for uncovering patterns, trends and predicting future events (Box et al., 2015). Time series data, which is frequently encountered in finance (Alshehadeh et al., 2023), meteorology (Sun et al., 2024), and healthcare (Morid et al., 2023), plays a vital role in making well-informed decisions and predictions. Nevertheless, the dependability and precision of conclusions drawn from such data are directly dependent on its quality. Ensuring high data quality in time series is crucial, as any inaccuracies or missing values can result in misleading analyses

and incorrect predictions. Missing values in time series data can frequently compromise its integrity. These missing values can occur due to various factors, such as equipment malfunction, human error, or gaps in data collection (Donders et al., 2006). The absence of these values has a significant effect, especially in time-critical fields such as stock market analysis or weather forecasting, where accuracy is crucial. Hence, it is imperative to guarantee optimal data quality by employing efficient data imputation techniques for conducting time series analysis.

Data imputation is the process of substituting missing data with alternative values. The application of imputation in time series data is particularly challenging and complex due to the sequential nature of the data. Time series data differs from cross-sectional data in that it exhibits temporal dependencies, indicating that each data point may be influenced by its preceding and subsequent points in time (Hyndman & Athanasopoulos, 2018). Specialized imputation techniques are necessary for this dependency to properly acknowledge and utilize these temporal relationships.

The range of imputation techniques available for time series data is extensive, encompassing both basic methods and advanced algorithms. Common techniques for handling missing values include mean, median, and mode imputation. More advanced methods, such as linear interpolation, involve filling in missing values by estimating them based on the linear patterns observed in neighboring data points. Advanced methodologies encompass statistical models such as Autoregressive Integrated Moving Average (ARIMA), as well as machine learning techniques, including but not limited to K-Nearest Neighbors (KNN) and deep learning algorithms such as Long Short-Term Memory (LSTM) networks (Fang & Wang, 2020; Jaradat et al., 2021). These advanced techniques utilize the inherent patterns and relationships within the data, providing more precise and contextually appropriate imputation. The importance of these imputation techniques has increased significantly due to the expanding volume and complexity of time series data. This review paper seeks to clarify the different imputation methods, their suitability, and efficacy in the domain of time series data. The paper aims to present a comprehensive perspective on current methodologies and their effects on the quality and dependability of time series analysis by examining a range of techniques, from basic to advanced. Furthermore, it will explore practical applications in various industries, showcasing the importance of effective data imputation in extracting precise insights from time series data.

In summary, data imputation in time series is not merely a corrective measure for missing data but a crucial aspect that ensures the integrity and usability of the data. The ongoing developments in this field highlight the growing importance of sophisticated imputation techniques in the face of increasingly complex and large-scale time series datasets.

The remainder of the paper is structured as follows. Understanding missing data in time series is described in Section II. Section III summarizes the different categories of data imputation in time series data. Section IV provides a comparative analysis metrics for data imputation in time series. Section V concludes the paper.

Understanding Missing Data in Time Series

In the field of time series analysis, dealing with missing data is an unavoidable and substantial obstacle that analysts and researchers must address. Comprehending the characteristics of missing data, its influence on the analysis of time series, and the inherent difficulties in dealing with it is essential for effective data imputation and subsequent analysis. Missing data in time series can be classified into three main types (Donders et al., 2006, Ahn et al., 2022): Missing Completely at Random (MCAR), Missing at Random (MAR), and Not Missing at Random (NMAR).

- *Missing Completely at Random (MCAR)*: This occurs when the probability of missing data is the same for all observations, implying that the missingness is independent of both observed and unobserved data. For example, if temperature readings from a weather station are missing due to random equipment failures, the missingness is likely MCAR.

- *Missing at Random (MAR)*: In this scenario, the missingness is related to the observed data but not the missing data itself. For instance, in a financial time series, if stock prices are recorded only on days when the market is up, the missing data on down days is MAR, as it depends on the market's performance (an observed variable).

- *Not Missing at Random (NMAR)*: Here, the missingness is related to the unobserved data. For example, if patients in a clinical study tend to drop out as their health deteriorates, the missing data (dropout) is related to the unobserved health status of the patient.

Understanding these categories is crucial for choosing the suitable imputation technique, as each category of missing data necessitates a distinct approach for precise imputation. Missing data can significantly distort the analysis of time series. It can lead to biased estimates, reduced statistical power, and it can make the data analysis more complex and less accurate. The impact is more pronounced in time series data due to its sequential nature and the temporal correlations present. For instance, missing data in a time series can disrupt the continuity needed for trend analysis and forecasting, leading to misleading conclusions.Imputing missing data in time series presents unique challenges (Moritz & Bartz-Beielstein, 2017; Ribeiro & Castro, 2021):

- *Maintaining Temporal Structure*: Time series data is defined by its sequential order and temporal dependencies. Imputation methods must preserve these characteristics to maintain the integrity of the data.

- Handling Seasonality and Trends: Time series often exhibit seasonality and trends. Imputation methods need to account for these patterns, which requires sophisticated techniques, especially when large portions of data are missing.

- Varying Missing Data Patterns: The pattern of missingness can vary greatly in time series data. Methods that work well for random, sporadic missingness might not be effective for systematic missingness, such as data missing at regular intervals.

- Computational Complexity: Some of the more effective methods for imputing missing time series data, like state-space models or multiple imputation, can be computationally intensive, especially for large datasets.

Imputation Techniques in Time Series Data

Imputation techniques in time series data can be broadly classified into two types (Morid et al., 2023; Ahn et al., 2022): Basic imputation techniques and advanced imputation techniques as shown in Figure 1.

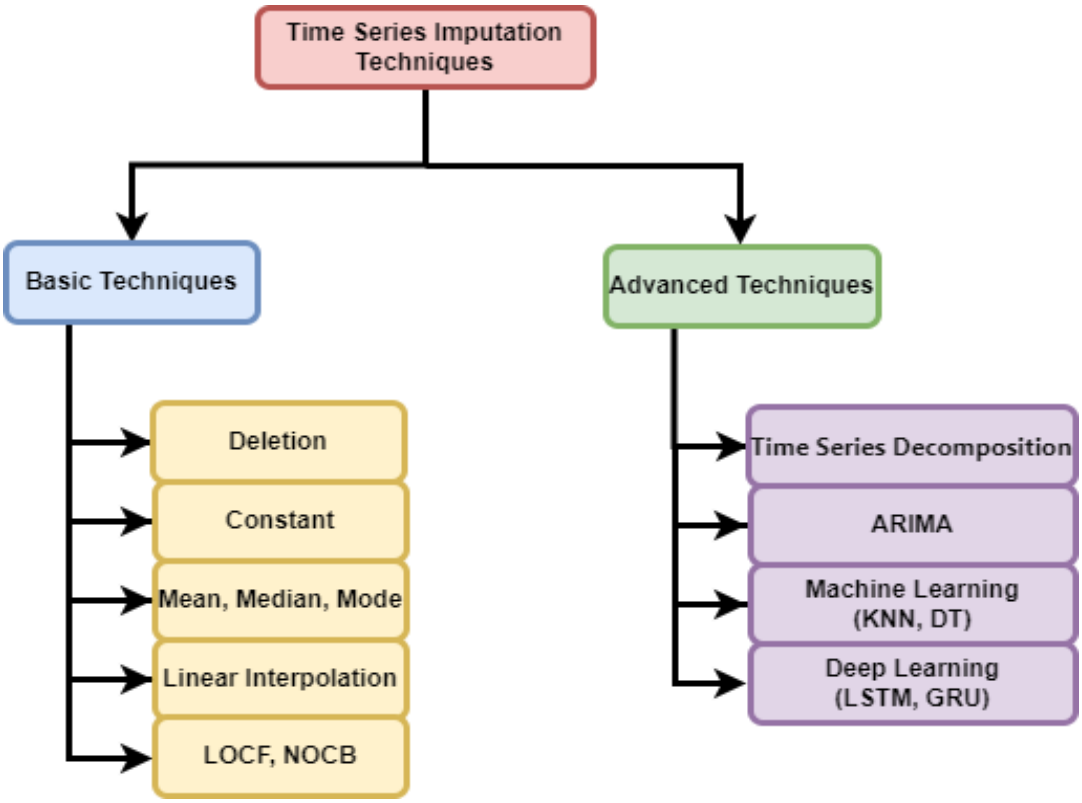

Figure 1. Time series imputation techniques

A) **Basic Imputation Techniques in Time Series Data** (Pratama et al., 2013; John et al., 2019).

- *Deletion*: This basic imputation method involves eliminating any data points in a time series that are missing values. It is particularly useful for large datasets with a small percentage of missing data. The process is straightforward and doesn't require the estimation of missing values. However, deletion can result in a significant loss of data and is not advisable for time series with a considerable amount of missing data. This method assumes that data is Missing Completely at Random (MCAR), which can introduce bias if this assumption is incorrect. Furthermore, deletion reduces the overall size of the dataset, potentially impacting the model's statistical power.

- *Constant Imputation*: This technique substitutes missing values in the data with a fixed constant. This constant might be a generic number such as zero, or a value that holds particular relevance in the analysis context. Advantages include its simplicity and the preservation of the original dataset size. However, it may lead to biased results and fails to consider the dynamics of the time series. When building models, using constant imputation can alter the natural pattern of the time series, potentially resulting in inaccurate outcomes in further analyses.

- *Mean, Median, and Mode Imputation*: This approach replaces missing values with the mean, median, or mode of the existing data. It is straightforward to apply and offers an improvement over constant imputation by utilizing information from the dataset. Nonetheless, these methods can be deceptive if the data is not MCAR and do not consider the specific dynamics of time series. In terms of model building, although these methods are an advancement over constant imputation, they can still result in skewed models if the assumption of MCAR for the missing data is not met.

- *Linear Interpolation*: This technique estimates missing values by creating a straight line between two neighboring known values and using this line for interpolation. It is advantageous as it considers the sequence of the data and is apt for datasets with linear trends. However, it is not appropriate for non-linear time series as it presumes that the data points between known values alter at a consistent rate. Regarding model building, while linear interpolation can be useful for linear time series, it may result in considerable bias when applied to non-linear series.

- *Last Observation Carried Forward (LOCF) and Next Observation Carried Backward (NOCB)*: In LOCF missing values are imputed using the last observed value. While in NOCB the next available observation is used to fill the missing value. These methods are straightforward and help to maintain the chronological integrity of the data. However, they can create lagged effects and are not suitable for time series with significant variability or trending behaviors. In terms of model building, while LOCF and NOCB maintain the data's time sequence, they might not accurately represent the true nature of the data, particularly in fluctuating time series.

B) **Advanced Imputation Techniques in Time Series Data** (Morid et al., 2023, Ribeiro & Castro, 2021).

- *Time Series Decomposition*: This method divides the time series into its constituent parts: trend, seasonal, and residual components, allowing for separate imputation of missing values in each. It is beneficial as it addresses the inherent patterns within the data, particularly useful for time series with seasonal variations. However, it is more intricate and relies on clearly identifiable trends and seasonality. Regarding its impact on model building, decomposition can notably enhance the precision of models in time series that exhibit seasonal and trend patterns, but it may not perform as well with data that is irregular or lacks seasonal characteristics.

- *ARIMA-based Imputation*: In this approach, missing values are predicted using the Autoregressive Integrated Moving Average (ARIMA) model, which relies on the existing data points. This technique capitalizes on the autocorrelations present in the data, making it ideal for stationary time series. However, it is a sophisticated method and necessitates that the time series be stationary. In terms of its effect on model building, while ARIMA-based imputation can improve accuracy in suitable situations, its effectiveness is constrained by the requirement for the data to be stationary.

- *Machine Learning Approaches*: This category includes techniques like K-Nearest Neighbors (KNN) and Decision Trees (DT), which predict missing values by identifying similar patterns or applying decision rules extracted from the dataset. These methods are adept at recognizing intricate patterns and are effective for

handling non-linear data. However, they demand a sizeable dataset and are computationally demanding. Regarding their influence on model building, these approaches are versatile and potent, yet they run the risk of overfitting the data and necessitate significant computational power.

Table 1. Summarizes the pros, cons and the impact on model building for all imputation techniques.

	Pros	*Cons*	*Impact on Model Building*
Deletion	- Simple and easy to implement. - No need to estimate missing values.	- Can lead to significant data loss - Not suitable for time series with substantial missing data. -Risks bias as it assumes the data is MCAR.	- It can lead to biased models if the assumption of MCAR is violated. - It also reduces the dataset size, which can affect the statistical power of the model.
Constant	- Simple and easy to implement. - Maintains the dataset size	- Can introduce bias -Doesn't take into account the time series dynamics	- Can distort the inherent structure of the time series data, leading to misleading results in subsequent analysis.
Mean, Median, Mode	- Easy to implement -Better than constant imputation as they use information from the data	- Can be misleading if the data is not MCAR - Does not account for time series dynamics.	-While these methods are better than constant imputation, they can still lead to biased models if the missing data is not MCAR.
Linear interpolation	- Takes into account the order of the data - Suitable for data with linear trends	- Not suitable for non-linear time series - Assumes that the data points between known values change at a constant rate.	- Can be effective for time series with linear trends, but it can introduce significant bias in non-linear series.
LOCF, NOCB	- Simple to implement - Maintains the data's temporal structure	- Can introduce lagged effects. - Inappropriate for time series with high variability or trends.	- Both LOCF and NOCB can preserve the time sequence but may not accurately reflect the underlying data process, especially in volatile time series.
Time Series Decomposition	- Accounts for underlying patterns in the data. - Effective for seasonal time series.	- More complex; requires a well-defined trend and seasonality.	- Can significantly improve model accuracy in seasonal and trended time series but may be less effective in irregular or non-seasonal data.
ARIMA	- Utilizes the autocorrelations in the data - Suitable for stationary time series.	- Complex - Requires the time series to be stationary.	-ARIMA-based imputation can enhance model accuracy in appropriate contexts but is limited by its assumptions about stationarity.
Machine Learning (KNN, DT)	-Can capture complex patterns. -Suitable for non-linear data.	-Requires a large dataset. -Computationally intensive.	-These techniques are powerful and flexible but may overfit the data. -Require substantial computational resources.
Deep Learning (LSTM, GRU)	-Highly effective in capturing long-term dependencies; -Suitable for complex and large datasets.	-Computationally expensive. -Requires expertise to tune and interpret.	-These methods can significantly improve model performance, especially in complex time series, but are resource-intensive and require careful tuning.

- *Deep Learning Methods*: Utilizing advanced neural networks like Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) (Park et al., 2023), these methods are ideal for modeling sequences that exhibit long-term dependencies. They are particularly adept at identifying long-range patterns and work well with complex, large datasets. However, these methods are resource-heavy and necessitate specialized knowledge for effective tuning and interpretation. In terms of their impact on model building, while they can greatly enhance the performance of models, especially in intricate time series, they demand considerable resources and meticulous calibration

Comparative Analysis of Imputation Techniques

When comparing basic and advanced imputation techniques, several key factors emerge (Jadhav et al., 2019, Hamzah et al., 2021):

1. *Complexity vs. Simplicity*: Basic techniques like mean, median, mode imputation, and LOCF are simple to implement but often fail to capture the complexities of time series data. In contrast, advanced techniques like ARIMA, machine learning approaches, and deep learning methods are more complex but can handle intricate patterns in data more effectively.

2. *Applicability to Data Structure*: Basic techniques are generally more suited to datasets where the missing data is random and does not form a significant portion of the dataset. Advanced techniques are preferred in scenarios where the data exhibits strong temporal dependencies, non-linear patterns, or seasonality.

3. *Accuracy and Bias*: Basic methods can introduce bias, particularly if the missing data is not random. Advanced techniques, with their sophisticated algorithms, tend to provide more accurate imputations but at the cost of increased complexity and the risk of overfitting.

4. *Computational Resources*: Advanced techniques, especially deep learning methods, require substantial computational resources and expertise, which may not be feasible in all scenarios. Basic methods are computationally inexpensive and easier to implement.

5. *Flexibility and Adaptability*: Advanced techniques are more adaptable to different types of data and missingness patterns. They can be tailored to the specific characteristics of the dataset, whereas basic techniques offer limited flexibility.

6. *Impact on Model Building*: The choice of imputation technique has a direct impact on the subsequent model building. Basic techniques might be sufficient for simple models and analyses, but advanced techniques are often necessary for complex, high-stakes analyses where accuracy is paramount.

Selecting between fundamental and sophisticated imputation methods for time series data hinges on several considerations. These include the characteristics of the missing data, dataset complexity, the level of accuracy sought in the imputation, available computational power, and the particular demands of the ensuing analysis. Basic methods are straightforward and user-friendly, whereas advanced techniques yield higher precision and are more apt for intricate datasets. Nonetheless, the latter demand greater computational effort and expertise. The optimal strategy typically involves striking a balance among these elements, customized to the unique requirements and limitations of the specific project.

Conclusion

This review has comprehensively explored the diverse landscape of data imputation techniques in time series data, offering insights into both basic and advanced methodologies, their applications, and a comparative analysis of their effectiveness. The journey from simple imputation methods like mean, median, mode, and deletion to more sophisticated techniques such as ARIMA modeling, machine learning approaches, and deep learning methods like LSTMs and GRUs, reflects the evolving complexity and growing needs of time series analysis in a data-driven world.

A key takeaway from this review is the critical importance of understanding the nature of the missing data and the specific requirements of the time series dataset. The choice between basic and advanced imputation methods should not be made lightly; it requires careful consideration of the dataset's characteristics, the pattern of

missingness, and the ultimate goal of the analysis. Basic methods, while easier to implement and less resource-intensive, may fall short in datasets where the missing data is not random or where complex temporal dynamics are at play. In contrast, advanced techniques, though more accurate and capable of handling intricate patterns, come with the cost of increased computational complexity and the need for specialized expertise.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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ChatGPT and High School Students' Eating Habits: Benefits, Risks, and Insights from a Cross-Sectional Study

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Abstract: This study investigated the eating behavior of high school students and the impact of ChatGPT on it, based on a survey of 315 adolescents aged 15-19 years in the district of Haskovo, Bulgaria. Survey results highlight significant concerns among participants related to body image, with 18.1% expressing dissatisfaction and 24.8% aspiring to achieve a thinner physique. Anxious eating patterns, such as vomiting after meals and using laxatives, were reported in 10.5% of respondents. The following factors associated with body image dissatisfaction were identified referring to eating disorders factors, fear of weight gain, alterations in eating habits, and emotional distress. The study revealed that 31.4% of participants were used to getting information on healthy eating from the Internet, including ChatGPT, while only 10.5% were used to consulting their general practitioner (GP). While ChatGPT certainly demonstrates its value by delivering personalized nutritional guidance and fostering a positive body image through respectful language, caution is essential due to potential risks. Concerns include the possibility of misinformation, as users might solely rely on ChatGPT without cross-referencing information from reliable sources. Unintentional contributions to unrealistic beauty standards and a lack of content personalization are additional considerations. In conclusion, ChatGPT can serve as a reliable tool to guide high school students to a healthier lifestyle. However, reasonable usage is very important. Stakeholders in education should encourage critical thinking, advocate for fact-checking, and promote a balanced approach to leverage both the benefits and potential risks associated with AI-generated content on health and nutrition.

Keywords: ChatGPT, Artificial Intelligence, Eating behavior, Eating disorders.

Introduction

Adolescence is a critical phase in human development, characterized by rapid changes across physical, cognitive, and psychosocial domains. It is a time when individuals experience significant transformations in their bodies, minds and social interactions, shaping their identities and influencing how they perceive and interact with the world. During this period, adolescents undergo profound emotional and cognitive growth, which greatly impacts their ability to regulate emotions, process thoughts, make decisions, and navigate social relationships (World Health Organization, 2021). One critical aspect of this developmental journey is the acceptance of one's own appearance. This process of self-acceptance not only affects adolescents' self-esteem and overall well-being but also plays a crucial role in shaping their eating habits and levels of physical activity (Kos et al., 2020).

In today's rapidly changing world, characterized by constantly evolving lifestyle trends, adolescents are frequently exposed to a flood of new and sometimes conflicting information regarding health and well-being. With easy access to social media, internet forums, and peer networks, young people are frequently exposed to a plethora of lifestyle choices, often without fully understanding the implications of their decisions. The inherent inclination towards risk-taking and experimentation, typical of adolescence, can lead teenagers to adopt certain behaviors without fully considering the potential consequences (Pender et al., 2015; Yang et al., 2019). Unfortunately, these behaviors, including unhealthy eating patterns and sedentary lifestyles, can persist into adulthood, laying the groundwork for long-term health issues (Liao et al., 2019). Research indicates a strong correlation between behaviors established during adolescence and various health problems in adulthood, underscoring the importance of early intervention and prevention strategies (Liao et al., 2019).

Given the malleability of adolescent behaviors and attitudes, promoting a healthy lifestyle during this formative period is of paramount importance. Unlike adults, who may be resistant to change due to entrenched habits, adolescents are more open to adopting new behaviors and habits (Kos et al., 2020). By instilling healthy habits early on, we can empower young people to make informed choices that will benefit their long-term health and well-being.

Recent studies conducted in Bulgaria have shed light on the eating behaviors of high school students, revealing concerning trends among this demographic. Despite the majority of students maintaining a normal body weight, a significant portion of them exhibited unhealthy eating patterns and engaged in insufficient physical activity (Merdzanova et al., 2019). Moreover, a noteworthy percentage of high school students expressed a desire to modify their diets in pursuit of improved attractiveness, often turning to various sources, including the internet, for guidance (Andonova et al., 2022). Weight loss diets and the fundamentals of healthy eating emerged as particularly popular topics of interest among these students, with internet platforms such as social media, blogs, and vlogs serving as primary sources of information (Andonova et al., 2022).

In today's digital age, the internet has become a ubiquitous source of information on various aspects of lifestyle and well-being. However, the proliferation of misinformation and unreliable sources poses a significant challenge. Recognizing this need for accurate and trustworthy guidance, innovative solutions such as chatbots have emerged to provide personalized advice and support. Leveraging advanced language processing and machine learning algorithms, chatbots like ChatGPT offer a convenient and accessible platform for individuals seeking reliable information and guidance on health-related matters (Sallam, 2023). This study aims to investigate the eating behavior of high school students and the impact of ChatGPT on it, based on a survey of 315 adolescents aged 15-19 years in the district of Haskovo, Bulgaria.

Materials and Methods

Study Design

The study design is cross-sectional, based on an online survey conducted among 315 adolescents aged 15-19 in the Haskovo region, Bulgaria. A convenient sampling technique was used to collect the data from the students. A link was sent to them via their e-mails. The number returned and validly completed questionnaires was 315.

Questionnaire

A self-administered questionnaire was used to to assess the perception of body image, eating behaviors, and the impact of ChatGPT on the eating behaviors of high school students. The questionnaire consisted of a total of 30 questions related to the perception of body image and eating behaviors, along with 1 question concerning sources of information on healthy eating habits. For 25 out of the 30 questions, responses were ranked on a 4-point Likert scale regarding the frequency of harmful eating habits among students and dissatisfaction with body image. The survey also included questions related to demographic characteristics such as gender and age.

Data Collection

The study was conducted from October 2023 to November 2023 using the Google Forms application for response collection. A total of 315 adolescents aged 15-19 participated in the survey, with 56.2% (n=177) being female. The average age of the surveyed individuals was 17.41±0.871 years.

Data Analysis

The analysis of the data relied on descriptive statistics, providing a comprehensive understanding of the dataset. To test hypotheses and explore correlations, non-parametric tests were employed, along with the Spearman correlation method. Central tendencies, indicative of the dataset's distribution, were illustrated using both the mean (M) and the standard deviation (SD). Moreover, a significance level of $P < 0.05$ was established to evaluate the significance of the null hypothesis, ensuring a rigorous and reliable analysis approach. Data processing was performed using SPSS 23 and MS Excel 2016 software.

Results

The results revealed that a significant part of the students (62.9%; n=198), responded positively to the question of whether they are satisfied with their body shape. However, 30.5% (n=96) indicated that they are not always satisfied, while 6.7% (n=21) explicitly stated that they are not satisfied with their body image. A moderate to significant correlation was found between the responses to this question and the following three questions: "Do you feel dissatisfied when you see your body in the mirror?" (r_s= - 0.359, P= 0.000), "Do you strongly desire to be thinner?" (r_s= - 0.359, P= 0.000), and "Do you feel fat even though you are not overweight?" (r_s= - 0.461, P= 0.000). The distribution of these responses is depicted in Figure 1.

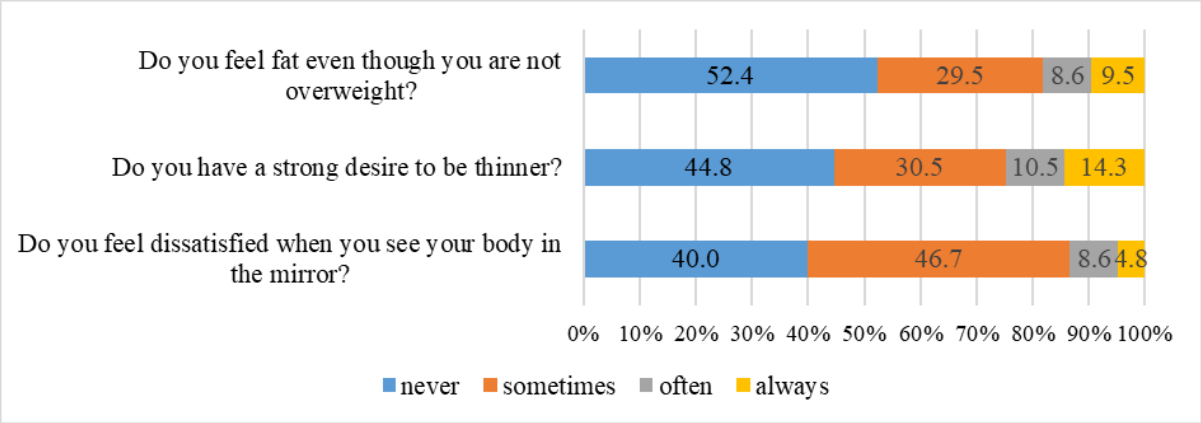

Figure 1. Body image satisfaction

A significant part of students, even if they are not overweight, are very afraid of gaining weight 39.0% (n=123). Almost a quarter (24.8%; n=78) wished to be thinner, with 18.1% (n=57) aiming to diet, while 33.3% (n=105) stated that their weight greatly affects their mood and self-esteem. A significant proportion of respondents noted that they exercised intensely to burn calories 38.1% (n=120).

The study identified harmful behavior patterns among students. Approximately one in ten students takes medication to reduce appetite (9.5%; n=30) and/or laxatives/diuretics to avoid gaining weight (10.5%; n=33). Similarly, approximately one out of every ten students reported frequently or consistently inducing vomiting after meals to avoid weight gain (10.5%; n=33). Additionally, nearly one-fifth of the surveyed individuals reported losing control while eating and consuming large amounts of food at once, followed by feelings of guilt (18.1%; n=57). Furthermore, 12.4% (n=39) prefer to eat alone to avoid others seeing how much and what kind of food they consume.

A significant finding from the study reveals that 31.4% (n=99) of participants rely on online resources, and more specifically ChatGPT, to acquire information on healthy eating, while only 10.5% consult a general practitioner (GP). The non-parametric Pearson Chi-Square test revealed a statistically significant difference in responses to this question between genders ($\chi 2 = 34.578$, P=0.000). Girls prefer to receive health information from their GP, health seminars at school, or the internet, while boys prefer to obtain it from their parents, friends, or relatives.

The main topics for which students search for information on the internet are related to how many calories are in each food, which foods have high carbohydrate content, and which foods negatively affect their figure, leading to overweight and/or obesity.

Discussion

The current study revealed that while most surveyed students were content with their body shape, they harbored fears of weight gain, aspired to be thinner, and consistently adhered to diets. Similar results were noted in a prior study conducted in Bulgaria, where 79% (n=88) of respondents had a normal body weight. However, over half of the high school students attempted dietary modifications to enhance their attractiveness and commenced diets in pursuit of greater appeal (Andonova et al., 2022).

Unlike our findings, studies among adolescents in other European countries reveal significantly more negative outcomes concerning normal body weight and students' satisfaction with their body shape. For instance, in Slovakia, overall body dissatisfaction was reported at 24.5% (191/780), with a higher prevalence among girls (104/344, 30.2%) compared to boys (87/436, 20%). The prevalence of overweight boys was 21.1% (92/436), with 28% (35/92) classified as obese. Among girls, 17.7% (61/344) were overweight, with 36.1% (22/61) classified as obese (Štefanová et al., 2020). A comprehensive study among Polish students indicated that every third respondent was either satisfied or very satisfied with their body image, while 28% expressed dissatisfaction. The most prevalent response regarding satisfaction with body image among their respondents was a lack of opinion - 38% (Kos et al., 2020).

Even more negative results were reported in a study conducted in China. Among 1585 junior high school Chinese students, 81.01% expressed dissatisfaction with their body shape. Of these students, 66.37% desired to be thinner, while 14.64% wished to be more obese. Female students exhibited a higher dissatisfaction rate compared to males (Song et al., 2023). Similarly, to our findings, however, students with a normal BMI desired to be thinner. Conversely, half of the overweight/obese students perceived their body shape as normal (Song et al., 2023).

Some research indicates that sociocultural pressures contribute to the internalization of thin and/or muscular/athletic body ideals and foster social comparisons. Failing to conform to socially stereotyped body images results in body dissatisfaction among both men and women (Rodgers et al., 2011; Tylka, 2011). Consequently, body dissatisfaction correlates with disordered eating behaviors (Neumark-Sztainer et al., 2018). Body image concerns and eating pathology are linked to reduced psychosocial functioning and an unhealthy lifestyle in young adults (Neumark-Sztainer et al., 2018; Sharpe et al., 2018). Our study confirms these findings. Students reported using appetite suppressants, as well as laxatives/diuretics, to avoid weight gain or vomiting after meals. Additionally, respondents admitted to overeating and attempting to conceal their eating patterns.

The increase in the internalization of thin/low-fat ideals may be linked to a significant rise in the hours spent browsing the internet. Lithuanian university-aged students were asked to report their time spent on screen-based activities for leisure purposes, excluding time devoted to work or academic study. The findings of the study revealed that greater daily screen time and increased use of social media were associated with higher levels of internalization of thin body ideals, negative body image, poorer well-being, and increased incidence of disordered eating (Baceviciene & Jankauskiene, 2021).

A significant finding from our study reveals that one-third of participants rely on online resources, and more specifically ChatGPT, to acquire information on healthy eating. Similar results were obtained in a previous study conducted in Bulgaria, where Internet posts, social networks, influencers, vloggers, and bloggers emerged as the most popular sources for information on topics like weight loss diets and basic principles of healthy eating (Andonova et al., 2022).

Recent studies on the application of ChatGPT in delivering nutritional information indicate that while it cannot replace the expertise of registered dietitians, it holds promise in addressing common inquiries (Garcia, 2023; Abhari et al., 2019). A comparative study between ChatGPT responses and those from human experts revealed similar accuracy levels (Kirk et al., 2023). Additionally, ChatGPT's capacity to generate personalized meal plans for healthy individuals has shown potential, albeit with some discrepancies in caloric recommendations (Papastratis et al., 2024; Niszczota & Rybicka, 2023).

Regrettably, ChatGPT's reliance on various publicly available databases for nutritional information may raise concerns about the accuracy and reliability of the data provided (Garcia, 2023). Despite these limitations, further development of ChatGPT could improve its effectiveness in offering nutritional guidance, particularly for underserved populations (Sharma et al., 2023). There are also ethical considerations regarding the confidentiality of sensitive health data shared with the system, necessitating data protection measures (Sallam, 2023).

The consensus among experts suggests that ChatGPT cannot fully substitute for human professionals in dietetics and nutrition counseling, emphasizing the importance of human interaction, empathy, and personalized recommendations (Garcia, 2023; Sivasubramanian et al., 2023). Critical thinking and validation are essential when considering responses from the model, highlighting the need for training individuals to assess AI-generated recommendations critically.

Conclusion

ChatGPT serves as a promising tool for guiding high school students towards healthier lifestyles. However, responsible use is very important. Stakeholders in education should encourage critical thinking, advocate for fact-checking, and promote a balanced approach to leverage both the benefits and potential risks associated with AI-generated content on health and nutrition.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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The Application of ARIAS Learning Assisted by Android-Based Castle Math Application

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Abstract: This research was conducted in Alkarim Junior High School of Bengkulu City which aimed to improve students' creative thinking and learning independence skills in mathematics, specifically in polyhedron material through the application of ARIAS learning model assisted by Castle Math application in smartphone. The method used in this research is classroom action with 2 learning cycles. The result of this research showed that the N-Gain value of students' creative thinking skill is 0.7064, it indicated that there is high improvement on students' creative thinking skill after participating in the learning activity. The data analysis of test result showed students' improvement of creative thinking skill in each cycle. The mean of students' creative thinking test in cycle I is 75.19 with learning success percentage of 62.5%. In cycle II, the test's mean increased to 91.3% with an increase of 16.11 from the mean of cycle I's value. The classical learning success in cycle II reached 93.33%. Students' learning independence also improved in each cycle. In cycle I, the observer's mean score for student learning independence is 77.03 with good criteria. In cycle II, the score increased to 94.76 with very good criteria. Therefore, it can be concluded that ARIAS learning model assisted by smartphone-based Castle Math application succeeded in significantly improving the students' creative thinking skill which can be seen from the N-Gain value, test result, and students' learning independence in each learning cycle.

Keywords: ARIAS, Castle math, Android-based application

Introduction

The ARIAS (Assurance, Relevance, Interest, Assessment, Satisfaction) learning model is considered highly important because it encompasses various aspects that significantly contribute to the effectiveness and quality of the learning experience. Here are some reasons why this model is deemed important:

1. Enhancing Student Participation and Engagement

By ensuring safety and creating a supportive learning environment, students are more likely to feel comfortable and participate actively. The aspects of interest and relevance also provide an extra boost for student engagement, as the learning material becomes more meaningful and interesting to them (Hanaris, 2023).

2. Improving Conceptual Understanding

Connecting learning material to students' everyday lives makes these concepts easier to understand. When students see the relevance in learning, they are more likely to grasp these concepts deeply and relate them to real-world situations (Siagian, 2016).

3. Motivating Learning

The aspects of interest and satisfaction help create intrinsic motivation in students. When students feel satisfied with the learning experience and positively challenged, they are more likely to sustain their interest and actively engage in the learning process (Daheri et al., 2023).

4. Providing Student Progress Mapping

Good and relevant assessments help teachers and students understand the extent to which understanding and skills have developed (Rambung et al., 2023). This provides guidance for identifying areas that need improvement and leads to overall learning enhancement.

5. Enhancing Teaching Quality

Teachers can use the ARIAS model as a framework to design and evaluate their teaching strategies (Rambung et al., 2023). By focusing on aspects such as safety, relevance, interest, assessment, and satisfaction, teaching can be more effective and responsive to student needs.

The ARIAS learning model is a development derived from the ARCS model (Attention, Relevance, Confidence, Satisfaction). The ARIAS learning model consists of five components (Assurance, Relevance, Interest, Assessment, and Satisfaction) arranged based on learning theory (Aziz et al., 2014). These five components constitute a unified entity required in learning activities. A brief description of each component and some examples that can be implemented to stimulate and enhance learning activities are as follows.

1. Assurance (Confidence)

It is related to the attitude of belief, confidence in success, or expectations for success. Someone with high self-confidence tends to succeed regardless of their abilities (Perdana, 2019). The attitude where someone feels confident, believing they can achieve something, will influence their behavior to achieve that success.

2. Relevance

It is related to students' lives, whether in terms of current experiences, past experiences, or career needs now or in the future. Students feel that the learning activities they are engaged in have value, are beneficial, and are useful for their lives. Students will be motivated to learn if what they are about to learn is relevant to their lives and has clear objectives (Jamil, 2019).

3. Interest

Learning truly does not occur without interest. Meanwhile, students' interest is greatly influenced by their motivation. Motivated students tend to be more active in the learning process (Oktaviani et al., 2019). Internal motivation, such as curiosity and the desire to achieve success, can be strong drivers for student participation in class and learning activities.

4. Assessment

Assessment is a fundamental part of learning that benefits both teachers and students. For teachers, assessment is a tool to determine whether what has been taught has been understood by students, to monitor students' progress as individuals or as a group, to record what students have achieved, and to assist students in learning.

5. Satisfaction

In learning theory, if students who have successfully completed or achieved something feel proud/satisfied with that success. That success and pride serve as reinforcement for the student to achieve the next success (Ghasya & Suryanti, 2014). Reinforcement that can provide a sense of pride and satisfaction to students is important and necessary in learning activities. Reinforcement is an important factor in learning.

The ARIAS (Assurance, Relevance, Interest, Assessment, Satisfaction) learning and smartphone-assisted learning can complement each other and create a more holistic and engaging learning experience. Smartphone technology can be an effective tool to provide support and accessibility in the context of ARIAS learning. Students can access learning materials, resources, and assessment tools through their smartphones, enhancing security and accessibility.

The use of smartphone technology in learning needs to be carefully considered, and there should be supervision to ensure that technology is used productively and does not disrupt the learning focus. Integration between the ARIAS learning model and smartphone technology can create a balanced learning environment, support student needs, and harness the positive potential of digital technology. Smartphone technology enables the presentation of learning materials interactively and visually (Septiasari & Sumaryanti, 2022). By combining it with the ARIAS model, teachers can present materials in an engaging and motivating way, stimulating students' interest and creative thinking abilities.

The ability to think creatively in mathematics learning has several significant benefits. Creative thinking in mathematics allows students to see various approaches and solutions to mathematical problems (Yazar Soyadı, 2015). This opens the door to more creative thinking and alternative solutions that may not be considered with conventional approaches. Creative thinking allows students to develop abstract thinking skills, which are important in understanding complex mathematical (Melia et al., 2021). Students can more easily visualize and understand mathematical abstractions by harnessing their creativity.

There are many creative applications that can be used to develop students' creative thinking abilities. Integrating smartphone technology allows students to actively participate in creativity-focused learning activities, thus fostering students' learning independence throughout the learning (Shubina & Kulakli, 2019). Student learning independence is a critical aspect of the education process. Students' ability to learn independently has several significant benefits.

Learning independence equips students with skills that will help them continue learning throughout their lives, as the rapid changes in today's world require adaptability and the ability to continuously update knowledge. Self-directed learners tend to have better resilience to challenges. They are able to overcome learning barriers, identify solutions, and remain enthusiastic even in the face of difficulties (Farisuci et al., 2019).

Based on observations conducted by researchers at SMP Alkarim Bengkulu, it was found that students' creative thinking abilities and learning independence in mathematics learning are still low. The average score for students' learning independence is 63.9, and the score for students' creative thinking abilities in flat-faced solid geometry material is still below 6.0. The low level of students' creative thinking abilities and learning independence in the classroom may be caused by various factors.

Some factors influencing the low level of creative thinking abilities and learning independence include the use of inappropriate learning models during the learning process, which have not been able to develop students' creative thinking abilities and learning independence. In addition, the lack of activities that stimulate imagination hinders the development of creative thinking abilities. The lack of imagination-stimulating activities has been identified as a problem in the development of students' creative thinking abilities. The use of appropriate learning models assisted by smartphone-based technology can help overcome these obstacles. Based on interviews between researchers and students at SMP Alkarim Bengkulu, it was found that students want easy access to educational resources, such as learning applications, and the information they need anytime, anywhere, without being constrained by limitations of place or time.

Based on research conducted by Ghasya & Suryanti (2014) on the influence of the ARIAS learning model (Assurance, Relevance, Interest, Assessment, Satisfaction) in enhancing students' mastery of concepts and creative thinking abilities, it was found that the pretest and posttest results of creative thinking abilities before and after receiving the ARIAS learning model showed improvement. Similar findings were also reported by Agus & Sholahudin (2023) in their study on the effect of Android-based learning media on improving students' mathematical creative thinking abilities, where it was found that Android-based learning media indeed enhanced students' mathematical creative thinking abilities.

Based on the aforementioned issues, the researcher conducted a study utilizing Android with a learning model suitable for students' needs. The use of the ARIAS learning model with the assistance of the Castle Math application based on Android is expected to enhance students' creative thinking abilities and learning independence.

This research is very important because it can provide insights into the extent to which the implementation of the ARIAS learning model and the Castle Math application can improve learning effectiveness. By understanding its impact, teachers and educators can optimize teaching methods to support better learning outcomes. This research can provide innovative learning alternatives that can be adopted by educators. If proven

successful, the ARIAS learning model aided by the Castle Math application could serve as inspiration for teachers to create more engaging and effective teaching approaches.

Method

The type of research conducted is Classroom Action Research (CAR). Classroom Action Research (CAR) is a research approach carried out by teachers or educational practitioners in their own classrooms to understand, improve, and address problems that arise in the learning context. CAR aims to create changes and improvements in teaching practices and provide a better understanding of the learning process. There are four main activities in Classroom Action Research:

1. Planning

The planning stage involves identifying problems or challenges in classroom learning. Researchers design steps to address the problems of students' creative thinking abilities and learning independence and set specific goals for improvement. This plan includes data collection methods, teaching strategies, and evaluation of outcomes.

2. Action

After planning, researchers implement it in the daily teaching process. Data is collected during this stage to monitor progress and evaluate the impact of the actions taken. Researchers use various data collection techniques, such as observation, interviews, or tests.

3. Observation

At this stage, researchers systematically monitor and observe the implementation of the action plan in the classroom. This observation involves direct observation of learning activities, student responses, and the effectiveness of adopted strategies. These observational data serve as the basis for identifying successes or obstacles in the improvements made.

4. Reflection

After completing the implementation stage, researchers evaluate the results of the actions taken. This involves reflecting on the collected data and analyzing the achievement of set goals. Researchers also determine whether the changes or innovations implemented have positively impacted learning and achieved the desired goals.

This process is cyclical because after the evaluation stage, researchers return to the planning stage to make further improvements or address new emerging problems. Thus, this Classroom Action Research is an ongoing effort that researchers undertake to improve the quality of learning in the classroom through reflection, corrective action, and continuous evaluation.

This research was conducted on eighth-grade students at SMP Alkarim in Bengkulu city, comprising 7 male students (46.666%) and 8 female students (53.333%). The learning material in this research was flat-faced solid geometry (Cube, Rectangular Prism, Prism, and Pyramid). All students participated voluntarily in this research. After the students completed the cycle test questions, the researcher checked the students' work and assessed their creative thinking abilities based on the answers they provided. Students' learning independence was observed by an observer during the learning process.

Mathematics learning activities using the Castle Math application through the ARIAS learning model at SMP Alkarim in Bengkulu city in this research are said to improve students' creative thinking abilities and learning independence if they meet several criteria: 1) $80<NR\leq100$, where NR is the average score of students' creative thinking abilities, 2) classical learning completeness score $\geq85\%$, 3) N Gain test score > 0.3, and 4) the average score of students' learning independence must be more than 80.

Results and Discussion

The smartphone application used in this research is Castle Math, developed by UHAMKA alumni. The Castle Math application is inspired by castle structures, which are composed of stacks of solid geometry shapes. The Castle Math application functions as a learning media for flat-faced solid geometry for junior high school/madrasah tsanawiyah students. The Castle Math application contains learning materials on cubes, rectangular prisms, prisms, and pyramids. The advantage of this application lies in its presentation of the properties of flat-faced solid geometry in an engaging manner with animated .gif format, making it easy for students to remember and understand. This application was developed by Barqilatief Mujasir, an alumni of UHAMKA.

The Castle Math application has a visually appealing interface, which attracts students when studying flat-faced solid geometry materials. When we open the Castle Math application, we need to click "start" to enter the material menu. Then, after entering the material menu, we will select the material according to our preference. The appearance of the Castle Math application is as follows:

Figure 1. Initial display of the Castle Math

Figure 2. Classroom Learning Using the Castle Math Application

Figure 3. Students Using the Castle Math Application in Class

The test of creative thinking ability was conducted by providing cycle I and cycle II test questions to the students to assess the extent of improvement in students' mathematical creative thinking abilities after using the ARIAS learning model assisted by the Castle Math application. After the test was conducted, the students' answers were corrected and scored based on the scoring guidelines for creative thinking abilities adapted from Surya et al., (2017), namely Fluency, Flexibility, Originality, and Elaboration. In this research, the researcher elaborated on the parts assessed for each indicator of students' creative thinking abilities.

Firstly, regarding Fluency, which refers to students' ability to generate a number of ideas or solutions quickly and without obstacles. In the context of flat-faced solid geometry learning, fluency means students' ability to smoothly and effortlessly generate various ideas or concepts related to the topic. For example, students may easily develop variations of flat-faced solid geometry shapes. Secondly, Flexibility reflects students' ability to think diversely and adapt their approach depending on situational demands. In the context of flat-faced solid geometry, flexibility means students can generate ideas or solutions from various perspectives or creative approaches. They can adapt their knowledge to solve problems or create new concepts differently.

Thirdly, Originality refers to students' ability to generate new, innovative, and unusual ideas or solutions. In flat-faced solid geometry learning, originality means students can develop concepts or solutions that not only follow common patterns or conventions but also provide elements of novelty and uniqueness. Fourthly, Elaboration involves developing ideas or solutions by providing more detailed, explanatory, or in-depth descriptions. In the context of flat-faced solid geometry, students who can elaborate will be able to explain and expand their concepts in more detail. They can articulate the relationships between elements, provide justifications, and

present their thoughts deeply. The analysis of the improvement in students' creative thinking can be calculated using the N-gain formula with the following criteria:

Table 1. Criteria For N-Gain Level (G)

Limitations	Category
$g > 0,7$	High
$0,3 \leq g \geq 0,7$	Moderate
$g < 0,3$	Low

Table 2**.** N-Gain value of students' creative thinking

	N	Minimum	Maximum	Mean	Std. Deviation
N_Gain	15	.08	1.00	.7064	.30159
Valid N (listwise)	15				

From the table 2 above, the N-Gain value obtained is 0.7064, indicating a high improvement in students' creative thinking after following the ARIAS learning model assisted by the Castle Math application. The higher the N-Gain value, the greater the improvement. Thus, the learning approach used has succeeded in substantially enhancing students' creative thinking abilities. This suggests that the teaching strategy or method is effective and can be considered for future use. The results of the students' creative thinking ability test using Castle Math show that there has been an improvement from cycle I to cycle II. The results are shown in the following Table 2.

Table 3. The results of the students' creative thinking ability test ın cycle ı and ıı.

No	Score	Cycle I	Cycle II
1	Highest score	95	100
2	Lowest score	65	68
3	Average Score	75,19	91,3
4	Classical learning completeness	62,5%	93,33%

The test results were analyzed, and the analysis showed the development of students' creative thinking abilities in each cycle. Based on Table 3, it can be seen that classically, students' learning success has improved. It is evident that the average score of students' creative thinking ability test in Cycle I, obtained by 15 students, was 75.19 with a learning success rate of 62.5%. In the Cycle II test, the average score of 15 students increased to 91.3, an increase of 16.11 from the average score of Cycle I, with a classical learning completeness rate of 93.33%.

In the Cycle II learning, students were already accustomed to learning activities using the ARIAS model assisted by Castle Math. From Table 1, it can be seen that in this final test of Cycle II, the average student score is 91.3, with a score range from 68 to 100. This indicates that in Cycle II, there has been an increase in the average score of the final cycle test by 16.11 points from the average score of Cycle I. The average score of students in Cycle II has reached the success indicator of the action. Therefore, the action implementation was not continued in the next cycle.

Observation of students' learning independence was carried out by observers tasked with observing 5 groups. Learning independence indicators based on Hidayati & Listyani (2010) include six aspects: (1) independence from others, (2) self-confidence, (3) disciplined behavior, (4) sense of responsibility, (5) initiative-based behavior, and (6) self-control.

In this study, students' learning independence is based on the following nine indicators: (1) having the initiative to learn mathematics, (2) analyzing mathematics learning needs, (3) setting learning targets and objectives, (4) monitoring, organizing, and controlling mathematics learning, (5) viewing difficulties as challenges, (6) utilizing and seeking relevant learning sources, (7) selecting and determining mathematics learning strategies, (8) evaluating the process and results of mathematics learning, and (9) self-confidence (self-efficacy). The overall observation results of students' creative thinking abilities can be seen in Table 4 below:

Based on Table 4, it can be seen that students' self-directed learning in the learning process with the ARIAS model aided by the smartphone-based Castle Math application improves with each cycle. Table 3 indicates that in Cycle I, the average observer score for students' self-directed learning was 77.03, rated as good, while in Cycle II, the average observer score for students' creative thinking ability was 94.76, rated as very good. This is

because in Cycle I, students were not yet accustomed to using the smartphone-based Castle Math application in the learning process. Therefore, teachers reflected on their actions to improve students' creative thinking abilities in Cycle I.

Table 4. Scores of observation results of students' creative thinking abilities in cycles ı and ıı

	Cycle I	Cycle II
Meeting I	34	42
Meeting II	41	47
Average Score	77,03	94,76
Category	Good	Very Good

Conclusion

The conclusion of this study is that ARIAS learning provides a foundation for teaching that motivates and engages. Activities involving students actively, providing realistic challenges, encouraging innovation, allowing room for artistic expression, and using symbols can trigger students' desire to learn and think creatively. The use of the Android-based Castle Math application provides interactive and enjoyable dimensions to learning. Students can learn through more visual and dynamic methods, thereby increasing their engagement and interest in the learning material. The success of this research is based on a good understanding of students' needs and characteristics. ARIAS learning is tailored to individual needs, allowing for more appropriate responses to differences in learning styles and students' levels of understanding.

Recommendations

Recommendations for this study include recommending the implementation of a monitoring and evaluation system to measure students' progress over time. This can help identify areas that need improvement and enhance the effectiveness of learning. Collaboration with external parties, such as students' parents or the community, should be encouraged to support learning outside the school environment. Involving parents in supporting creative learning and self-directed learning can create positive synergy.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Exploring Metacognitive and Discursive Activities Using a Video Transcript

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Abstract: Metacognition plays an essential role in learning mathematics. However, due to the lack of observational systems for evaluation of metacognition in mathematics instruction, rarely anything is known about how metacognition is practiced and fostered when teaching and learning mathematics in class. The study aims to evaluate the metacognitive-discursive activity in a real class when solving mathematical problems. During the learning implementation, we use document camera technology so that students can present their solutions and show that they are responsible for them. The type of research used is interpretative qualitative. The data collection methods used were documentation and learning videos. Data collection procedures in this study are 1) the teacher asks all students to solve the given problem 2) students are asked to discuss the problem with all other students in front of class, 3) the researchers observe and listen to the results of discussion, choose a conversation during discussions, transcript it 4) Interpretate of each utterance by using the system for an evaluation of metacognitive-discursive activities, 5) Analysis of all selected learning scenes guided by several questions, The results show that (1) there are a metacognitive activities both from the teacher and from the students, (2) there are metacognitive activities with justification when students give answers without being asked by the teacher, (3) there are discursive activities with special qualities, (4) there are negative discursive activities that make difficult to understand the mathematical content.

Keywords: Technology, Video transcript, Metacognition,

Introduction

Many studies in education have been conducted to improve the quality of mathematics learning. The purpose of learning mathematics is learning to reason, learning to control mathematical activities, learning to solve problems; learning to link ideas; and learning to represent ideas and to communicate. These competencies are needed so that students can have the ability to obtain, manage, and utilize information to survive in an ever-changing, uncertain, and competitive situation. However, in reality, mathematics learning has not achieved optimal results. The results of Programme for International Student Assessment (PISA) test, especially in the field of mathematics from students in Indonesia are still very low. In 2003, Indonesia ranked 38th out of 40 participating countries with an average score of 360, in 2012, Indonesia ranked 64th out of 65 participating countries, with an average score of 375, in 2015, Indonesia ranked 74th out of 79 participating countries, with an average score of 386, and in 2018, Indonesia ranked 73rd out of 79 countries with an average score of 379 (OECD, 2019).

Various studies have been conducted in an effort to improve PISA results including the development of PISA model statistics questions (Junika et al., 2019), and the development of questions using the context of Lampung (Putra et al., 2016), the application of problem-solving-oriented learning approaches, the development of teaching materials and curriculum changes, However, these efforts seem to have brought little success or have not experienced significant changes, as seen from the results of the last PISA assessment. Indonesia consistently ranked in the bottom 10 of all countries involved in the assessment.

This fact is reinforced by several studies, such as Hamidi (2019) who reported that students' ability to solve mathematical problems of the PISA model is still low, with an overall score of 415 below the average OECD score (500). Similar findings were also reported by Andriani (2018) regarding students' ability to solve science literacy problems using the PISA framework, where only 54.9% of students could work on problems at level 2. Noviana (2020) reported that students' mathematical literacy skills in solving problems were also still very low, only 7.13% of students were able to solve problems. Ate (2021) stated that students' numeracy literacy skills were still very low, with 90% of students unable to solve problems. Thus, these various studies indicate the challenges still faced in improving the quality of mathematics learning in Indonesia.

The efforts that have been made have focused more on improving output and there does not seem to be any systematic research to evaluate the learning process i.e. the actual instruction provided that affects output. Cohors-Fresenborg and Kaune (1993) see metacognition as a feature of teaching quality that can be used to evaluate the learning process. In general, metacognition is defined as thinking about what one thinks (Schoenfeld, 1992), but this definition does not adequately explore students' metacognition when solving mathematical problems. Some experts more specifically define that metacognition is one's knowledge of cognitive processes and one's awareness of a mathematical problem that involves the process of planning, monitoring, and evaluating problem solutions (Flavell, 1976; Wilson and Clarke, 2002). Most definitions of metacognition distinguish between metacognitive knowledge (e.g. one's knowledge about cognitive tasks in mathematics, about strategies for coping with these tasks, and about one's competencies related to these tasks and strategies), metacognitive skills (e.g. one's procedural knowledge for organizing one's own problem solving and learning activities) and the exercise of such skills in the form of metacognitive activities (Veenman at al., 2006). Such differentiation is important for theoretical considerations regarding the meaning of metacognition, whereas in concrete situations it is almost impossible to distinguish between these different components.

Metacognition has been considered to play an important role in regulating students' cognitive processes in problem solving and in mathematics learning in general, particularly when constructing and organizing knowledge (Schraw & Moshman, 1995; Wilson & Clarke, 2004), as well as in the use of self-regulated mathematics in different contexts to achieve some goals (Boaekaerts, 1999). Thus, from a teacher's point of view, promoting students' metacognition can be considered as a means for effective teaching - to engage students in the cognitive processes necessary to understand the mathematical concepts and methods to be learned. Metacognition should also be considered as an instructional goal - as an important aspect of students' mathematical competence to be enhanced through teaching.

Much research has been conducted on modeling, analyzing and promoting metacognition in solving mathematical problems. Many of the paradigms adopted in this context in previous research are based on the assumption that the way students learn to solve problems is to "first acquire the needed mathematical knowledge, then acquire problem-solving strategies that will help them decide which procedures to deploy, then acquire metacognitive strategies that will trigger the proper use of the problem-solving strategies (...)." (Lesh & Zwojewski, 2007). Such paradigms not only separate problem solving from concept development. They also separate metacognition from teaching mathematical concepts and reduce the promotion of metacognition to teaching a list of simple rules (e.g., make a plan, draw a picture, mark important words, control your solution, evaluate the result). This separation is considered one of the possible reasons for the unimpressive results (ibid.) of this kind of research, as it seems almost impossible to acquire sufficient metacognitive knowledge to solve problems without engaging in metacognitive processes when building substantial meta-mathematical knowledge. It is therefore necessary to shift the focus of research on metacognition from teaching problem solving to ordinary teaching situations where learners have to learn mathematical concepts and methods.

Since little is known about how metacognition can be effectively developed, this article will deeply analyze metacognitive practices in regular classrooms so as to improve students' metacognition. Moreover, promoting metacognition does not mean simply teaching one student how to organize, control and evaluate his/her cognition when learning and applying mathematical concepts and methods, but needs to organize teaching in such a way that as many students as possible engage in metacognitive activities. This can be achieved by building a culture of discursive discussion that encourages students to control and regulate their own cognition

and understanding when other students or the teacher explain their ideas, solutions, conceptions or difficulties in understanding the mathematical ideas discussed. This concept is known as metacognitive-discursive activity. Metacognitive-discursive activities can be stimulated, maintained and habituated through tasks (Kaune, 1999, 2001a, b; Kaune, et al., 2010; Sjuts, 2001b) and appropriate didactic contracts (Sjuts, 2003). The tasks are designed in such a way that students are not only instructed to use metacognitive activities to support the problem solving process, but also students use metacognitive activities to understand mathematical terms (understand definitions, theorems), use these terms to justify problems, check the use of mathematical terms, check for possible misunderstandings, reflect on mathematical terms, discuss combinations between explanations and results of thinking as a form of problem solving that uses metacognitive activities.

Didactic contract is a conceptual framework that emphasizes the importance of interaction between teachers and students in the process of learning mathematics (Brousseau, 1986). This concept aims to create an effective learning environment. In this study, the didactic contract includes students who want to ask questions or answers or argue, must raise their hands first and will speak if they have been asked by the teacher or other students; students explain and give reasons for arguments or answers and if possible students do it themselves without being asked by the teacher; students ask questions about explanations that are not understood, and students argue when they disagree. In order for the didactic contract to be implemented, it is necessary to have digital technology that makes it easy for students to point to the parts that are being explained, makes it easy for other participants to see the answers clearly, or if another participant wants to check or comment on certain parts, then the participant can easily point to the part in question. Thus, this technology can facilitate discursive discussions. By presenting their solutions via a document camera students show that they are responsible for their writing. In Moza et al. (2024) there is analyzed a lesson at the beginning of grade 7, where the teacher and the students learn to practice that contract.

Method

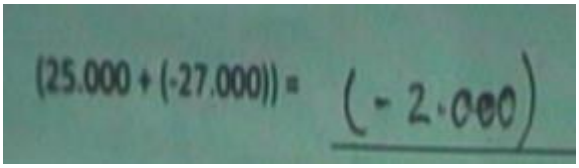
This research analyzes the discussions conducted by teachers and students, as well as between students as far as these discussions can be heard by all students in the class and does not analyze the teacher's remarks to individual students when they work in small groups or discussed in small groups when solving problems. The population in this study was seventh grade students and the sample was selected by purposive sampling technique. Data was collected through audio-visual recordings. From these recordings, the researcher will select the part, which will be analyzed, transcribing it using Video Transcript-10.8 program. The documents used in this study are photos from a document camera. This way one can see better what students or teachers display under the document camera. Data analysis in this research uses inductive data analysis and the theory used is *grounded theory*. This *grounded theory* research uses three sequential steps, namely *open coding, selective coding* and *theoretical coding* (Jones and Alony, 2011). In the *open coding* stage, the researcher interpreted the transcribed teaching scenes into codes that fit the metacognitive-discursive activity category system developed by Cohors-Fresenborg and Kaune (2007), further developed by Nowińska (2018) and Cohors-Fresenborg and Nowińska (2021). The researcher has to justify his coding in the separate column "Comments". At the *selected coding* stage, *the* researcher deepened the code obtained from the *open coding* process. Deepening analysis is carried out by validating data to experts. *The theoretical coding* stage is the last stage in *grounded theory,* namely the preparation of theories or conjectures.

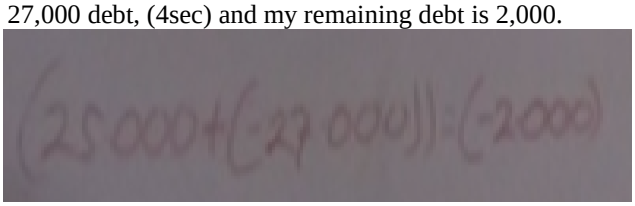
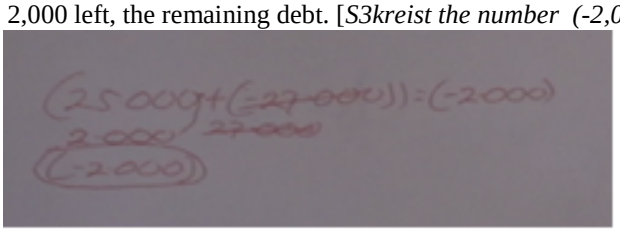
Results and Discussion

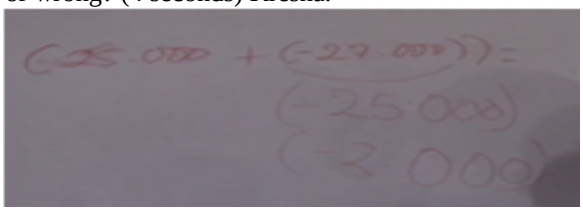
In this study, a 7th grade class was observed that had been taught mathematics since the beginning of the school year according to the new concept (Kaune & Cohors-Fresenborg, 2021). The transcripts were analyzed with the aim of seeing how teachers and students practiced metacognitive-discursive activities after only a few weeks in class. This lesson was chosen because it was a very interesting discussion between several students who all had different thoughts about the presentation of the given problem. The following will present transcripts of conversations between students and teachers when solving simple arithmetic calculation problems and the results of analyzing the transcripts. The entire conversation is not written in this article as there is not enough space. However, the graph depicts the entire discussion during solving the problem.

In the prefix of the code the letter "*b*", written in italics, means that the person gives a justification, in the prefix of the code the letter "*f*", written in italics, means that the person requests a metacognitive-discursive activity, in the prefix of the code the two letters "*bf*", written in italics, mean that the person gives a justification of her/his request for a metacognitive-discursive activity.

Table 1. Text, code and comments

P	Text	Code	Comments
L.	We continue with part a. (4sec) [*Some students raise their hands.*] S1.		It is a question of mathematical discussion of the tasks set. Therefore, no metacognitive or discursive activities were classified.
S1	Min 2,000. Open bracket, min 2,000 close bracket. [*S1's answer from his chair and the teacher wrote S1's answer under KD.*] Sa... I have 25,000 money and I deposit 27,000 debt. So, I paid the debt with 25,000, (3sec) paid paid the debt 27,000, so sa so the final balance is min 2,000. How about you guys, is my answer right or wrong? Anyone want to comment? 	R7 ND3b *f* M5	S1 imagined algebraic calculation as a bookkeeping process (R7). The argumentation is incomprehensible because there are missing sentences, so it can be classified as ND3b. S1 also asked his friends to check his argument (*f*M5).
S2	That's because it says [we] have to increase the debt. But actually we have to borrow 2,000 to the bank, then we form the opposite, so that the initial balance does not change, we add minus 2,000. That money, we combine 25,000 money with 2,000 money, it will work ... yes ... it will be 27,000 money, then we will pay it.	*b*M2 D1a D1b R7 *b*R3c	S2 explained that he disagreed with the formulation in S1's answer (*b*M2 with respect to D1a and D1b). As a result of the reflection process, he chooses a specific decomposition to make his calculations understandable (*b*R3c).
L.	How is S1?		The teacher encourages S1 to say something about S2's utterance. This is not classified as an invitation for metacognitive activity.
S1	My explanation is also correct. I have 25,000 so I subtract me... minus 27,000. So I pay first, I divide 27,000 into minus two... 27,000 becomes minus 25,000 and minus 2,000. So, I paid. So I paid 25,000 debt from 27,000, so the remaining 2,000, which is minus 2,000. (6sec)	*b*R3c D1b R7	S1 ignored S2's explanation and maintained his explanation. He explained his strategy in a simpler way so that his calculation could be understood (*b*R3c in relation to D1b).S1 envisioned the division of debt precisely into 25,000 debt and 2,000 debt (R7).
L.	What do you think, S2?		The teacher encourages S2 to say something about what S1 said. This is not classified as an invitation for metacognitive activity.
L.	Okay, I ask S2 to make it on the board as S2 has said earlier about this. Let's demonstrate on the board, later S1 will have a version on the board too, then we will see which reason is appropriate for the term [*Teacher asks S2 to present his explanation on the board*]. Come on S2, as you explained earlier, make it on the board here. Like using cards, right you explained earlier visualization, try it!. (5sec) Try S2! (4sec) Come on, as S2 explained earlier, just make it on the board. Write this, this, so that it is clear to, friends can also understand. Can you? [*S2 ignores the teacher's invitation and questions*] S1, want S1...? Want to? (8sec). [*S3 raised his*	*bf*R3c P2 D1d	In this part, an L. plays the role of a teacher. The teacher suggested that S2 and S1 write their versions on the board. With the following statement she also gave a reason for her request "then we will see which reason fits the term" (*bf*R3c). Then she wants both versions to be analyzed

	hand, then S1 got up *from his chair*] S3 want to help? Yes, you two can make the same version how? According to S1's thinking. [*teacher gives marker to S1*] (6sec) Who wants to go first? Oh S3 first yes. Others try to pay attention, later you can comment on the explanation, pay attention to every word that is said.	P2 D1d	to see which version fits the term better. The teacher planned how the students' metacognitive activities would be organized (P2). This step also facilitates the debate. Therefore, D1 is also classified. By requesting that students pay attention to each word, the teacher wants to lay the foundation for the students' subsequent metacognitive activity. So he is planning a metacognitive activity. That's why P2 is classified. This reprimand is a measure for structuring the debate later, which is why D1d is also classified.
S3	[*S3 demonstrated it with the visualization method. At the same time he writes on the board what he says*]. I have, here I wrote 25,000 money, and I paid my money, I paid 20 ... min 27,000 debt, (4sec) and my remaining debt is 2,000.  I got minus 2,000 because here, I have minus 27,000 debt, and here I only have 25,000 money. So that I can pay two ... minus 27,000 debts, I borrow money, add money 2,000. (3sec) [*S3 writes 2,000 with the number 25,000 on the board.*] So that my initial balance remains, mena ... I then borrowed money, I borrowed minus twoapu... 2,000 debt. (5 seconds) [*S3 writes (-2,000) under the number 2,000 on the board*] minus 27,000 can already be paid here, this is added, minus you ..., 25,000 plus 2,000 equals 27,000. [*S3 writes 27,000 on the board.*] This is the remaining debt, here I have 2,000 left, the remaining debt. [*S3kreist the number (-2,000)*]  How about you guys, is my answer right or wrong? (3 sec) S4.	*b*R3c D1a *f* M5	S3 explained his idea again in great detail (so here with bR3c in conjunction with D1a is classified). S3 asked his classmates to check his reasoning (*f*M5).
S4	S3, I'm still confused about this, said S3, uh S3 I ... mem ... make doubling of words, minus and debt. And that's it, what he pays is still owed *to* [*dialect*], can it be paid with money? Uh right, I was wrong. (4dtk)	*b*M5 D1b M8e	First S4 said that he was still confused with the explanation of S3 (D1b). S4 gave reasons after checking the explanation of S3 (*b*M5). When giving reasons for S3's explanation, he checked his own argument (M8e).
S3	Anyone else want to comment? (13 sec)	*f* R4	S3 asked his friends to recheck the solution method that had been explained

			(fR4).
L.	S1 want to explain too? [*S1 nods*] okay.	P1a D1a	Here the teacher has determined the steps that S1 will take so this is categorized as one-step planning (P1a).The teacher also immediately mentions the person (D1a).
S1	I have 25,000 money, [*S1 did not write the amount of money but the amount of debt (-25,000) on the board*].	R3b ND3b	Since the explanation of S1's chosen representation was not grammatically comprehensible, it was coded R3b with respect to ND3b.
S	Money, not debt.	M2	Students comment on the choice of words used, S1 mentions Rp 25,000 but writes Rp 25,000 debt (M2).
S1	[*S1 removes useless minus signs and brackets*]. I had 25,000 debt and I paid minus two...debts, uh mem...I...paid, paid 27,000 debt. (3sec) So the final result is 2,000 debt. (4sec) [*While S1 was explaining, he wrote each number he mentioned on the board*]. I divide by two... 27,000 becomes minus 25,000 becomes minus 2,000. (3sec) So, I deleted this one because this one is already split. [*S1 wants to delete (-27,000) off.*] This is already there, this will be 25,000, I de...ut...u...money 25,000, pay, I pay with 25,000 debt. So, I remove this, [*S1 wants to remove 25,000 and (25,000) and leave (-2,000) there.*] so that the final balance becomes 2,000 debt. How about you guys, is my answer right or wrong? (4 seconds) Kresna.  	M8b D1d *b*R5 *f*M5 D1a	S1 self-monitored the choice of words he used to review his strategy explanation (M8b). He also wrote down what he said on the blackboard so as to make it easier for other students to understand (D1d). Here S1 explained his argument in a structured manner (*b*R5). At the end of his explanation, S1 asked friends to check his argument (*f*M5). S1 also mentioned the person who meant Kresna (D1a).
S6	That's right.	M5	S6 checked the argumentation of S1 (M5).
S1	Does anyone have any comments? [*S4 raises her hand.*] (8 seconds) Lora.	*f* R4	S1 asked his classmates for comments (*f*R4); since it was not only asking if it was correct, it was not classified with *f*M4.
S4	S1 here, what do we want to pay, can we split it? (3sec) Uh, what do we want to deposit, can we split it? (4sec) [*S1 erases result (-2,000) and L. helps him*].	R4	S4 assessed S1's use of methods through a question (R4).

a) : How are cognitive teaching activities seen in this scene?

It can be seen from the transcript that the teacher himself conducts monitoring or reflection at the end of the discussion. This activity serves to summarize what has been discussed previously between students. From the transcripts, it can also be seen that from the beginning students practiced metacognitive activities without special instructions from the teacher.

The first two statements from the teacher, classified as requests, are more of an encouragement for students to debate on their own. Even after that, students were metacognitively active without being prompted by the

teacher. It is noteworthy that two students monitored their own statements such as: S4 checked his own argument (M8e) and S1 checked his own choice of words (M8b). This part shows that it is important that both students formulate what they mean. This kind of behavior is remarkable for students of their age.

Figure 1. The overall output results using the video transcript software

b) Does the metacognitive activity contain detailed reasoning or explanation?

Many students' statements were immediately made in great detail and with reasons without being asked by the teacher. Often, students asked other students to do metacognitive activities accompanied by reasons. Only at the end of the conversation was there a metacognitive activity with reasoning (*b*R3c) on the part of the teacher.

The teacher's explanation was remarkable in that she explained why she required two students who had made different judgments to present their thoughts, namely for all the other students to see (*bf*R3c).

c) Are there discursive activities with special qualities?

In this scene, the first surprising thing is that teacher P2's specific discursive activity has been classified twice with respect to D1d. This shows that the two alternatives are seen as the basis of a complex discourse.

But even among the students, discursive activity of a special quality can be found in some places: S5 repeats what S1 says so that it is clear what is being said (D1c). S1 repeats in two places, what he said earlier so that his opinion becomes clear (D1c). S2 refers to what S1 said (classified as D1c).

The teacher also refers to her summary analysis according to what S1 said (classified as D1c). The specific discursive activities mentioned here (D1d and D1c) show that not only the teacher knows how important it is that all students involved in the discussion always know exactly what is going on. The students have also learned how to quote statements (or mathematical representations) from their classmates to ensure that a discussion relates precisely to its topic.

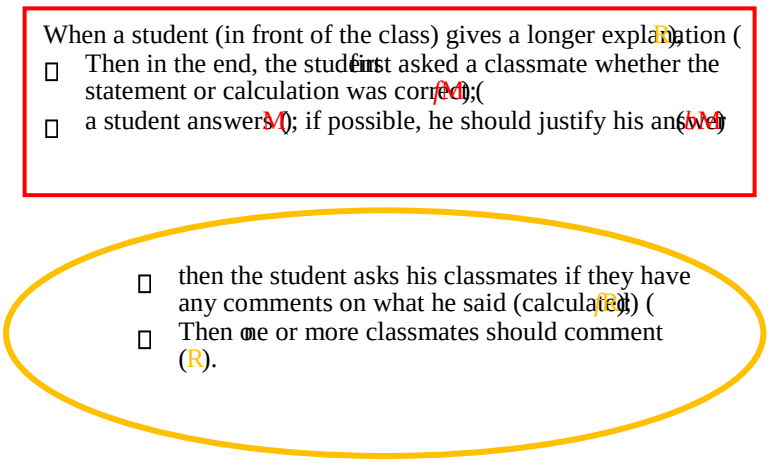
d) Are there negative discursive activities that make it difficult to understand the mathematical content?

There are only a few places where negative discursive activity has also been coded: four times, it was not possible to understand exactly what he meant when S1 made a statement (ND3b). He tried to explain what he was imagining, but S1 was not yet linguistically capable at these points.

The teacher did not try to urge S1 to use a clearer expression of language, but rather offered S1 a formulation that better expressed what S1 meant.

e) To what extent do students practice discussion among themselves, or does the teacher comments with a metacognitive activity on students' individual statements before they speak again?

In the chart above those parts are framed in blue color, in which there are no such interventions practiced. The following activities have been agreed with the class for the cognitive-discursive teaching activity:



f) Relationship between learning process analysis and metacognitive-discursive activity analysis

At the beginning of the transcript, S1 imagined the abstract math problem in the banking world. This activity has been classified as R7. In the *Theoretical Background* chapter of the textbook (Kaune & Cohors-Fresenborg, 2021), where the theoretical considerations behind this teaching *concept are explained*, in the sub-section *Model Concepts, Micro-worlds and Elementary Metaphors* (pp. 1-2) it is explained, that the discussion of ordering credit and debt balances should be done in such a way that later students can translate the task at hand into the banking world when calculating "abstract" arithmetic problems so that it becomes clear what is meant and what should be done. The whole discussion between students shows that this idea of metaphor can add to understanding. After S1's first statement, there was another interesting interaction between representation and imagination (R7): S2 imagined that he borrowed an additional 2,000 from the bank and compensated it with credits; then he had 27,000 credits and could continue counting. S1 imagined the exact division of debt into 25,000 debt and 2,000 debt. Then he could continue counting. By being asked to document the different forms of solving under the document camera or on the blackboard, and the practiced discursive activities (D1a, D1b and D1c), students can precisely follow the different thinking of S1, S2 and S3.

Complex discussions can be deciphered very precisely due to the accurate classification and reasoning given by each student during the conversation. Comprehension can be difficult (characterized by ND3a, ND3c, or ND3d) when participants in a conversation talk together without responding to the question or topic being discussed. Comprehension can also be impaired if each participant conveys their thoughts in a way that is difficult to understand linguistically (ND3b) or if the arguments presented are too brief or incomplete (ND3a).

Such a classification then makes it clear that the public classroom discussion is likely to be directionless or perhaps even chaotic. An assessment of the quality of teaching can be obtained through analyzing the entire teaching scene, not just from individual contributions to the conversation. The beam line helps to provide an overview, while the pattern of the conversation is described in the previous section. Justification in teaching culture can be observed at the first level when the teacher asks students to give reasons, the second level when students follow the request, the third level when students voluntarily give reasons without being asked, and a higher level when students ask their classmates to give reasons. Another indicator of teaching quality is seen when teachers or students, in difficult discussions, take steps to facilitate orientation in the discussion. For example, pointing appropriately to the point of the question, naming classmates who want to speak, clarifying different opinions at the beginning of contributions, and making appropriate notes to ensure differences in arguments are clear. Although, there are sometimes discrepancies between teachers' claims to summarize what students say and what is actually conveyed, which can affect the quality of teaching (ND3c).

Conclusion

From the discussion, it can be seen that learning with metacognitive-discursive activities and supported by teaching materials, didactic contracts and advanced digital technology is effective. Through the provision of

teaching materials, students are helped to solve mathematical problems that refer to the micro world to build confidence when solving abstract tasks. In addition, teachers can exhibit different behaviors, listening and analyzing more than talking to themselves. Students can actively participate and provide clear arguments and listen to each other. Through digital technology, learning can take place quietly, students do not give answers in chorus so that the discussion can run well. So the effectiveness of the learning process, is not only determined by the number of metacognitive activities of individuals, but the quality of these activities shown in the interaction between participants; the more detailed the metacognitive activities are presented, the more precise and directed the control of the process of learner understanding.

Recommendations

In order to be able to conduct this kind of teaching analysis, the theoretical basics must first be practiced. The transcripts of these teaching videos, *especially the column "Comments",* can be used as learning materials. Furthermore, teachers should always train students to get used to raising their hands if they want to express their opinions or questions in class and get used to students automatically asking other friends for an answer or argument without waiting for the teacher's direction. In addition, when designing lessons, steps are needed that motivate students to carry out metacognitive activities and when implementing learning, it is necessary to use digital technology such as document cameras so that it helps to present students' answers and ideas.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Use of Android-Based E-Modules for Statistical Thinking Abilities

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Absract: Developing statistical thinking skills is an important need in the industrial era 4.0 and society 5.0. Where the availability and openness of data is not limited by space and time. Statistical thinking is very important to help students focus so they can consume educated and accurate information. Statistical thinking is a way of understanding the complex world by describing it in relatively simple terms. This research aims to improve students' Statistical Thinking abilities by using Android application-based learning media. The method used in this research uses the literature study method. Data collection was carried out through literature reviews from several relevant studies, then continued with content analysis. The results of this research show that in general the use of Android-based E-Modules can improve statistical thinking abilities. The use of Android-based E-modules also increases students' learning activities to become more active during the learning process. Apart from that, another positive impact is the acceleration and improvement of students' mathematics skills. The mobile characteristics of Android applications provide opportunities for students to re-study material they have not mastered anywhere and at any time.

Keywords: E-module, Android application, Statistical thinking

Introduction

The concept of the Society 5.0 era was first conveyed by Japanese Prime Minister Shinzo Abe by encouraging the role of humans in overcoming progress in the Industrial Revolution 4.0. In this 5.0 era, humans are required to have more problem-solving abilities, critical thinking abilities, and creative abilities (Nurjanah et al., 2021). The priority of this era is the ability of society to adapt to the future by having HOTS capabilities(Higher-order thinking Skills) to think complexly, hierarchically, and systematically in everyday life. The availability of high-level technology has become a trend for automation and data exchange during the Industrial Revolution 4.0 as it is the Internet of Things (IoT) and artificial intelligence (Ellitan, 2020). Along with this progress, it has an impact on life throughout the world which is full of turmoil and full of uncertainty. With the presence of the era of society 5.0, it can be a solution to existing problems (Sugiono, 2020).

The fundamental principle in the era of Society 5.0 is the role of humans together with the technology that has been created. Humans create a balance between economic progress and solving social problems through an interconnected system between the virtual world and the real world(Ellitan, 2020). The relationship between the Industrial Revolution 4.0 and the era of society 5.0 is the use of big data. Big data that follows the development of the Society 5.0 era is found in various fields, such as the use of technology wearable (Sugiono, 2020). Wearable technology is a device Internet of Things (IoT) found on smartphones physically worn by individuals to track, analyze, and send personal data. This device is commonly used to assist communication

and navigation activities in everyday life. But then, it was transformed into a technology for collecting big data information contained within smartphones.

Furthermore, the era of Society 5.0 is also related to data analysis using high-performance computers to solve the issue of environmental change, a smart city that is safe, comfortable, and efficient. So this needs to be adapted to the world of education in Indonesia. Education currently faces many challenges in meeting 21st-century learning targets. The current challenge is a call to integrate Information and Communication Technology (ICT) into learning activities. 21st-century learning habits can be seen in the increasing use of technology. There is a structured movement to apply a combination of humans and technology in life so that the world of work requires people who can take the initiative, think critically, and be creative and capable of solving problems (Batubara, 2018). Teachers as important agents in the learning process are the main potential for scientific development. Teachers must always explore their potential to improve the quality of learning. There are many ways to improve the quality of learning, including using learning design (Komariah et al., 2018) that involves technology.

In the era of digitalization, the government requires Information and Communication Technology (ICT) subjects in every school, then it is recommended to integrate technology into every learning process, including mathematics learning. The application of digital technology in learning can help make learning more effective and interesting, presenting events that rarely occur, and showing events that can make it easier for students to understand abstract material (Anita & Nugraha, 2022). The presence of technology can help students improve their problem-solving abilities.

Branca states that problem-solving skills are the core of mathematics learning (Creswell, J.W. 2014). Applying statistical problem-solving or decision-making skills requires statistical thinking. Thought terms statistics were first created by Wilks in a presidential speech at the forum American Statistical Association (Wilks, 1951), when he quotedWells that “Statistical thinking will one day be as necessary to every citizen as the ability to read and write!” (Coleman, 2013). Statistical thinking skills are not only needed when students are studying but are needed when someone makes decisions (Meylasari, 2020). NCTM (2020) includes the content of data analysis and probability into one of five standards which include number operations, algebra, geometry, measurement, and data analysis and probability.

Several higher-order thinking skills such as asking questions, making interpretations and estimates, reasoning, critical thinking, drawing interference, metacognition, the ability to detect inadequate reasoning, problem reasoning skills, and making mental calculations and estimates are also included in statistical thinking abilities. Statistical knowledge helps in the decision-making process and in solving real-world problems involving data. However, the reality in the field is that students have difficulty learning statistics. According to previous research, the source of secondary school students' difficulties is teaching unrelated statistical concepts and procedures, learning without real examples, and also prioritizing memorization over conceptual understanding (Çakmak & Durmus, 2015; Ben-Zvi & Garfield, 2008). According to Ben-Zvi and Garfield (2008), conceptual learning is necessary for the development of statistical thinking because conceptual learning involves understanding and interpreting data as well as making conclusions from the data found.

Statistical thinking is not just about carrying out statistical calculations or defining concepts, but this requires interpretation, reasoning, deduction, and making generalizations about data (Mooney, 2002; Ben-Zvi & Garfield, 2008). Therefore, statistical thinking requires more than just knowing concepts and procedures and doing calculations. Considering that statistical data plays a large part in modern daily life, it is important to develop statistical thinking while studying mathematics at school. Statistical thinking is the ability to describe, organize, present, analyze, and interpret data as well as apply an understanding of statistical concepts in everyday life by providing critical evaluations and making generalizations (Gal, 2002). If statistical thinking skills are high then understanding of the definition of statistical objects and attention to statistics are also good (Aizikovitsh-Udi et al., 2016).

Statistical thinking can develop students' critical thinking, especially on how to receive information, manage the truth of information, and provide comments (Aizikovitsh -Udi, 2016, 2017; Lizarelli et al., 2020). Moreover, it relates to students' creativity in solving problems with various solutions (Akaike, 2010). This is also able to develop students' reasoning in decision-making and helps build a basic understanding of statistical material (Garfield et al., 2015). In this case, understanding students' statistical thinking in general and examining students' stages of statistical thinking, in particular, is very important to inform learning practices, especially problem-solving activities in the classroom, which can continue to be improved to support the development of students' thinking (Marlissa & Widjajanti, 2015; Sopamena et al., 2018). Observing students' statistical thinking

processes can be done by giving students problems so that the cognitive processes that occur can be observed directly (Lailiyah et al., 2020).

Statistical thinking is everything a statistician does, including summarizing data, solving statistical problems, drawing conclusions through procedures, and explaining interpretations of results (Chance, 2002). Hogg et al, 2000) defines statistical thinking as the ability to formulate appropriate questions about data, how to collect effective data to answer them, and how to summarize and interpret information, and come to conclusions. Mooney and Edwar (2002) define statistical thinking as describing data, organizing it, summarizing it, representing or displaying it, analyzing it, and interpreting it.

According to Chan and Ismail (2014), statistical thinking is the ability to understand the statistical process as a whole and apply statistical understanding to real problems by providing criticism, evaluation, and making generalizations in terms of describing data, organizing data, representing data, analyzing and interpreting data. This is in line with the opinion of Ulusoy and Altay (2017) who state that there are four processes/constructs in statistical thinking based on the framework of Jones et al. (2000) namely describing data, organizing data, representing data, analyzing and interpreting data. The first process, describing data, shows that someone can completely read the data presented in the data display. The second process, data organization, and reduction, reveals that one can group data into classes in various ways and can explain the size concentration, and distribution of the data. The third process, data representation, states that someone can present the data with various data displays. The fourth process, analyzing and interpreting data, shows that someone can provide contextual responses and make conclusions or predict population/sample characteristics based on data (Ulusoy & Altay, 2017). In this research, statistical thinking refers to students' cognitive activities that reveal the ability to understand how to describe, organize reduce, represent analyze, and interpret data, which is implemented in real problems.

Statistical Thinking involves critical evaluation and analysis of statistical research results. Gomez-Blancarte et al (2021) also agree that statistical thinking involves a comprehensive understanding of statistical concepts and processes, including the rationale behind various methods of data analysis and the context of statistical research conducted. Abbiati et al (2021)highlight in their research that statistical thinking differs from mathematical thinking in that it focuses on the variability and production of data and relies heavily on one's interpretation and critical judgment. Delmas (2004) defines statistical thinking as a person's ability to know when and how to apply statistical knowledge and procedures effectively and efficiently. This application involves a good understanding of statistical concepts and methods and using them appropriately in different situations. The ability to integrate statistical conclusions with the context of a problem is an important aspect of statistical thinking.

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Applying statistical thinking skills to a problem in mathematics learning activities is very important. Based on the results of Kim's research (2020), students can understand mathematics learning optimally by using teaching aids or learning media that are appropriate to their level of development. The use of media in the learning process aims to make the learning process effective and efficient so that the quality of education can be improved (Batubara, 2018). The use of learning media must adapt to student characteristics, where students currently live side by side with technology. Android applications are one of the learning media choices that every student is interested in nowadays because they are easy to use and can be taken anywhere. The use of Android applications is intended to complement existing learning and provide opportunities for students to re-study material they have not mastered anywhere and anytime (Nurwita et al., 2023). Using this Android application can certainly provide students with a different experience in the mathematics learning process.

The choice of learning media needs to be adjusted to student characteristics because media can have a different learning motivation influence on each student. Azkia et al. (2023). The closer the student's characteristics are to

the media used, the higher the motivational influence generated by the media. Along with changes in progress, technology has been created that makes human activities easier, one of which is the smartphone. Smartphones, which were originally used as communication tools, now have more than their basic function. Various features have been embedded, such as image and video processing, document processing, and others. The growth of mobile devices, especially smartphones, has experienced very rapid growth from year to year. According to www.sampoernauniversity.ac.id, there will be 167 million smartphone users in Indonesia in 2022. This number is believed to continue to grow rapidly, especially in urban areas. Seeing the number of smartphone users, Android-based learning (blended learning) will be very supportive (Fitriani et al., 2021).

Research conducted by Fitriani et al. (2023), obtained the results that students who were taught using the blended learning learning model had a better rotation of cognitive conflict strategies than those taught through conventional learning. Research by Indrapangastuti et al. (2021) also states that blended learning can significantly improve learning achievement. Research by Fitriani et al. (2021) obtained results that e-book-based blended learning integrated with YouTube in mathematics learning geometry material met the criteria of valid, practical, and effective. Furthermore, the results of research by Setiawan et al. (2021), found that the average student in Indonesia who uses blended learning effectively can improve their mathematical abilities. Therefore, teachers are expected to be able to implement blended learning effectively. Educators are required to be able to keep up with technological developments to improve the quality of education by continuing to innovate and be creative. Teachers can develop technology-based, student-oriented learning systems and facilitate their needs with learning activities that are challenging, active, creative, innovative, effective, and fun (Nurjanah et al., 2021). This policy is used in the hope that it can have a better impact on the sustainability of education. The use of technology in the 21st century is highly recommended in education so that teachers and students can adapt and utilize technology in facing the industrial era 4.0 and society era 5.0.

The use of technology in education is very useful for facing future challenges. So blended learning must be used in schools from now on. Baloran's (2020) research states that students and teachers must get used to blended learning from now on to face future challenges. Learn from the COVID-19 experience, when learning methods were suddenly shifted everyone was not ready to do blended learning. Therefore, blended learning will continue forever, not because of COVID-19, but rather because it is a learning process that has positive benefits for Indonesian education in the future. This has the positive impact that blended learning has become an option for learning on campuses (Lapitan et al., 2021). In response to this, of course, there needs to be media that supports learning so that it becomes more effective. Research by Setiawan et al. (2021) states that blended learning, which is used effectively, can improve mathematical abilities. Therefore, the author provides a solution to overcome this problem, namely by developing innovative learning media in the form of electronic modules (e-modules) that can be used in blended learning. Research by Anik et al. (2019) states that e-modules are very significant in improving student learning outcomes.

Based on the explanation above, developing e-modules for blended learning learning is believed to provide better learning outcomes. Moreover, the e-module developed takes into account student characteristics in the learning process. The difference between Android-based e-modules and other learning models lies in the stage of preparing the detailed design section that integrates technology into the e-module. Apart from that, the e-module was developed using an Android-based application, namely sketcware, so that the e-module can be used on laptops as well as cell phones and Android online or offline. Furthermore, in the e-module, there is an independent learning section with learning video facilities that train students to understand the material independently or collaboratively, and each activity contained in the e-module has a problem-solving stage to achieve statistical thinking skills so this becomes a novelty in the study.

Method

The method used in this research is literature/library study. Literature study is an activity to study the theories underlying research, both theories relating to the field of science being researched and methodology. Putrihapsari and Fauziah (2020)defines literature study as research carried out by reviewing various literature studies required in the research. The purpose of using the literature study method in this research is as a first step in planning further research by utilizing literature to obtain data in the field without needing to go directly. The data sources used as references in this research are relevant library sources as primary data sources. research data, research reports, scientific journals, books, theses, theses, dissertations, and even newspapers that are relevant to the topic being discussed. After obtaining the data source as a reference, it is continued with analysis of the literature review data which is carried out using content analysis. Content analysis is where the researcher examines a text objectively to get an overview of the content as it is, without the intervention of the

researcher(Ahmad J, 2018).In this case, the researcher conducts an in-depth discussion of the content of information from a data source which requires setting time to read and examine the data so that he can find a solution according to the topic being discussed. It is hoped that these results can answer the problem and be used as a consideration in the scope of using Android-based e-modules to achieve the capabilities of statistical *thinking* learners.

Results and Discussion

Mastering basic mathematical concepts is the basic foundation that students who study mathematics must have in the future (Suhandri et al., 2017). This is intended so that students do not experience learning obstacles when studying mathematics at a higher level such as studying statistics. However, existing facts show that many students experience difficulties when they have to solve the problems they study (Hermaini & Nurdin, 2020). This difficulty occurs because students do not understand the basic concepts that have been studied previously so when faced with problems, students tend to be confused, and even forget which concept to use to find a solution to the problem being faced. According to Ben-Zvi and Garfield (2008), several students' challenges in understanding mathematical concepts, especially statistics, which can interfere with their statistical thinking abilities include many statistical ideas and rules that are complicated, difficult, and/or counterintuitive. Teachers find it difficult to motivate students to engage in calculating work in statistics learning. Many students have difficulty with basic mathematics such as fractions, decimals, and algebraic formulas which interferes with learning statistical content.

Based on the results of a survey conducted by Makmuri et al. (2021), it was found that learning using books makes learning less interesting, mathematics lessons are still considered unpleasant and difficult lessons. Limited media and learning resources are also considered to be one of the factors that cause students to have difficulty learning. Azkia et al. (2023) stated that most students find it difficult to construct and visualize mathematical problems (geometry and statistics). This material requires imaginative thinking to explore relationships between points, lines, planes, and between data. Based on the problems and difficulties experienced by students, learning media is needed.

Using learning media can make it easier for students and teachers to carry out learning activities. Learning media has an important role in the student learning process because abstract learning materials can be made concrete in learning using the animations presented (Kuswanto & Radiansah, 2018; Novianti, 2018; Shodikin, 2017). A good solution that can answer this problem is to use digital-based learning media. Azkia et al. (2023) stated that digital-based learning media has a big influence on mathematics learning outcomes. Apart from that, in line with research by Tumangkeng et al. (2018) where electronic learning media makes a greater contribution than print media such as books. This is also in line with the results of research conducted by Tamur et al. (2020) that the effectiveness of using mathematics applications provides an average effect size in the high category and based on the results of research conducted by Wungguli and Yahya (2020) that digital-based learning media makes it easier for students to understand abstract mathematical concepts. With the development of this learning media application, it is hoped that it can create a learning atmosphere that is more practical, and fun and can be accessed anywhere and at any time. This learning media application is presented in an attractive package, so it is hoped that it can increase students' interest in studying mathematics. The learning media developed is an Android-based application. So this learning media can be easily operated because students are used to using smartphones in everyday life. This learning media is included in the e-module-based media category which uses blended learning.

According to Tenmau et al. (2023) stated that Android-based learning media has advantages, namely: applications can be run on all versions of Android, applications can be run on all screen resolutions, and applications can be used anytime and anywhere. The existence of Android-based learning media can be an alternative learning resource for students so it is hoped that students can be motivated to be enthusiastic about learning. This learning media can motivate teachers to always explore their creativity in using appropriate learning media so that it attracts students' interest and they want to learn in a class atmosphere that is fun, effective, conducive, and active. Apart from that, research conducted by Muyaroah and Fajartia (2017), the results obtained by Android-based learning media have advantages, namely: (1) the media has an attractive design appearance for students, (2) it is easy to operate, and understood and understandable by students, (3) students do not feel bored when using it, (4) can be used independently either at school or at home. Based on relevant literature studies, the use of Android e-modules can improve students' thinking skills when compared to other learning media, this is because Android modules have several advantages including a) broad application and design prospects so that the delivery of material becomes more interesting and can increase student learning

motivation, b) able to present movements to shape the learning experience of students, c) is flexible so that it can be used anytime and anywhere (blended learning), and d) is more practical because it can contain materials, assignments, learning videos and also direct learning activities (touch screen).

According to Hamzah et al. (2022) said that the use of Android-based e-modules is effective in improving students' mathematics learning outcomes. According to Kartiko & Mampouw (2021), the Android application-based E-module supported by LKPD is very effective in helping students achieve 85% complete learning of mathematics material. according to Astuti et al. (2022) stated that the Android-based Statistics E-Module had a statistically significant effect on students' mathematics learning outcomes. According to Dewimarni and Rizalina (2022), Android-based statistics learning media (e-modules) are effective in improving statistics learning outcomes. According to Rismayanti et al. (2022), a modular-assisted e-module on smartphone Android is interesting and worth using and can improve the critical thinking skills of mathematical students. According to Nurwita F, et al (2023), that android application-based learning media (e-modules) can improve the mathematical problem-solving skills of learners. Learning outcomes also show a positive impact on accelerating and improving students' mathematical abilities because the characteristics of Android application-based e-modules provide students with the opportunity to re-study material they have not mastered anywhere and anytime. This also cannot be separated from how to teach statistical material to support the abilities of statistical thinking learners.

Based on research results (Hamzah et al., 2022; Kartiko & Mampouw, 2021; Astuti et al, 2022; Dewimarni &; Rizalina, 2022; Rismayanti et al., 2022; Nurwita et al., 2023) the presentation of the material strongly supports statistical thinking skills. The characteristics of the material presented from the results of these studies construct the characteristics of statistical thinking skills according to Martadipura, (2012), namely, there are four constructions, namely: (1) describe the display of data, (2) organize and reduce data, (3) representing data, (4) analyzing and interpreting data. The characteristics of the results of the researchers above also apply the stages of cognitive thinking to the SOLO model (Structure of the Observed Learning Outcome) from Biggs and Collis (1991) and Jones, et al. (2000) divide the level of statistical thinking into four, namely: 1) Idiosyncratic; 2) Transitional; 3) Quantitative; and 4) Analytical.

Statistical thinking is known as a cognitive action in which students engage in statistical tasks, such as describing, organizing, summarizing, representing, and analyzing data (Mooney et al. 2001). This means statistical thinking is a mental process that allows students to use statistical methods to describe, analyze, evaluate, and make decisions, while the ability to think here means mental thinking, which arises from activities carried out by students. The statistical thinking process is very important to answer future challenges so it needs to be emerged to form flexible and organized mental processes carried out by students. The aim of applying statistical thinking skills is to solve statistical problems and problems through the use of several skills of induction, deduction, interpretation, and perception of relationships which refer to the ability to handle data descriptively. Further than that is how to make decisions to apply them in everyday life.

Conclusion

The use of Android-based e-modules in mathematics learning is very urgent and crucial for teachers in the industrial era 4.0 and society era 5.0. Previous research shows the advantages and capabilities of Android-based e-modules that can improve students' mathematics learning outcomes, including statistical thinking abilities. The need for students in guidance activities and dependence on learning assistance to understand concepts is still very high. With Android-based e-modules, it is hoped that you can learn independently anytime and anywhere. Thus, students' ability to define problems and direct them to find the answer/resolution of the problem given can be realized. Android application-based e-modules can be a learning alternative that can be applied during the distance learning period. Teachers can assist students through electronic teaching materials distributed to students, learning media, or step-by-step guidance through Questions and discussions can be done online or offline. Teachers need to design learning media well so as not to cause students to depend on the assistance provided. The application of Android-based e-module learning to achieve statistical thinking skills in mathematics learning using blended learning needs to be followed up.

Recommendation

The development of Android-based e-modules is very relevant to the Industrial Revolution 4.0 era, especially during face-to-face and virtual learning. Therefore, the author recommends using Android-based e-module

learning media so that statistical material can be developed. The use of LKPD to support blended learning needs to be organized and planned well so that it can function as a tool for controlling students' learning progress as well as an evaluation tool for indicators of students' achievement of statistical thinking abilities.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Computational Thinking, Plug and Unplug Theory: A Review of the Literature

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Abstract: The purpose of this study was to ensure that computational thinking (CT) is viewed as a critical skill necessary to adapt to the future. However, educators, especially teachers and researchers, have not made it clear how it should be taught. In this study, we conducted a meta-review of studies published in academic journals from 2018 to 2023 and divided them into application courses, adopted learning strategies, participants, teaching tools, programming, impact, creativity and course categories for CT education. The review results depicting that the promotion of CT in education has made great strides over the past decade. In addition to the increasing number of CT courses in each country, the subjects, research topics and materials have also become more diverse in recent years. It was also noted that CT applies primarily to program design and computer science activities, with some research being related to other subjects. On the other hand, most studies employ project-based learning, problem-based learning, collaborative learning, and game-based learning for CT activities. This means that activities such as aesthetic experiences, design-based learning, and storytelling are employed relatively infrequently. In addition, students' cognitive abilities vary by age, so CT skill development methods and content standards should vary accordingly. Furthermore, most studies reported on CT performance and prospects of learners, but little training of learners' information social skills. Research trends and potential research topics in CT are therefore suggested as a reference for researchers, educators, and policy makers.

Keywords: Computational thinking, Plug and unplug theory, Technology

Introduction

The concept of Computational thinking (CT) was initially introduced by Paper (1990), and since then, it has been a topic of discussion among several scholars regarding its definition, education, and assessment (Grover & Pea, 2013). CT as a learning approach is still very much a trend at the moment, in this article we will look at a systematic literature review on taxonomy, the use of subject divisions, levels and tools, assessment and learning strategies. According to Wing (2006), CT is not just a programming skill limited to computer scientists, but an everyday skill necessary for everyone. Wing (2010) also defined operational thinking as the problem-solving process, enabling successful execution of message processing agents and resolution of problems. Computers can assist us in problem-solving through two key steps: firstly, analyzing the steps required to solve the problem, and then utilizing technical expertise to operate the computer for problem-solving. For instance, one must have a

grasp of mathematical formulas and explain the problem, and then apply basic methods or formulas to solve the problem using computer computation. Similarly, when designing animations, the animator must first plan the storyline and shooting techniques before creating the computer animation using software and hardware. These two examples illustrate that computational thinking (CT) is the thought process that individuals must engage in before operating computers and machines.

As an illustration, the United States has established curriculum frameworks to promote computational thinking abilities in K-12 education and instill a favorable disposition towards computer science among young students (Santos et al., 2018). In this regard, Code Hour, Code Week, and Scratch Day are some of the initiatives that foster the development of computational thinking and promote its integration in the curriculum (Eguíluz, Garaizar & Guenaga, 2018; Hava & Koyunlu Unlu, 2021). It means that CT has used by many countries for their curriculum.

Literature Review

Computational Thinking

Computational thinking is a skill that has become essential in our daily lives, and it is no longer limited to computer engineers. It is important for everyone to have a positive attitude towards, comprehend, and apply this skill in their routine (Wing, 2006). The capabilities and constraints of CT are based on computational processing, whether it is the human mind or computers that are utilized to process the problem. In addition to the 3Rs (reading, writing, and arithmetic), children in their early learning phase should be educated on how to implement CT and perform logical analysis (Wing, 2006). CT comprises four operational skills, namely simplification, integration, transformation, and simulation. To make a problem easier to understand, CT applies fundamental computer science concepts to resolve issues, design systems, and transform them into a thinking mode that humans can comprehend (Wing, 2006).

CT encompasses the processes and techniques used to operate a system and focuses on how individuals use computers to solve problems (Wing, 2008). CT is not concerned with computer hardware or imitating the computer's thinking mode. Furthermore, Wing (2008) argues that CT is not only crucial for problem-solving, but also for identifying and developing problems. CT is not solely dependent on machines, as individuals can use machines to produce CT processes (Wing, 2008). Therefore, Wing (2008) suggests that CT is no longer limited to learners in computer science but is also essential for learners in other domains. Educators must create and promote facilities for learning computational thinking. Computational thinking is acknowledged as a skill that students must acquire in the twenty-first century to comprehend the information technology-dominated world and actively participate in it (Wu et al., 2019; Zhang & Nouri, 2019).

Taxonomies of CT

According to Wing (2006), CT can be classified into 11 thinking processes, including abstraction, algorithm design, decomposition, pattern recognition, and data representation. We also added the other steps of computational thinking that we found in the past studies, as shown in Table 1.

Application Any Subject Area

CT can be integrated with a variety of disciplines, yet some instructors still rely on programming languages to impart its principles (Lye & Koh, 2014; Zhong et al., 2016). While many educators contend that programming languages are the most straightforward and fitting approach to teaching CT, this narrow view may limit the potential of logical thinking to a select few subjects and learners (Wing, 2006, 2008). In truth, CT has been extensively employed in diverse fields, such as mathematics (Benakli et al.,, 2017; Snodgrass et al., 2016; de Freitas, 2016), biology (Dodig-Crnkovic, 2011; Libeskind-Hadas & Bush, 2013; Navlakha & Bar-Joseph, 2011; Rubinstein & Chor, 2014), computer science (Repenning, 2012; Shell & Soh, 2013; Repenning et al., 2015; Grover et al., 2015), language (Evia, Sharp, & Pérez-Quiñones, 2015), and programming (Bers et al., 2014; Kazimoglu et al., 2012, p. 316; Wolz et al., 2011).

Computational thinking it’s just a not for computer using only, but many subject matter, CT helping for hot to learn and teach some subject areas. Numerous contemporary scientific predicaments necessitate the cooperation

of experts from diverse scientific domains. Novel scientific disciplines, such as biostatistics, physical chemistry, and theoretical physics, have even emerged. Nevertheless, the educational curriculum segregates subjects in distinct categories. In Slovakia, science subjects are also partitioned into physics, chemistry, and biology. Both mathematics and science education aspire to facilitate students in comprehending the marvels of the surrounding world. They utilize comparable approaches to problem-solving and scientific investigation, which encompass logical reasoning, hypothesis formulation, observation, analysis, and experimentation. Even tertiary-level students lack experience in resolving practical issues, and consequently, they struggle to interpret the findings they acquire (Bobo ˇnová, 2019).

Table 1. Computational thinking steps

Num	Thinking steps	Definition	Resource
1	Abstraction	Identifying and extracting relevant information to define main ideas.	(Barr & Stephenson, 2011; Grover & Pea, 2013; Wing, 2006)
2	Algorithm	Design Creating an ordered series of instructions for solving similar problems or for performing a task	(Barr & Stephenson, 2011; Grover & Pea, 2013)
3	Automation	Having computers or machines do repetitive tasks.	(Fletcher & Lu, 2009; Forrest & Mitchell, 2016; Kafai & Burke, 2013)
4	Data Analysis	Making sense of data by finding patterns or developing insights.	(Angeli et al., 2016; Atmatzidou & Demetriadis, 2016; Basu et al., 2017; Cesar et al., 2017; Choi et al.,2016; Magana & Silva Coutinho, 2017)
5	Data Collection	Gathering information	(Barr & Stephens, 2011; CSTA, 2011)
6	Data Representation	Depicting and organizing data in appropriate graphs, charts, words, or images.	(Benakli et al., 2017; Gynnild, 2014; Manson & Olsen, 2010; Stefan, Gutlerner et al., 2015; Weintrop et al., 2016)
7	Decomposition	Breaking down data, processes, or problems into smaller, manageable parts.	(Kilpeläinen, 2010)
8	Parallelization	Simultaneous processing of smaller tasks from a larger task to more efficiently reach a common goal.	(Barr & Stephenson, 2011)
9	Pattern Generalization	Creating models, rules, principles, or theories of observed patterns to test predicted outcomes.	(ISTE & CSTA, 2011)
10	Pattern Recognition	Observing patterns, trends, and regularities in data	
11	Simulation	Developing a model to imitate real-world processes.	(Barr & Stephenson, 2011; Grover & Pea, 2013; Wing, 2006)
12	Transformation	Conversion of collection information.	(Wing, 2006)
13	Conditional logic	Finding the associated pattern between different events.	(Grover & Pea, 2013)
14	Connection to other fields	Finding the relationships between information.	(CSTA, 2011)
15	Visualization	Visual content is easier to understand	
16	Debug & error detection	. Find your own mistakes and fix them	(Atmatzidou & Demetriadis, 2016; Berland & Lee, 2012; Yadav et al.,, 2014)
17	Efficiency & performance	Analyze the efficiency of the final results in order to achieve a more perfect goal.	(Grover & Pea, 2013)
18	Modeling	Solve the current problems through the model architecture or develop a new system.	(Barr & Stephenson, 2011; ISTE & CSTA, 2011)
19	Problem solving	The final step of logical thinking	(Kim & Kim, 2016; Ngan & Law, 2015)

In other hand acquiring mathematical proficiency alone is no longer sufficient in the 21st century. Critical thinking, creativity, and technology literacy are also essential skills. One of the recommended teaching methods for active learning in mathematics is collaborative problem solving. Studies have shown that this approach

yields better results in standardized mathematics tests compared to traditional transmissive methods, especially when the problems are related to real-life situations faced by students and involve the use of technology. Collaborative problem solving also enhances students' appreciation for mathematics and science, which can positively impact their academic performance and career choices in the future.

Moreover, it is anticipated that computing will comprise half of the STEAM-related occupations in the coming years. Although children and adolescents frequently use smartphones and tablets, they are primarily used for amusement rather than educational purposes. Conversely, mathematicians regard the efficient utilization of technological resources as a "valuable aspect of the mathematics practice. Similarly, scientists share this perspective. As a result, there has been significant growth and experimentation in the creation of resources designed to cultivate computational thinking (L'ubomíra Valoviˇcová et al., 2020).

However, not all approaches are appropriate for problem-centered learning. Utilized opaque objects as the central concept for tasks that promote computational thinking, which generated a strong response (Cápay & Magdin 2011; L'ubomíra Valoviˇcová et al., 2020). Created an exercise that allowed students to learn about the physical principles of an ultrasonic sensor, linking knowledge from physics and computer science (Burbaite et al., 2018). This enabled students to acquire conceptual knowledge in physics while designing algorithms. Another instance of an interdisciplinary approach is found in Lytle et al.'s 2019. work, which focused on an agent-based simulation with an emphasis on students' perceived ownership of their created programs. Students who utilized the use-modify-create approach felt more confident and considered the code they developed during the guided portion, with minor adjustments, to be more familiar than the transmissive approach used by the control group.

Several studies have indicated that a design-based approach can enhance students' computational thinking and self-efficacy in using computers while also increasing their awareness of the various tasks that can be accomplished with a computer. Relationship between students' computational thinking skills and (creativity, algorithmic thinking, cooperative thinking, and critical thinking) and their STEM career interest Hava & Koyunlu -Unlu, 2021). So that many learning strategies can be based with CT to teach the concept of measuring connects mathematics and physics, and the problem-based orientation of the analyzed activity supported the interdisciplinary learning of participating students.

Learning and Teaching Strategies

As per the literature review on CT, it is evident that the advancement of operational thinking is not limited to computer programming but can also be implemented in mathematics and biology to enhance students' logical concepts, CT, and problem-solving abilities.

Table 2. Categories of the 16 learning strategies in the CT learning activities adopted in this study.

Num	Strategy	Explanation
1	problem-based learning	The definition of problem-based learning is helping students toset their own learning goals through a problem scene. Students will explore the learning solution by themselves, and report their own learning conclusions and feedback to the team. Problem-based learning is not only used to solve problems, but also to enhance students' understanding of new knowledge through appropriate questions (Wood, 2003)
2	collaborative learning (teamwork)	Group learning is divided into: collaborative learning and cooperative learning. In cooperative learning, partners splitthe work,solve subtasksindividually, andthenassemble the partialresults into the final output. Incollaborative learning, group members are required to complete the task together, negotiate, and share meanings relevant to the problem-solving task (Dillenbourg, 1999; Roschelle & Teasley, 1995).
3	project-based learning	Project-based learning (PBL) is a model that organizes learning around projects. Projects are complex tasks, based on challenging questions or problems, that involve students in design, problem-solving, decision making, or investigative activities; PBL gives students the opportunity to work relatively autonomously over extended periods of time, and culminates in realistic products or presentations (Jones et al., 1997)
4	game-based learning	Game Based Learning (GBL) is similar to Problem Based Learning (PBL), wherein specific problem scenarios are placed within a play

		framework (Barrows & Tamblyn, 1980). GBL can provide a Student-Centered e-Learning (SCeL) approach (Motschnig-Pitrik & Holzinger, 2002). Moreover, games include many characteristics of problem solving, e.g. an unknown outcome, multiple paths to a goal, construction of a problem context, collaboration in the case of multiple players, and they add the elements of competition and chance
5	scaffolding	Scaffolding provides the framework of learning to help the students learn the new knowledge at the beginning. The purpose of scaffolding is to train the students to solve problems independently.
6	problem solving system	To find the solution to problems through logical or special methods, and to understand the goals of the problem and apply the appropriate abilities and methods to solve the problem
7	storytelling	Pesola (1991, p.340) suggested that storytelling is "one of the most powerful tools for surrounding the young learner with language.'' According to Isbell (2002), many stories that work well with children include repetitive phrases, unique words, and enticing descriptions. These characteristics encourage students to join in actively to repeat, chant, sing, or even retell the story. Much of the language children learn reflects the language and behavior of the adult models they interact with and listen to (Strickland & Morrow, 1989). ''Listening to stories draws attention to the sounds of language and helps children develop a sensitivity to the way language works'' (Isbell, 2002, p. 27).
8	systematic computational strategies	Systematic computational learning theory provides a formal framework in which to precisely formulate and address questions regarding the performance of different learning algorithms so that careful comparisons of both the predictive power and the computational efficiency of alternative learning algorithms can be made.
9	aesthetic experience	Aesthetic experience provides the means through which meanings that are ineffable, but full of feeling, can be expressed and understood, helping us to tolerate ambiguity, to discern subtle relationships, and to focus on details (Kokkos, 2010).
10	concept-based learning	Concepts are a way to organize and make sense of learning. The students try to define the attributive differences among different concepts. Other researchers have made use of concept-based models or graphic organizers. The model described here relies heavily on including attributes that can be generalized to multiple instances. The other concept depends on the definition of the concept of exclusion featuring a collection of example facts (Boudah et al., 2000; Erickson, 1998; Kameenui & Carnine, 1998).
11	HCI teaching	Human-Computer Interaction teaching (HCI teaching) is suitable for all grades of college students to learn natural science, and is also a common online teaching method (McCoy & Ketterlin-Geller, 2004).
12	design-based learning	Design-based learning is integrated design thinking and processes in the curriculum, which can be applied to many subjects. It asks students to set up their own goals and to create ideas to achieve them
13	embodied learning	Theories of embodied cognition argue that mental modal simulations in the brain, body, environment and situated actions are composed of central representations in cognition. Based on embodied cognition, body movements of performing natural science experiments can provide learners with external perceptions for better knowledge construction.
14	teacher-centered lecture	Students put all the focus on the teacher, and concentrate on lectures without collaborative learning activities. Students will not miss the key points through the teacher guiding all of the activities.
15	Critical computational literacy	A concept of "computational literacy" helps us better understand the social, technical, and cultural dynamics of programming. Critical computational literacy emphasizes how to use the computational method, and what can be done.
16	Universal Design for Learning	The basis of Universal Design for Learning (UDL) is grounded in emerging insights about brain development, learning, and digital media (Hitchcock, Meyer, Rose, & Jackson, 2002). It arouses the learners' interest through multiple methods of communication and expression.

In addition, strategies for learning or teaching not only in the school, but also it can be applying in higher education too. Depends or they want to use it or need analyzing firstly. So this study making some suggestion for using CT for teaching and learning based on Figure 1 below:

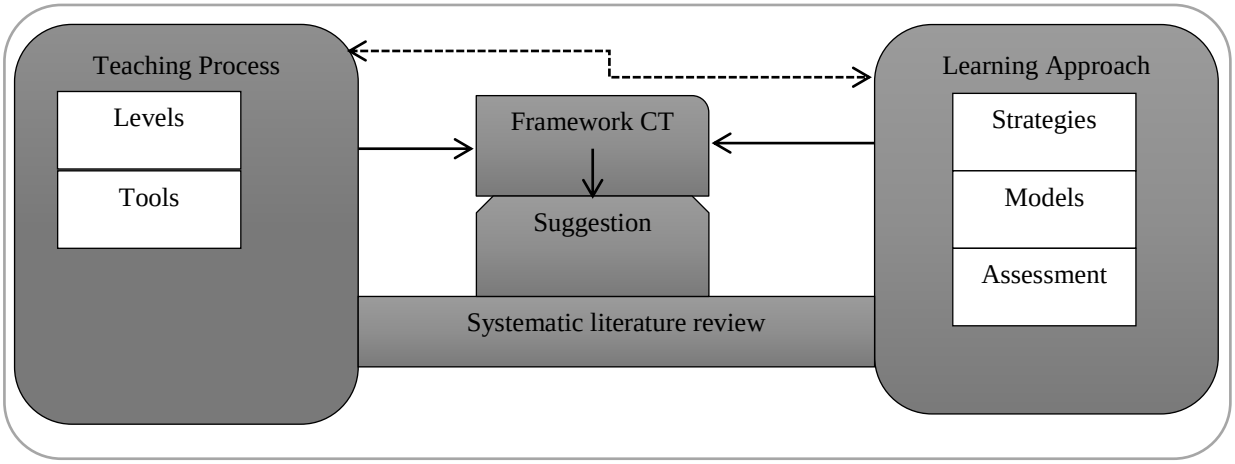

Figure 1. Conceptual framework of CT teaching and learning

The objective of this investigation is to create a basic structure for introspective reasoning and application in the realm of scientific education by recognizing the instructional and evaluative techniques that aid in revolutionary learning worldwide. The inquiries for research are categorized into two sections as stated below:

RQ 1: What is the dispersion of research based on the qualities of the material?
RQ 2: What are the prevalent themes and methods employed in literature to encourage computational thinking's application in science education for suggestions?

Method

The SCOPUS, SCI and SSCI database was utilized as the primary source for this research. Initially, we conducted a search using the term "computational thinking" to retrieve relevant papers, abstracts, and keywords. In the subsequent step, we narrowed down our search period to include articles published from January 1, 2006 for basics and 2018-2023 for primary resources. Upon establishing the time frame for publication, the search yielded a total of 1112 CT-related articles within the specified dates.

Subsequently, we narrowed down the article type to published academic journal papers, academic journal papers (in press), and books, resulting in a total of 262 journal papers or books. To further refine our analysis, we eliminated non-SCI and non-SSCI journal articles, leaving us with 120 articles for further examination. To ensure accuracy, two seasoned researchers scrutinized and classified the papers using our coding scheme. In cases where there were conflicting codes, the researchers were required to deliberate and reach a consensus. Then finally 52 selected articles for this systematic literature review for suggestions.

Data Distribution

Figure 1. depict the publishing scenario of CT papers from January 2006 until 2023. The earliest manuscript, authored by Wing (2006), elucidated the meaning of computational thinking to aid readers in comprehending CT. The quantity of CT articles escalated steadily from 2006 to 2023, with the original solitary paper expanding to 21 in 2018 and 44 in 2023. As shown in Figure 1, a total of 52 papers were published throughout the aforementioned period. This outcome is logical since CT is a novel benchmark for educators to formulate learning activities. Initially, academics defined CT and endeavored to promote it until it gradually progressed to implementation in the classroom. Furthermore, they shared concerns regarding integrating CT into courses and presented solutions for future research to design courses and activities. In addition, the number of CT papers doubled from 2018, indicating that it has gradually captured the attention of scholars and educators, and is a new topic that cannot be ignored in the future.

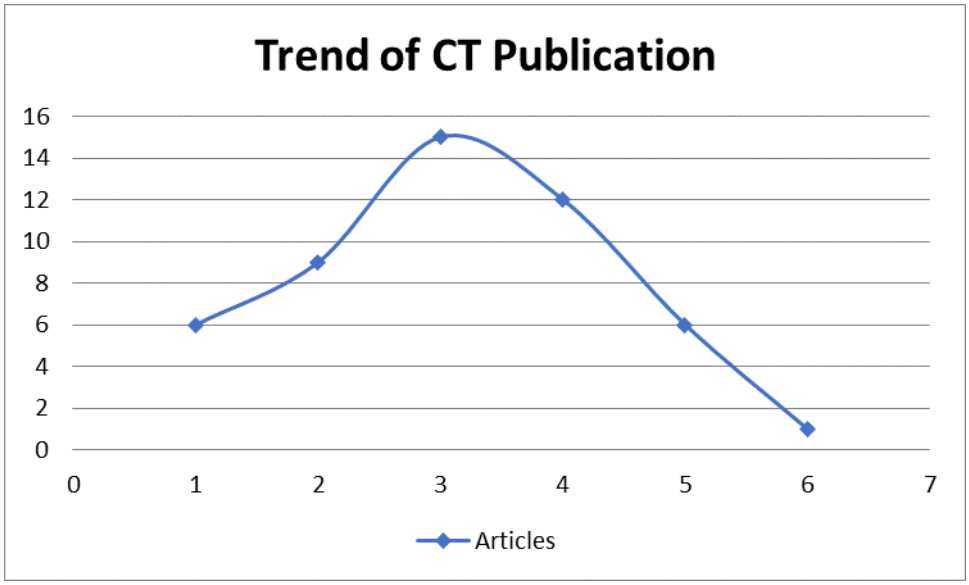

Figure2. Trend of CT publication

Coding Systems

The coding system was altered from the one created by Hwang and Wu (2014) and Hsu et al. (2018,) which consisted of variables such as nationality, writer, periodical, training program, educational approach, and participants (Hwang & Tsai, 2011; Hwang & Wu, 2014; Hsu et al, 2018). Furthermore, we compiled pertinent educational material information, which included teaching resources, programming dialects, and course classifications (formal or informal). The ensuing sections elaborate on the coding system for each aspect.

Identity

The fundamental details regarding the released documents are deliberated, encompassing writers, origin, participant and periodicals. The aim is to comprehend which nations have published CT studies with greater frequency. The data compilation project also comprised of publications and evaluations of literature.

Application Used

The CT field contains programming, information engineering, computer application software, mathematics, biology, medicine, society, business management, language, music, computer science, journalism, robotics, science and technology, epidemiology, physics, STEM, social ecosystems, and algorithms.

Learning Strategy

The category of 16 learning strategies was composed based on the previous studies in each country, and counted in project-based learning, problem-based learning, teacher-centered lectures, collaborative learning, game-based learning, aesthetic experience, concept-based learning, systematic computational strategies, scaffolding, problem-solving systems, storytelling, embodied learning, universal design for learning, HCI teaching, design-based learning, and critical computational literacy.

Teaching Tools that are often Used in CT Courses

The teaching tools that are repeatedly used in CT courses embrace programming software, games, mobile games, board games, experiments, Arduino, robots, Game Maker, video, IRS (Clickers) and e-books; however, in order to coordinate with the course, and considering suitability for different ages, the programming language categories include LoGo, LEGO, ViMap (based on Logo), MATLAB, ALICE, TurtleArt (similar to Scratch),

Scratch, Scratch4SL (Scratch for Second Life), Code.org (similar to Scratch), AgentCubes (making 2D/3Dgames), Scalable Game Design, Java, C, and C++. Apart from the plug model, CT learning can be done in an unplugged way, taking into account the concept of computation.

Results and Discussion

Research Question 1: What is the dispersion of research based on the qualities of the material?

Identity of Articles

In this investigation, we solely recorded the origin details of the leading author in the CT document. Furthermore, the meta-evaluation approach employed was based on the principles of a systematic review, as proposed by Wang et al. (2017) and Hsu et al. (2018). Based on the findings of the present meta-evaluation, various nations have initiated the development of CT instructional design. The distribution status of the leading five countries is visible in Figure 2. As a result of the study's selection pool, the top four are the United States, Turkey, Spain, and the United Kingdom. Additionally, this meta-evaluation examined the organizations that published more than two CT research papers, including the country and indexing depict of figure 3 and table 3 below:

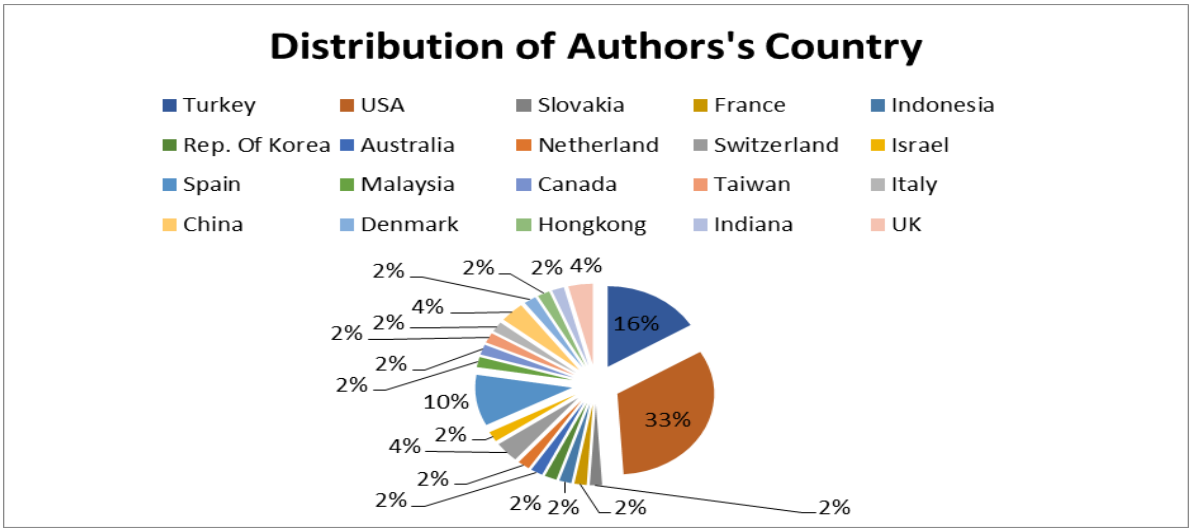

Figure3 . Distribution of Authors's Country

Furthermore, a SLR is carried out to evaluate the input of each nation. Figure 4 illustrates the allotment of writers of articles by nation. Turkey and United States of America (USA) are at the top of the list of publications in CT topics. Spain is in the third position with 5 writers, followed by UK with 2 writers. Moreover, China and Switzerland each have 2 writers.

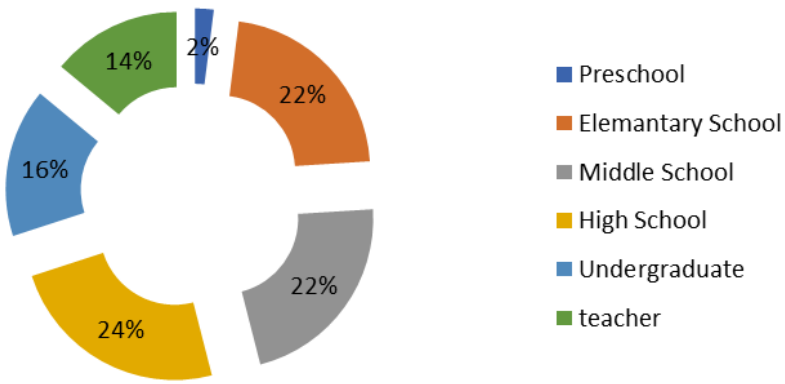

Figure 4. Levels of participants

Table 3. Journal metrics and ındexing ınformation

No	Journal	F	%	Indexed by (H Index/SJR 2023)	WoS (H Index/JIF for SSCI or JCI for ESCI 2021)
1	Journal of Science Education and Technology	18	36,735	Scopus (Q1/1.15)	WoS (SSCI/1.47)
2	Mathematics MDPI	1	2,041	Scopus (Q2/0.54)	WoS (SCIE/2.15)
3	Computers and Education	5	10,204	Scopus (Q1/3.68)	WoS (SSCI/3.75)
4	Heliyon	3	6,122	Scopus (Q1/0.61)	WoS (SCIE/0.72)
5	Information Discovery and Delivery	1	2,041	Scopus (Q2/0.54)	WoS (ESCI/0.52)
6	Journal of Educatioanal Computing Research	1	2,041	Scopus (Q1/1.67)	WoS (SSCI/2.20)
7	Journal of Educational and Technology System	1	2,041	ERIC	
8	Frontiers in Education	1	2,041	Scopus (Q2/0.66)	WoS (ESCI/0.89)
9	Journal of Digital Learning and Teacher Education	1	2,041	Scopus (Q1/0.87)	
10	Technology, Knowledge and Learning	2	4,082	Scopus (Q1/1.11)	WoS (ESCI/1.93)
11	TechTrends	1	2,041	Scopus (Q1/0.8)	WoS (ESCI/1.18)
12	International Journal of STEM Education	1	2,041	Scopus (Q1/1.67)	WoS (SCIE/2.46)
13	International Journal of Child-Computer Interaction	2	4,082	Scopus (Q1/1.07)	
14	Education and Information Technologies	3	6,122	Scopus (Q1/1.25)	WoS (SSCI/1.90)
15	Asia-Pacific Edu Res	1	2,041	Scopus (Q1/0.99)	WoS (SSCI/1.25)
16	Interactive Learning Environments	1	2,041	Scopus (Q1/1.17)	WoS (SSCI/1.93)
17	Comput Appl Eng Educ.	1	2,041	Scopus (Q1/0.65)	WoS (SCIE/0.64)
18	Education Tech Research Dev	2	4,082	Scopus (Q1/1.52)	WoS (SSCI/2.83)
19	Science and Education	1	2,041	Scopus (Q1/01.31)	WoS (SSCI/1.77)
20	Instructional science	2	4,082	Scopus (Q1/0.93)	WoS (ESCI/1.05)
Total		49	100		

RQ 2: What are the prevalent themes and methods employed in literature to encourage computational thinking's application in science education for suggestions?

Application Used

Afterwards, we examined the areas where CT was utilized. As depicted in Fig. 5, the highest percentage of papers, totaling 31, implemented CT in programming subjects. This was followed by 26 papers in the field of computer science, 11 in mathematics, and 9 in biology. Additionally, there were 28 papers pertaining to preliminary single-case design or recommendations for instructional design utilizing CT, which did not belong to a specific subject category and were thus excluded from this section of data classification. Furthermore, there were 30 papers that employed more than two subjects in their study. Therefore, it can be concluded that CT was predominantly used in programming design and computer science courses, but some scholars also integrated it

into diverse subjects like biology, mathematics, language, and music. These findings demonstrate that CT is not only crucial for computer-related subjects, but also for enhancing computing skills in mathematics and fostering problem-solving abilities in any subject material. the used of CT can be integrated or combined with various learning strategies, this is done as an effort to improve. Various learning strategies can be seen in the table below:

Table4. Strategie and learning models used.

Strategies and learning models	
C2STEM	Digital Story Telling
CCPS	Evaluation and developing
Coding Apps	Inquiry
Comparasion	Integrating
Computational physics Course	Intructional intervention
computer simulation	Modeling
Contructing Models	NGSS
correlation	Problem Solving
CPS	programming app
CT	SRA
CT Course	STEAM
Ct engineering	STEM
CT test	STEM and ACTMA evaluation
CT with reflective	STEM and CTIEs
CTAE	STEM and SEM
Design based learnig	Validating and reability

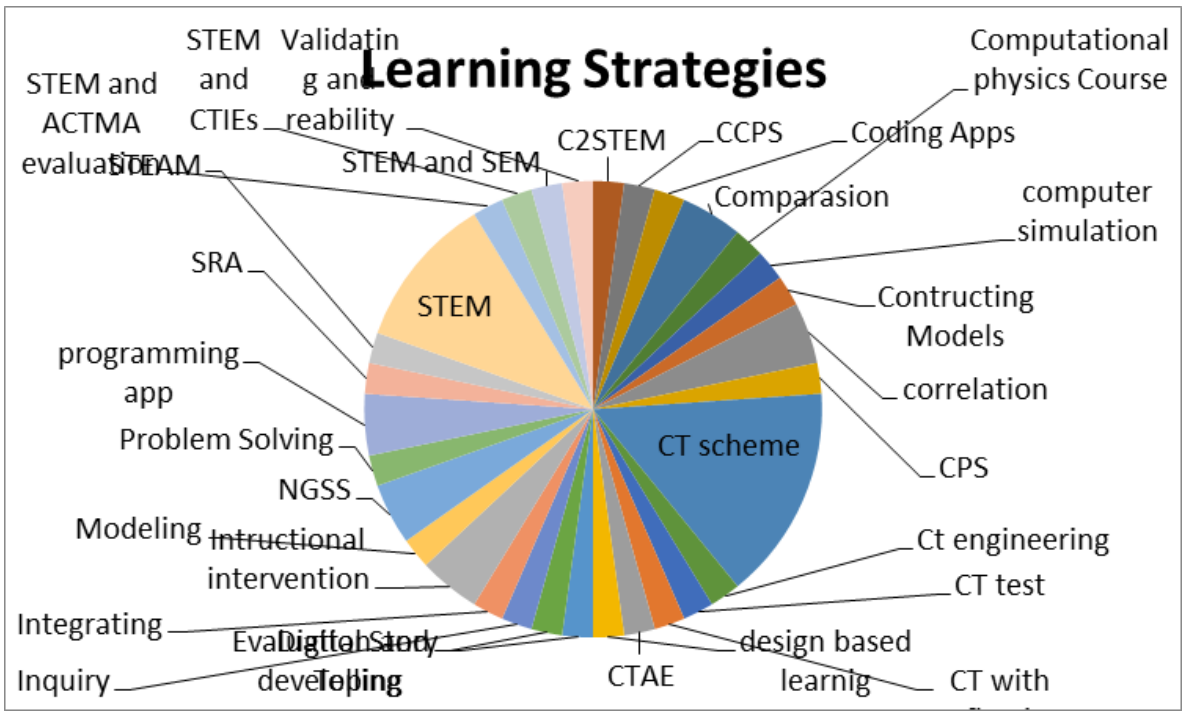

Figure 5. Learning strategies

CT can be used as a result variable by influencing the dependent variable, both of which can meet the needs of educators, with CT indicators that are adjusted to needs, some articles only use at least two variables, depicting or table . below:

Table5. Variable

Variable	
As dependent	44.90%
As Independent	55.10%

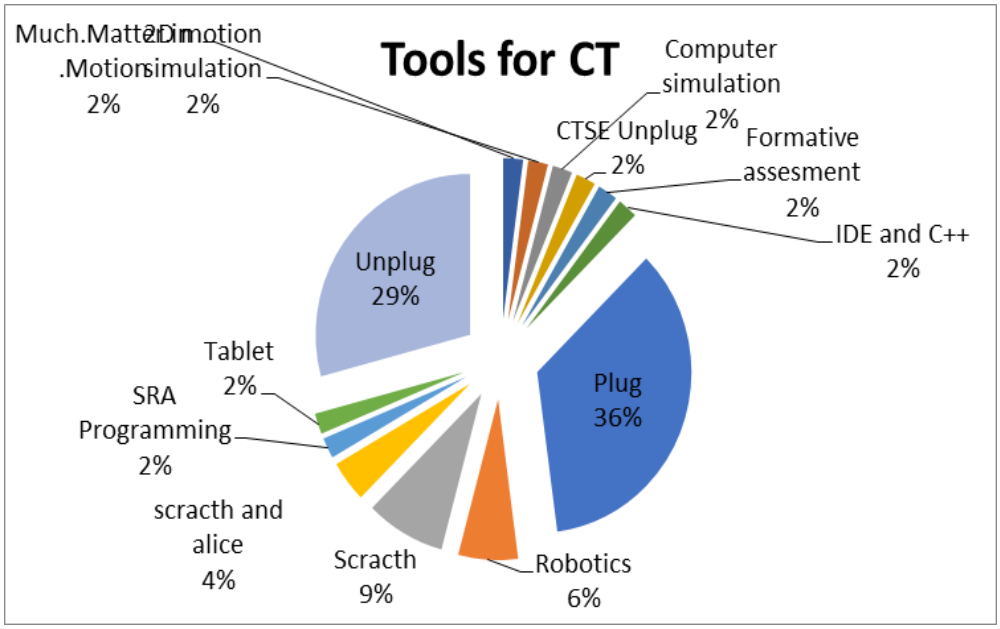

Figure 6. Tools for CT

Conclusion

This research involved a review and analysis of CT articles published in academic journals between 2006 and 2023. The data was classified and discussed, and it was discovered that the number of CT articles has significantly increased in recent years. Scholars from various countries, such as Balanskat & Engelhardt (2014), Falkner et al. (2014), Sysło & Kwiatkowska (2015), Heintz et al. (2016), and Hsu et al. (2018), have provided positive feedback on CT, emphasizing its importance in achieving future educational goals. Statistical analysis revealed that CT activities were mainly incorporated into program design, computer science, biology, and robot design courses. Thus far, numerous CT activities have been integrated into various subjects in a way that aligns with the CT concepts proposed by Wing (2006). According to Wing, CT is a skill that can be applied in everyday life, rather than being exclusively used by computer engineers. It is a skill that deserves a positive attitude in daily life and should be known and engaged in. Therefore, CT is a subject that requires in-depth research in the future, and its impact on children's academic performance is also worth discussing.

The discussion also touched upon the utilization of CT and learning techniques. Studies have primarily focused on Project-based Learning, Problem-based Learning, Cooperative Learning, and Game-based Learning. Over the past decade, numerous scholars have acknowledged the advantages of CT in enhancing children's learning. Therefore, further research should explore diverse learning methods such as Scaffolding Learning Strategy, Storytelling Learning, and Aesthetic Experience to facilitate learners in various aspects, such as subject development and advanced skills training, including critical thinking and problem-solving abilities. And also how the CT as a dependent and independent variable depict the same value of research in importing things.

a. Educate teaching staff on CT. To ensure a comprehensive introduction and development of CT courses, primary teaching staff must receive comprehensive training and establish accurate concepts to effectively carry out and enhance their CT teaching.

b. Evaluate students' learning progress effectively. As different learning strategies and subjects are applied at different ages, formal and informal courses require distinct scoring guidelines. Such evaluations can assist in future teaching activity design and modification of teaching strategies.

c. Be aware of students' learning status. Teachers must consider students' learning status to guide them through CT training courses, as well as provide appropriate assistance or feedback for different students.

The objective of this investigation is to assess and scrutinize the advancements and transformations in CT research pertaining to its application in teaching and learning, during the period of 2018 to 2023. The virtual and tangible worlds are increasingly converging due to the rapid development of technological skills and

computerized information. This digitalization and computation of computers have become fundamental aspects of contemporary society. To enable students to comprehend and integrate into the information society, it is imperative to not only foster their creativity and enhance their digital literacy, but also augment their CT competency, acquire knowledge of recent technological skills, and utilize them optimally to adapt to the fast-paced changes in the information society. Consequently, it is crucial to investigate the means of designing CT teaching and research, and integrating suitable learning tactics with the subjects at hand. Furthermore, from this research SLR, STEM is the most of learning and teaching strategies and formative assessment for CT.

Recommendations

As cognitive abilities vary among students of different ages, CT ability cultivation methods, content criteria, and learning strategies should vary accordingly. CT training courses should be designed for different age groups using appropriate strategies. Utilize cross-domain teaching methods to enable students to manage and analyze materials from various domains through computing. This will deepen their understanding of cross-domain knowledge, allow them to experience the roles played by cross-domain knowledge and computing in solving complex real-world problems, and foster their interest in science, technology, engineering, and mathematics. CT is still widely applied in schools; therefore, it is recommended to be applied at the university levels, apart from that, the problems used must be more complex and have rich context problems. Using plug and unplug theory separating and should be used simultaneously and will be a force for maximum results

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Challenges and Opportunities for Using Website-Based Technology to Increase the Technological and Engineering Literacy

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Abstract: Science education must continue to evolve in this era of fast-paced technological innovation if it is to remain relevant and help students meet the challenges of the future. This research aims to explore the challenges and opportunities of using website-based technology to increase the technological and engineering literacy of Science Education students with a STEM approach in Indonesia. This research method involves literature analysis, surveys with an interview approach with respondents in several science education study programs in Indonesia. The main challenges faced include limited access to adequate technological infrastructure, lack of training for lecturers in integrating website technology in learning, and resistance to change from several parties. However, there is a great opportunity in using website-based technology to increase the technological and technical literacy of Science Education students. These opportunities include developing interactive learning platforms that can increase student involvement, provide diverse and easily accessible learning resources, and increase collaboration between students and lecturers in developing learning content. The implications of this research are the need for greater investment in educational technology infrastructure, ongoing training for lecturers in integrating technology in learning, as well as the development of policies that support the use of website-based technology in science education in Indonesia.

Keywords: Website based technology, Engineering literacy, Technological literacy

Introduction

More and more attention is being paid to Science, Technology, Engineering, and Mathematics (STEM) in order to prepare students to meet the needs of the 21st century workforce. However, technological and engineering literacy is still a big problem for science education students (Hamka & Suwarma, 2024). Awareness of the importance of incorporating technology into Science education to equip students with the skills necessary in this digital era has increased in recent years (Basilotta-Gómez-Pablos et al., 2022; Palacios-Rodríguez et al., 2023). The use of web-based technology in STEM learning approaches is one emerging effort (Suwarma et al., 2019) (Akcay & Akcay, 2020).

With increasing internet access in Indonesia, web-based technologies offer new opportunities to expand access to educational materials and facilitate interactive and up-to-date learning experiences (Yang & Baldwin, 2020;

Kefalis & Drigas, 2019). The use of web-based technology can also increase student engagement and facilitate them to explore STEM concepts in various ways (Iyamuremye et al., 2023;Subramaniam & Yeh, 2020).

However, there are still issues to overcome when using web-based technologies in STEM education. For example, inadequate infrastructure may hinder implementation, and access to the internet and technology may not be uniform across all regions of Indonesia (Tondeur et al., 2016). Additionally, training teachers in the use of new technologies and integrating them into existing curricula is still necessary (Carlgren, 2019; Schindler et al., 2017).

STEM learning not only prepares students for jobs in technology, but also provides a solid foundation for solving the big problems of the future, such as global health and climate change. Additionally, inclusive STEM education can ensure that everyone can access education, ensuring that no one is left behind in technological advances. By prioritizing technology and engineering literacy in STEM education, we can ensure that future generations are ready to face the challenges and opportunities of an increasingly connected and rapidly changing world.

Science education must evolve to remain relevant in preparing students for the future, especially at a time when technology is developing rapidly. Traditional curricula often cannot keep up with rapid technological developments, leading to discrepancies between what is taught in the classroom and what is needed in the real world (UNESCO, 2017). Additionally, in some cases, teachers in science fields may not understand technology and engineering enough that they are unable to integrate elements of technology and engineering into their curriculum (American Association for the Advancement of Science, 2019). In order to ensure that students are prepared for an increasingly connected and changing world, it is crucial to emphasize the significance of technological and engineering literacy in science education and to identify successful strategies for incorporating these aspects into the curriculum (National Research Council, 2012).

In this context, it is important to conduct research on the opportunities and challenges associated with the use of web-based technologies to improve the technological and engineering literacy of Indonesian students in science education. A better understanding of the factors that influence the adoption of technology in STEM education will help us find better approaches to support technology-based learning and prepare students with the skills they need to succeed in this digital era.

Theoretical Framework

The theoretical underpinnings of this study draw from a range of literature in the fields of STEM education, technological literacy, and educational technology. A prominent framework guiding this research is the Technological Pedagogical Content Knowledge (TPACK) framework proposed by Mishra and Koehler (2006). TPACK emphasizes the intersection of technological knowledge, pedagogical knowledge, and content knowledge, highlighting the importance of integrating these domains effectively in educational practice.

According to Mishra and Koehler (2006, p.108), "Effective technology integration for pedagogy around specific subject matter requires developing sensitivity to the dynamic, transactional relationship between these components of knowledge situated in unique contexts" . This perspective underscores the need for educators to possess not only technological proficiency but also an understanding of how to leverage technology to enhance teaching and learning within the context of specific subject areas.

Furthermore, the Connectivism theory proposed by Siemens (2005) provides insights into how learning occurs in the digital age, particularly in networked environments. Siemens argues that "Learning is a process that occurs within nebulous environments of shifting core elements – not entirely under the control of the individual" (p. 4). In the context of website-based technology in STEM education, Connectivism emphasizes the importance of leveraging online resources and networks to facilitate collaborative learning and knowledge construction.

Additionally, the SAMR (Substitution, Augmentation, Modification, Redefinition) model introduced by Puentedura (2011) offers a framework for understanding the levels of technology integration in education. According to Puentedura (2011, p.1), "The SAMR model provides a framework through which to consider and discuss the potential impact of digital technologies on teaching and learning. By categorizing technology use into these four levels, educators can evaluate the extent to which technology enhances learning tasks and promotes higher-order thinking skills.

By integrating these theoretical perspectives, this study seeks to explore how website-based technology can be effectively integrated into STEM education to enhance technological and engineering literacy among science education students in Indonesia. Through a comprehensive understanding of these theoretical frameworks, educators can design pedagogically sound approaches that leverage technology to support student learning and development in the digital age.

Method

This research uses a research design with a combined approach between quantitative and qualitative data to comprehensively investigate the challenges and opportunities associated with the use of website-based technology in learning with a STEM approach. To see the opportunities and challenges of using website-based technology in STEM learning, data will be collected through literature analysis from existing journal articles through databases such as Scopus and Scholar. Then, to obtain more accurate data, an approach was carried out through surveys and interviews with the aim of exploring students' experiences, attitudes and effectiveness of website-based technology in improving their learning.

This mixed methods approach will allow triangulation of data sources, increasing the validity and reliability of research findings. In this research, the number of respondents was 52 science education students who were actively registered in the study program. The purpose of selecting this number of respondents is to obtain a fairly broad representation of various experiences and perspectives regarding the use of website-based technology in STEM education. Thus, it is hoped that the data obtained will provide a more comprehensive picture of the challenges and opportunities associated with the integration of technology in the context of science education.

Results and Discussion

The data obtained regarding the opportunities and challenges of using website-based technology to increase technological and engineering literacy in science education students through the STEM learning approach in Indonesia was carried out through literature analysis. Literature analysis was carried out to examine existing opportunities related to discussion topics sourced from articles from the last 10 years. Table 1 below is a description of the data resulting from the literature analysis carried out.

Table 1. Describes data from literature analysis.

Opportunities	Findings	References
Enhanced access to learning resources	Website platforms increase access to educational resources in rural areas	Susilo et al. (2023); Smith et al. (2023)
Interactive science education	Websites enable interactive learning experiences in STEM education	Utomo & Sari (2021); Johnson & Chen (2021)
Development of digital literacy	Websites contribute to the development of students' digital literacy	Pratama & Nugroho (2020); Wang & Li (2020)
Adaptation and personalization	Website-based learning allows adaptation and personalization of content	Wijaya et al. (2019); Brown et al. (2019)
Real-world connections	Educational websites facilitate connections between classroom and real-world	Suryadi & Setiawan (2018);Garcia & Martinez (2018)
Collaboration and networking	Websites promote collaboration and networking among students and teachers	Kurniawan et al. (2017); Lee et al. (2017)

The data analysis from the table above reveals a series of findings that support the opportunities of utilizing website-based technology in the context of science and technology education in Indonesia. Firstly, the use of website platforms expands access to educational resources, particularly in rural areas, as evidenced by research conducted by Susilo et al. (2023) and Smith et al. (2023). Next, websites facilitate interactive learning

experiences in STEM, enhancing student engagement and understanding of materials, as demonstrated in studies by Utomo & Sari (2021) and Johnson & Chen (2021).

Furthermore, website usage also plays a role in developing students' digital literacy, enabling them to access and critically evaluate information, as shown in research by Pratama & Nugroho (2020) and Wang & Li (2020). Additionally, adaptation and personalization of learning content are another advantage of this approach, allowing for education tailored to individual student needs, as observed in studies by Wijaya et al. (2019) and Brown et al. (2019).

Moreover, educational websites facilitate connections between classroom-learned concepts and real-world applications, providing relevant contexts for students, as demonstrated by Suryadi & Setiawan (2018) and Garcia & Martinez (2018). Lastly, website usage also fosters collaboration and networking among students and teachers, creating an inclusive and supportive learning environment, as evidenced by Kurniawan et al. (2017) and Lee et al. (2017).

Quantitative analysis of survey data indicates that while science education students in Indonesia generally possess basic technological literacy skills, there is a need for further development in areas such as programming, data analysis, and problem-solving using technology. Additionally, the majority of students express positive attitudes towards the use of website-based learning tools in STEM education, citing increased engagement and enjoyment of learning. The research findings are presented below, incorporating quantitative data in the form of percentages to enhance clarity and comprehensiveness:

Table 2. Percentages to enhance clarity and comprehensiveness

No.	Question	Answer	Percentage
1	Level of technological literacy among students	High	40%
		Moderate	35%
		Low	**25%**
2	Perception towards the use of website-based technology	Positive	60%
		Neutral	25%
		Negative	**15%**
3	Frequency of technology use in STEM learning	Often	45%
		Sometimes	30%
		Rarely	**25%**
4	Difficulties faced in using technology	None	20%
		Some	40%
		Quite a few	25%
		A lot	**15%**
5	Satisfaction level with technology use in STEM learning	Very satisfied	30%
		Satisfied	40%
		Dissatisfied	20%
		Very dissatisfied	10%

The survey data revealed that 55% of students faced challenges related to access to technology, such as limited availability of digital devices or unreliable internet connectivity. Additionally, 45% of students cited a lack of training and support from teachers as a barrier to effectively utilizing website-based learning tools in their coursework. By presenting research findings in the form of percentages, this study provides a quantitative overview of students' experiences and perceptions regarding the use of website-based technology in STEM education. These findings offer valuable insights into the effectiveness of technology integration efforts and highlight areas for improvement in promoting technological and engineering literacy among science education students.

Qualitative findings conducted on 8 students from interviews provide deeper insight into students' experiences with website-based technology. Students report that interactive features such as simulations, virtual laboratories, and multimedia resources enhance their understanding of STEM concepts and facilitate hands-on exploration. However, challenges such as unreliable internet connectivity and limited access to digital devices hinder their ability to take full advantage of these resources. Based on the description of the interview results in Table 3, it can be found and provide a detailed understanding of students' experiences, perceptions and challenges related to the use of website-based technology in STEM education.

Table 3. Description of interview results

Theme	Code	Responder	Interview result
Perceived Benefits of Website-Based Technology	Increased Engagement	R3, R8	Q1: Can interactive learning activities increase your involvement in the learning process? R3: "Yes, interactive learning activities have a significant impact on my involvement in the learning process. When I engage in activities like group discussions, online simulations, or interactive quizzes, I feel more connected to the material. R8: "Certainly. Interactive learning activities greatly enhance my engagement in the learning process. These activities stimulate my curiosity, encourage critical thinking, and foster collaboration with classmates.
	Enhanced Understanding of STEM Concepts	R5, R6	Q1: Can interactive learning activities improve your understanding of STEM concepts? R5: "Absolutely. Engaging in interactive learning activities greatly enhances my understanding of STEM concepts. R6: "Yes, interactive learning activities significantly contribute to my understanding of STEM concepts.
Challenges in Implementation	Technical Difficulties	R1, R4	Q1: Do you face technical difficulties while learning STEM concepts? R1: "Technical difficulties can indeed pose challenges in understanding complex concepts in STEM. R4: "Yes, technical difficulties can sometimes hinder our understanding of STEM concepts.
	Access Constraints	R2	Q1: Do you feel barriers to accessibility impact your ability to learn STEM concepts? R2: “Access constraints can indeed pose significant challenges in the learning process, especially in STEM learning.
Teacher Support and Training Needs	Lack of Training in Technology Integration	R6, R7	Q1: How does a lack of training in technology integration affect your ability to integrate technology in learning? R6: "Lack of training in technology integration significantly impacts my ability to incorporate technology into teaching. R7: "For me, the lack of training in technology integration makes me feel limited in my ability to incorporate technology into teaching.
	Inadequate Support from Educators	R4, R7	Q1: How does inadequate support from educators affect your confidence and ability to implement new teaching methods or technologies? R4: "Inadequate support from educators deeply affects my confidence and ability to implement new teaching methods or technologies. R7: "The impact of inadequate support from educators on my confidence and ability to implement new teaching methods or technologies cannot be overstated.

Student Preferences and Usage Patterns	Preference for Interactive Features	R1, R5	Q1: How do interactive features help you understand and remember learning material? R1: "Interactive features play a crucial role in helping me understand and remember learning material. R5: ""Interactive features are invaluable tools for enhancing my understanding and retention of learning material.
	Independent Exploration of Online Resources	R6, R8	Q1: What are the main benefits you gain from independent exploration of online resources in your learning? R6: "The main benefits I gain from independent exploration of online resources in my learning are flexibility and diversity. R8: "The main benefits I derive from independent exploration of online resources in my learning are accessibility and self-directed learning.
Impact on Motivation and Learning Outcomes	Impact on Motivation and Learning Outcomes	R3,R5	Q1: Do you feel your independent exploration of online resources has had a positive impact on your academic achievement or study skills? R3: "Yes, I strongly believe that my independent exploration of online resources has had a positive impact on both my academic achievement and study skills. R5: "Absolutely, my independent exploration of online resources has had a positive impact on both my academic achievement and study skills.
	Improved Academic Performance	R4, R7	Q1: What types of online resources have you found most effective in improving your academic performance? R4: "I have found various types of online resources to be highly effective in improving my academic performance. R7: "I have found several types of online resources to be highly effective in improving my academic performance.

There are a number of intricate obstacles to overcome in Indonesia when integrating website-based technology to improve engineering and technological literacy among scientific education students using STEM learning techniques. The nation's inadequate technological infrastructure is one of the primary issues. There are still many places without reliable internet connectivity, and schools frequently have trouble getting the technology they need. Students' access to digital learning resources and interactive tools is hampered by the ineffective use of website-based technology in STEM education in the absence of a strong infrastructure (Johnson et al., 2016; Wahyu et al., 2020).

Moreover, a major barrier is the degree to which educators are prepared to incorporate website-based technology into their pedagogical approaches. Despite the possible advantages, a lot of teachers lack the knowledge and experience needed to successfully incorporate technology into their curricula. To tackle this issue, comprehensive professional development programs that equip educators with the skills and self-assurance to use web-based resources to improve STEM education for their students are needed (Widowati et al., 2021).

The difficulties in increasing pupils' technological and engineering literacy are made worse by the digital divide. The gaps in educational opportunities caused by unequal access to technology and the internet exacerbate the divide between pupils who can fully participate in website-based learning materials and those who cannot. It will take coordinated efforts to guarantee all students, regardless of socioeconomic status or geography, fair access to technology and digital learning opportunities in order to close this gap (UNESCO, 2019).

Despite these challenges, there are significant opportunities to harness the potential of website-based technology to advance STEM education in Indonesia. Collaboration among government agencies, educational institutions, and technology companies can play a pivotal role in addressing existing barriers (OECD, 2019). By pooling resources and expertise, stakeholders can work together to improve technology infrastructure, provide teacher training initiatives, and develop high-quality, locally relevant digital learning content.

Additionally, higher education institutions have a crucial role to play in preparing future educators with the skills and competencies needed to effectively integrate website-based technology into STEM teaching practices. By incorporating technology-focused curricula and offering professional development opportunities for pre-service teachers, universities can ensure that graduates are equipped to meet the evolving demands of 21st-century education (Gumus et al., 2024; Niederhauser & Schrum, 2016).

In summary, while challenges abound, the opportunities presented by website-based technology in enhancing technological and engineering literacy through STEM education in Indonesia are vast. By addressing infrastructure limitations, enhancing teacher readiness, bridging the digital divide, and fostering collaboration across sectors, stakeholders can pave the way for a more inclusive and effective approach to STEM education that leverages the power of digital technology.

Overall, the study underscores the importance of addressing infrastructure constraints and providing adequate support and training for educators to effectively integrate website-based technology into STEM education. By addressing these challenges and capitalizing on the opportunities presented by technology-enhanced learning, Indonesian science education students can develop the critical skills and competencies needed to thrive in the digital age.

The findings of this study reveal both challenges and opportunities for integrating website-based technology into STEM education in Indonesia. Challenges include limited access to technology, lack of teacher training, and infrastructure constraints. However, opportunities exist in the form of increased student engagement, improved learning outcomes, and enhanced technological and engineering literacy. Furthermore, the study highlights the importance of addressing socio-cultural factors and contextualizing website-based learning tools to meet the unique needs of Indonesian science education students.

Conclusion

In conclusion, the integration of website-based technology holds promise for enhancing the technological and engineering literacy of science education students in Indonesia. However, concerted efforts are needed to address the challenges associated with its implementation. By leveraging the opportunities presented by website-based learning tools and adopting pedagogically sound approaches, educators can effectively prepare students for success in an increasingly technology-driven world.

Recommendations

The need for greater investment in educational technology infrastructure, ongoing training for lecturers in integrating technology in learning, as well as the development of policies that support the use of website-based technology in science education in Indonesia.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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Data-based Analysis of Experience as an Influence on Focus in Project Execution Phases

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Abstract: Project management models and guidelines focus on standardizing and describing which kind of tasks project managers need to perform and how to perform these tasks. While these frameworks detail such activities, they do not cover how much project managers should perform different tasks depending on their particular project phase and other factors like project size and experience of the team. This article is based on the concept of multivariate regression and optimization being used to improve Project Process Relevance Factors as described in the Ph.D. thesis "Optimized Tailoring of Agile Project Management Frameworks - From Combining Scrum and PMI towards Multivariate Optimization" by Philipp Rosenberger (Rosenberger, 2022). The doctoral dissertation provided the data and scientific approach that was utilized as well in this article. The purpose of the research is to examine how project experience affects the project management activities that must be completed throughout the execution phase in order to optimize the health and success of a project. The data analysis indicated significant similarities in the distribution of emphasize between novice and skilled project management practitioners. After optimizing the distributions of relevance, the results indicate that experienced project managers need to concentrate more on supporting the project process as such. This involves conducting risk responses and overseeing stakeholder participation. In contrast, novice project managers should to focus on managing specific outcome-related project tasks.

Keywords: Project management experience, Process optimization, Multivariate regression

Introduction

Project management requires diverse tools, skills, and approaches. Based on the uniqueness of projects, the international project management framework offers different certificates, guidelines, and modules to manage projects effectively. Some of the common frameworks are the project management body of knowledge (PMBOK) (PMI, 2017), the ICB4 of the International Project Management Association (Dittmann, 2021), and the PRINCE2 framework of Axelos (Axelos, 2017). Mostly, frameworks show the distinct kinds of tasks needed to be fulfilled by any project manager. The amount of focus and effort that managers must exert to accomplish various tasks is a crucial yet often neglected aspect.

The hypothesis of this article elaborates that experienced project managers distribute their focus and work in a project in different ways than inexperienced project managers. The approach and concept for maximizing project success and optimizing project relevance distributions is described and proven to be applicable in the Ph.D. thesis of the main author (Rosenberger, 2022), where he proposed an optimized distribution of project process relevance factors in continuous processes of the PMBOK project execution phase. This paper shall provide orientation for experienced and inexperienced project managers to make a proper distribution in focus, and they can optimize their distributions to tailor their way of working to their level of experience.

Definitions Based on Literature Review

This paper focuses on implementing mathematical techniques such as optimization and regression that define the optimal approach for diverse project mapping depending on discrete profiles for project managers. The optimization is implemented on collected data from the participants from various fields in project management. It is important to clarify various terms and definitions before describing the methods used (Rosenberger, 2022).

Project Process

The sixth version of PMBOK delineates forty-nine distinct project processes that serve as a guideline for the project management framework. These processes guide the project managers to shape their daily work and tasks, such as risk analysis using appropriate techniques, i.e., fuzzy method (Takacs, 2010.), and PRISM (Bognar, 2021) based methods that control the stakeholder's engagement and the overall budget. Project processes behave like a tool cabinet filled with activities and methods to be utilize by project managers.

Relevance of Project Process

For the fundamental basis of the hypothesis, this research concludes that project managers constantly make decisions about how much time and focus they distribute into different tasks to be performed. Therefore, "project process relevance" is defined as how much time and focus a project manager requires in any specific project process.

Project Process Relevance Distribution

As an input factor to the multivariate optimization, project process relevance distributions are used. An online survey was conducted among inexperienced and experienced project managers, and the questions were asked about tasks that were relevant to managing their projects. The different amounts of effort put into the different tasks of project process relevance forms a final distribution when combined. It has to be mentioned, that not all project processes of PMBOK are applicable in this research. Only the processes of the execution phase are in scope.

Project Health Factors

For optimization output, this article uses factors, considering the measurement of the project's current health. Success as a single concept is not used because it depends upon many different influence factors related to ongoing projects. Further, success is a state after finishing a project. The survey however investigates ongoing projects, making the term project health more suitable as an output variable to be optimized. The interviewed project managers had to estimate the current status of the schedule, budget, scope and customer satisfaction (Varga & Csiszarik-Kocsir, 2019). These four factors of project health are combined into a single output that serves as factor for the aimed optimization. Converting different responses into a single answer is based on the research of Khuri and Conlon (Khuri & Conlon, 1981). Constrained optimization elaborates that this single output for leading and remaining for constraints are not used because multiple project health factors have the same importance in the project's success (Del Castillo & Montgomery, 1993).

Definition of Optimization Focus

PMBOK, developed by the Project Management Institute (PMI) underscores the significance of processes, tasks, and documentation (Matos & Lopes, 2013) for the stated research framework. However, it neglects soft skill activities, which often pose a challenge in terms of objective evaluation. According to PMI, they currently have 700,000 active members (PMI. 2017).

The present survey has been conducted among participants actively engaged in specific projects, which necessitated the selection of a pertinent project phase for the purposes of this research. Although planning has been identified as a critical factor for successful project management (Gyorgy, 2006), the execution phase, which accounts for the majority of project work and spans over a considerable duration (Project Engineer,

2021), has been deemed most appropriate for this research. Furthermore, the availability of pre-existing data collected during the Ph.D. research project enables addressing the stated question. Eight of the ten pertinent processes conducted during the project execution phase are ongoing. The following optimization is based on these processes.

Below is an overview of these processes along with the corresponding identification numbers pertaining to the chosen execution phase (PMI, 2017):

- Process P1 “Direct and Manage Project Work”: Defines the process of directing and executing activities specified in the project management plan while applying approved adjustments into practice to meet project objectives.
- Process P2 “Manage Project Knowledge”: Is the approach of achieving project goals and advancing organizational learning by making use of current knowledge and creating new expertise.
- Process P3 “Manage Quality”: The quality management plan serves as the basis for executable actions that incorporate the organization's quality guidelines into the project.
- Process P4 “Develop Team”: This approach strives to improve teamwork, interpersonal competencies, and general team atmosphere to increase project performance.
- Process P5 “Manage Team”: To enhance the project's overall performance, this process entails monitoring the team's performance, issuing input, addressing problems, and supervising team transformations.
- Process P6 “Manage Communications”: Project information must be developed, shared, stored, collected, controlled, tracked, and subsequently disposed within an appropriate and feasible form.
- Process P7 “Implement Risk Responses”: This process aims to put the established strategies for responding to risks into execution.
- Process P8 “Manage Stakeholder Engagement”: Working and cooperating with stakeholders to satisfy their requirements and standards, address problems, and foster appropriate stakeholder participation are the objectives of this task.

Four project health factors contribute to the optimized outcome. These factors are based on the traditional project management triangle of cost, scope, and time (Wyngaard, 2011) enriched with an additional factor of customer satisfaction. High client satisfaction, particularly in IT projects, can result in project success despite the fact that the scope, budget, or timeline are not fulfilled (Atkinson, 1999).

Sampling Procedures

The data set was acquired through personal inquiries at conferences and networking events, emails issued to a community of graduates from the UAS FH Campus Wien master's course "Technical Management," and posting invitations to project management practitioners on social media channels like Facebook and LinkedIn. Participants might be anyone who has worked in project management in any capacity in the past or present. Furthermore, even if they did not work in management, current students at the partnering institutions in Budapest and Vienna who had prior job experience in these fields were welcome to take part.

For this research, a rudimentary understand of project work and the PMI project methodology was sufficient. Over the duration of eighteen months, an estimated six hundred invitations were sent out, and 103 genuine and legitimate survey replies were received. By guaranteeing the inclusion of participants with varying degrees of expertise in the study, applicants with disparate perspectives on project management were able to provide a diverse range of opinions.

Questionnaire Design

A specially designed, cloud-based data collection web portal was used to conduct the actual data gathering (Heroku, 2023), as pre-packaged survey software solutions lacked the capability to disseminate relevance factors. The survey conducted can be accessed via the link https://agile-projects-survey.herokuapp.com/home.

The survey participants also shared details about their projects and backgrounds, in addition to the distributions of project health variables as output parameters and project process relevance as input variables. Except for the section that follows, which summarizes the qualities of the participants, these extra characteristics are not acknowledged as such in the research findings.

Respondents

There were 103 valid replies in total. Men form 73% of the participants, while women make up 27%. Out of the participants, 22% are older than 40, 33% are between the ages of 30 and 40, and 45% are between the ages of 20 and 30. 83% of the participants hold a university degree, and 51% have worked as project managers or sponsors. Also, 51% of participants are employed in management and business in the financial or IT sectors. Of the participants, 52% use either hybrid (Tolbert & Parente, 2020) or agile (Ashmore, 2014) project management frameworks. On a Likert scale of 1 to 5, where 5 represents "very experienced project management skills" and 1 represents "novice project management skills", 69 (67%) out of the 103 participants assessed their project experience as a 4 or a 5. The study that follows summarizes this group as "Experienced". The remaining participants gave themselves a rating between 1 and 3. This group is referred to as "Inexperienced".

Initial Analysis of Process Relevance Distribution in Dependence of Project Manager's Experience

The following section compares the project relevance distributions before optimization to get a first understanding of the difference between the focus distribution of the aforementioned groups “Experienced” and “Inexperienced”.

Table 1. Collected (not optimized) distribution values for different self-evaluations

	“Experienced”	“Inexperienced”
Process P1	19%	19%
Process P2	14%	15%
Process P3	10%	12%
Process P4	8%	8%
Process P5	14%	11%
Process P6	15%	15%
Process P7	9%	9%
Process P8	11%	11%

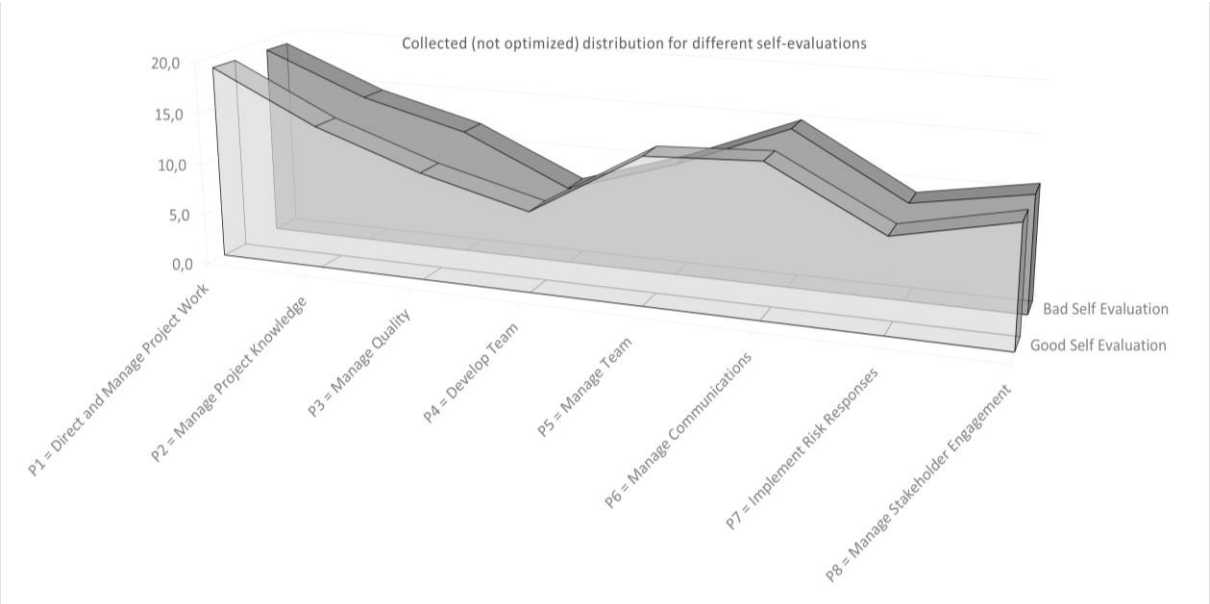

Figure 1. Distribution for different self-evaluations (not optimized)

Comparing the different project process distributions, there are only minor differences. Experienced project managers tend to put slightly less effort into project processes such as "Direct and Manage Project Work", "Manage Project Knowledge", and "Manage Quality", and therefore focus more on the "Manage Team" project process. The group of less experienced project practitioners execute the processes analogously.

The next step is to use the collected data from experienced and inexperienced project managers to optimize project health and success. To enhance project health, the four project health indicators were added together, divided by four hundred, and then the reciprocal value was calculated using the MATLAB R2018b minimization solver.

Analysis of Optimized Process Relevance Distribution in Dependence of Project Manager's Experience

This section examines project health based on the optimized distribution of focus of experienced versus inexperienced project managers during the project execution phase. The following regression parameters have been developed:

Regression function for “Experienced”:

- Second-degree degree polynomial function with twenty-two terms in seven predictors
- Unsatisfying p-values in the process x3 with a value of 0.169
- RMSE: 0.14
- R-squared: 0.707
- Adjusted R-Squared: 0.573

Regression functions for the “Inexperienced”:

- Second-degree polynomial function comprising thirteen terms across seven predictors
- Rambling p-values with the highest in the factor x2*x5 with 0.02
- RMSE: 0.0814
- R-squared: 0.917
- Adjusted R-Squared 0.843

Table 2. Optimized distribution values for different self-evaluations

	“Experienced”	“Inexperienced”
Process P1	9%	29%
Process P2	4%	22%
Process P3	20%	22%
Process P4	0%	0%
Process P5	4%	21%
Process P6	22%	5%
Process P7	19%	0%
Process P8	21%	1%

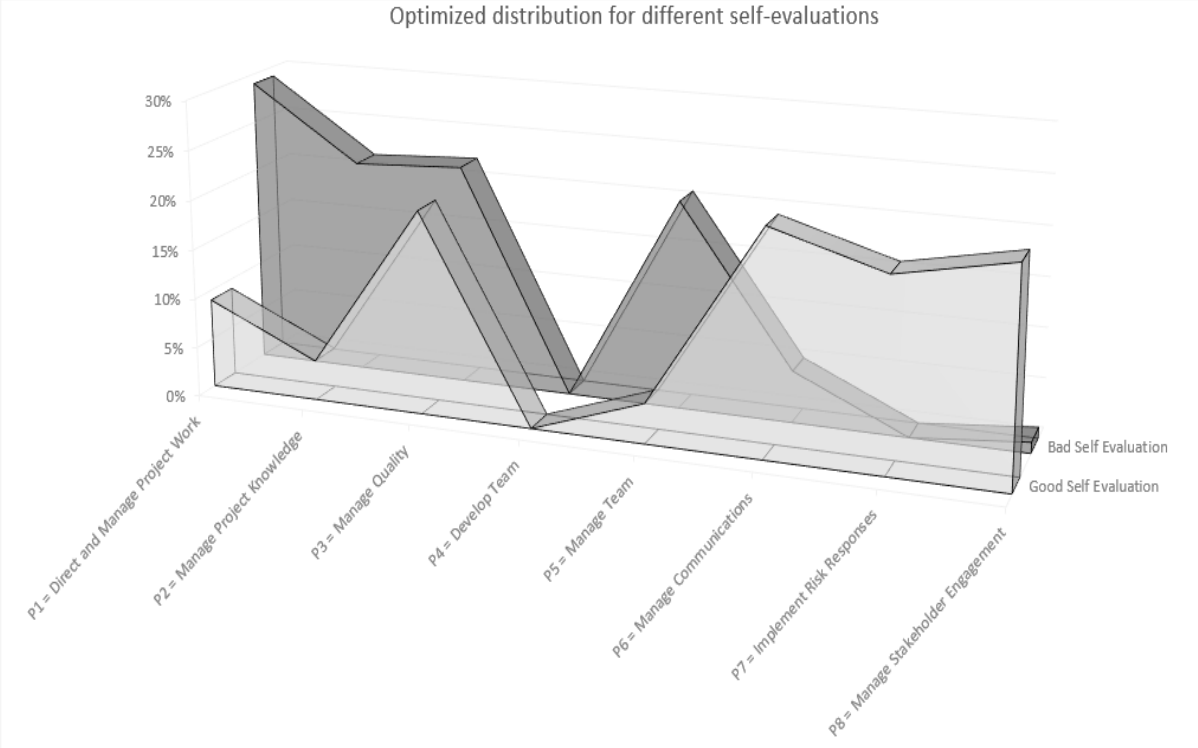

Figure 2. Optimized distribution for different self-evaluations

Limitation

The analysis of the regression parameters showed that, mostly as a result of insufficient data, the p-values are not ideal. Consequently, the results have to act just as an initial idea for a reliable optimization outcome.

Conclusion

After optimizing, the distributions differ for all processes except “Manage Quality” and “Develop Team”. The reason for these substantial changes is that the data collected for optimization, which indicates the current health of the project, has a strong influence on the results. The optimization result indicates that project managers who rated their project skills as inexperienced should focus strongly on the project process "Direct and Manage Project Work", "Manage Project Knowledge", "Manage Quality" as well as "Manage Team". Experienced project managers should focus on the processes "Manage Quality", "Manage Communication", "Implement Risk Responses" and "Manage Stakeholder Engagement".

The purpose of this research was to investigate how project managers perform the project execution phase based on their self-assessed level of experience. It also aimed to highlight an optimized way of performing project management tasks to maximize project health and success. Based on an extensive online survey, the distribution of project process relevance of 103 survey participants was analyzed. The results show that the two groups of "Experienced" and "Inexperienced" participants have almost identical distributions of project process relevance. Thus, the behavior of the project managers is comparable. This correlation changes when these distributions are optimized. According to the results of non-parametric multiple regression, the two groups need to focus on different project processes to ensure maximum project success and health. While inexperienced project managers should focus on directing and managing project work and project knowledge, experienced project managers have to manage quality, communication, risk response, and stakeholder engagement.

Interpreting the optimized results, it can be concluded that experienced project managers do not need to focus extensively on the work packages themselves, but rather on creating a stable and robust working environment to be successful. More of an enabler than a micromanager. In contrast, the optimized results propose that inexperienced project managers should focus on the details and control the essential project work to be successful. However, these interpretations must always be considered with the limitation of unsatisfactory p-values of some regression polynomial factors.

Scientific Ethics Declaration

The authors affirm that this article published in EPSTEM entails scientific, ethical, and legal responsibility. The journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Technology (www.icontechno.net) held in Alanya/Turkey on May 02-05, 2024.

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Digital Shopping Experience in the Metaverse from a User Perspective

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Abstract: The digital world and digital space have become part of our everyday lives in the 21st century. Many aspects of our lives have moved into the digital realm, from our shopping and entertainment to our social and civic life. Such an advance of the metaverse poses a number of challenges for individuals, families and organisations. Changing consumer preferences, the human psyche and the marketing space require unconventional responses from organisations. Many organisations have recognised this and are trying to respond to all these challenges. The aim of our study is to look at projects that target the metaverse in order to increase their sales. We want to present in detail projects that are innovative and forward-looking and can serve as examples for other organisations, from the marketing, sales and technology sides. The study aims to shed light on how these innovations are received by users, with a particular focus on their generational characteristics.

Keywords: Metaverse, Digital shopping space, Project scope

Introduction

The rise of digitalisation has brought change in all areas of our lives. This is a trend that is profoundly affecting society and business (Parviainen et al., 2022). The emergence of new technologies in all areas of business, such as artificial intelligence, big data, blockchain, virtual reality and robots, has created a paradigm shift (Cham et al, 2022). However, this is not only radically transforming the world of business, but also profoundly changing the lives of everyday people. Indeed, digitalisation is a process, as it is associated with transformation (Liu et al, 2011) and has an impact on wider society. Not only is business becoming more efficient, but it is also changing people's daily lives, consumer habits and even culture and communication.

The digital transformation is developing new skills in everyone through the development of information and communication technologies (Martin, 2008). If we approach this from the perspective of individuals, we see significant changes in consumption patterns. Digital tools and solutions have shaped a whole new consumer behaviour. If we add to this the major events of recent years, such as the impact of the COVID-19 pandemic, it becomes even clearer to everyone why digital solutions have gained so much ground, not only in our work, but also in our everyday shopping. In addition, the rise of digital solutions in the shopping and consumer space can also be explained by the convenience of being able to access products and services by simply using digital technology. This avoids queues, journeys and long waits, and allows customers to access their preferred products or services quickly and in the same way as if they were trying to physically obtain them. The retail sector has also adapted very quickly to online shopping. Many online shops and social media have given way to an increasing proportion of our waiting time being spent online. Of course, this does not mean that everyone is turning to online shopping with the same degree and frequency. Nor is it possible to generalise on this topic, as generational factors, among others, determine online shopping habits, but differences can also be found between men and women, even across generational groups (Chiu & Cho, 2021). Digitalisation undoubtedly represents a

new alternative for everyday shopping and meeting consumer needs. As much as it has its advantages, its disadvantages cannot be forgotten, as online shopping can in many cases be associated with risk or uncertainty. In addition to paying in advance, you may not receive the quality you expected or you may even experience a supplier default. That said, shopping in the digital space is booming and technology is supporting and facilitating this process in every way. Digitalisation also offers a new user experience, as younger generations are more aware and regular users of digital tools and solutions, and are now more willing to do their business using their smart devices. It could even be said that an increasing proportion of potential customers can be reached and addressed in the digital space, and today's marketing strategies cannot ignore this.

Literature Review

The development of the internet, telecommunications and information technologies has opened up new ways of doing business. The e-commerce market is growing globally and this growth has been even more intense after the COVID-19 pandemic (Almunawar et al., 2021). The popularisation of digital platforms has started to play a very important coordinating and mediating role in economic and social transactions (Hagberg et al, 2016). Digitalisation has brought with it a transformation of social and spatial relations (Couldry & Hepp, 2017). In the process, exchanges and relations in the economy and society have been and are being reorganised through the integration of digital technologies, resources and infrastructures. And the interaction between technological change and the cultural organisation of society is clearly evident (Fast et al., 2018). Digital shopping is also known as e-commerce. The use of smart devices and digital applications and platforms is a key factor. The physical presence is replaced by convenient online shopping options, while consumers are also excluded from a wide range of choices, as they can access mostly all relevant information online (Tahalele et al., 2021). Sellers would therefore have a very high responsibility to communicate and disclose correct and credible information to customers, otherwise they may mislead individuals in making their purchasing decisions. Digital shopping can also be advantageous in that the customer can compare prices, see the main features of the product and even read reviews about the product (Yunanto & Paizal, 2019). All these can clearly help him/her to decide which product to choose and what is more useful for him/her. Digital shopping platforms often provide various tools and features to enhance the shopping experience, such as personalised recommendations, virtual fitting rooms and secure payment options (Kedah, 2023). Although digital shopping is clearly gaining ground, it will never completely replace physical shopping. The explanation is simple. There are products that are better bought by experiencing the product in person. There are also individuals who prefer to feel the material and quality of a product with their own hands before buying it. There is no doubt that it is more convenient to shop from home, not only to buy but also to have the product delivered to your home and even to return it, but it will not replace physical shopping entirely. The rise of online shopping has been catalysed by the development of logistics and supply chains, the modernisation of infrastructure and technological advances in general. The emergence of online marketplaces and digital shops, which seek to entice individuals to shop with an even wider choice. And the aforementioned COVID-19 pandemic has further stimulated this process (Tahalele et al., 2021), as people who had never before taken advantage of this option are also turning to online spaces. However, after the COVID-19 pandemic subsided, many people realised the benefits of being online and their shopping habits remained. Buying behaviour is in effect a collective term for the set of choices and factors that explain why an individual buys a product or uses a service (Braithwave & Scott, 1990). These preferences are influenced by a number of factors, ranging from personal tastes to family socialisation, schooling or cultural habits (Bhukya & Paul, 2023). These are coupled with the achievements of digitalisation and technological developments, which have the potential to influence the choices of individuals. More marketing, more information, more information is flooding the consumer, whose decisions can be profoundly affected by these factors. It has become easier than ever before for operators to reach and address potential customers, but they need to apply and use the opportunities offered by the digital space in a good and informed way. By identifying and serving the preferences of their target audience, businesses can improve the shopping experience and build lasting relationships with their customers (Yasin, 2021).

The online space offers an even better opportunity for businesses to understand people's preferences. Valuable insights can be gained from ongoing contact and communication (Zellweger et al, 2010), customer feedback, customer ratings or satisfaction. In addition, it should be ensured that, although the seller and the buyer often do not meet face-to-face during the online shopping experience, the buyer's experience is one that will make him return to the seller's website, app or online shop (Wells, 2015). Total customer satisfaction should also be maximised in online shopping and should be made to feel that everything is for the customer. In the 21st century, only marketing strategies that can take these aspects into account will be successful, while organisations that can understand their customers' habits and behaviour, even in the online space, will be truly effective.

Composition of the Sample

In the present study, we aim to examine two metaverse purchasing entities through a project-based evaluation, which can serve as a model for other initiatives. The megaprojects presented in our study are included in the list of the most inspiring projects of 2022 published by the Project Management Institute (PMI, 2022). In the questionnaire survey, respondents were asked to rate the selected projects on some factors of project scope. We wanted to highlight the elements of project scope that related to, among others, future focus, profit orientation, cost savings, innovativeness, uniqueness. Respondents rated the factors on a scale of 1 to 4, with a score of 1 indicating a very weak factor and a score of 4 indicating a very strong factor. The survey was conducted in spring 2023. The composition of the sample by generational affiliation is shown below.

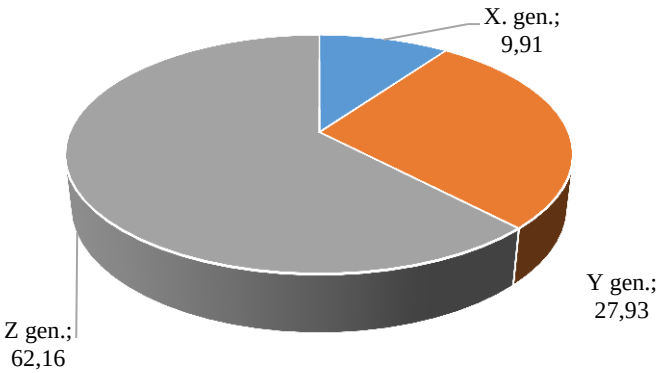

Figure 1. Composition of the sample by respondents' generation
Source: Own research, 2023, N = 399

Results

Store of the Future

The project is a shining example of how retail is being reimagined with immersive digital experiences that will lure even the most jaded shoppers to the mall. It is an oft-repeated truth that the rise of online shopping has meant the slow death of the mall. Majid Al Futtaim (MAF), a mall development company based in the Emirates, aims to reverse this trend, with the initiative taking pride of place in the Mall of the Emirates.

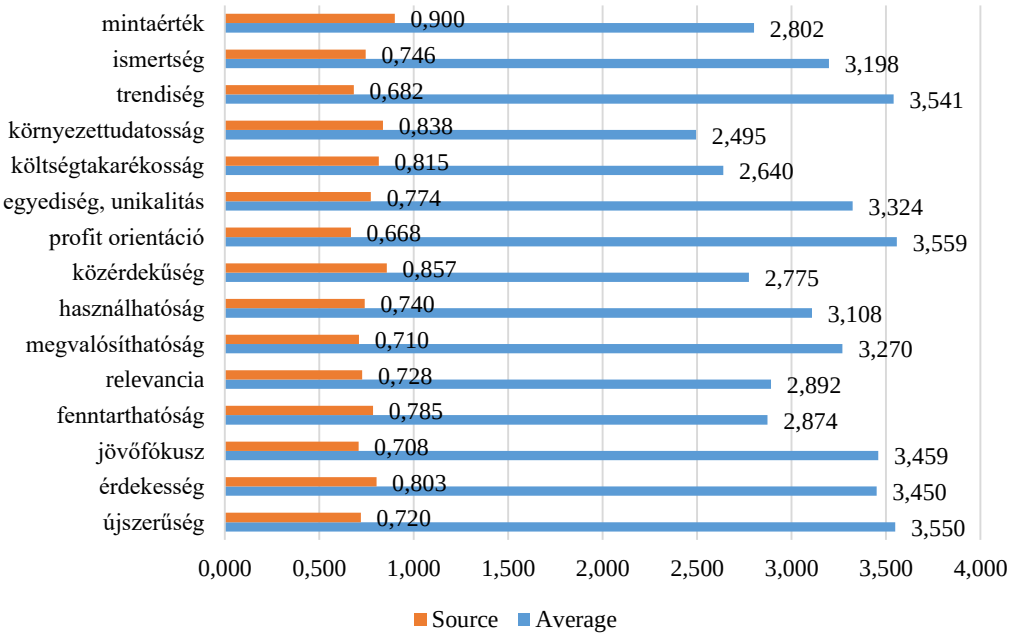

Figure 2. Evaluation of the elements of the Store of the Future project scope
Source: Own research, 2023, N = 399

Table 1. Correlation of Store of the Future project scope elements with age of respondents

		Sum of Squares	df	Mean square	F	Sig.
Novelty	Between Groups	10,331	2	5,165	10,374	0,000
	Within Groups	219,579	441	0,498		
	Total	229,910	443			
of interest	Between Groups	14,751	2	7,376	11,996	0,000
	Within Groups	271,158	441	0,615		
	Total	285,910	443			
Future Focus	Between Groups	1,553	2	0,776	1,551	0,213
	Within Groups	220,718	441	0,500		
	Total	222,270	443			
sustainability	Between Groups	7,869	2	3,935	6,546	0,002
	Within Groups	265,068	441	0,601		
	Total	272,937	443			
relevance	Between Groups	2,660	2	1,330	2,527	0,081
	Within Groups	232,151	441	0,526		
	Total	234,811	443			
Feasibility	Between Groups	2,042	2	1,021	2,033	0,132
	Within Groups	221,525	441	0,502		
	Total	223,568	443			
usability	Between Groups	1,923	2	0,961	1,760	0,173
	Within Groups	240,888	441	0,546		
	Total	242,811	443			
public interest	Between Groups	0,999	2	0,499	0,679	0,508
	Within Groups	324,479	441	0,736		
	Total	325,477	443			
profit orientation	Between Groups	4,878	2	2,439	5,584	0,004
	Within Groups	192,600	441	0,437		
	Total	197,477	443			
uniqueness, uniqueness	Between Groups	4,755	2	2,378	4,025	0,019
	Within Groups	260,542	441	0,591		
	Total	265,297	443			
cost savings	Between Groups	7,606	2	3,803	5,849	0,003
	Within Groups	286,736	441	0,650		
	Total	294,342	443			
environmental awareness	Between Groups	12,777	2	6,388	9,447	0,000
	Within Groups	298,214	441	0,676		
	Total	310,991	443			
trendiness	Between Groups	10,555	2	5,277	11,891	0,000
	Within Groups	195,716	441	0,444		
	Total	206,270	443			
visibility	Between Groups	11,390	2	5,695	10,680	0,000
	Within Groups	235,168	441	0,533		
	Total	246,559	443			
sample value	Between Groups	9,423	2	4,712	5,951	0,003
	Within Groups	349,135	441	0,792		
	Total	358,559	443			

Source: Own research, 2023, N = 399

The store of the future will offer an intensely personalised, immersive shopping experience, fuelled by a combination of cutting-edge technologies. Young shoppers in Dubai are a tough audience who are largely immune to the usual retail temptations. The final design uses digital screens, video collaboration tools, virtual mirrors and augmented reality to engage and delight shoppers at every step.

Digital display screens greet every shopper upon arrival. As they move through the store, artificial intelligence and computational tools use data to deliver a personalized experience, giving each shopper a unique product discovery journey as they walk through the store. When a shopper pulls something off the shelves, sensors automatically retrieve and display product details on a nearby screen. The so-called magic mirrors allow users to

search for variations of products while being offered the right accessories. It's the store of the future, promising bold new experiences for consumers and a whole new set of lessons for retailers.

After describing the project, we will now look at which characteristics were rated highest and lowest by respondents. For the project under study, it can be seen that respondents clearly gave the highest average value to profit orientation, followed by novelty and trendiness. Factors that are the most pressing issues of the 21st century, such as sustainability, public interest and value for money, were ranked at the bottom of the list. Looking at the factors evaluated from the back, it can be seen that the lowest score was given to the environmental relevance of the project, with cost-effectiveness receiving a slightly better average score, and the third place was given to the public interest of the project. This shows that respondents clearly see a business objective behind the project and value its innovativeness or public interest less. The fact that the project itself tends to serve the needs of more affluent customers also makes the situation worse, which reinforces the negative assessment of the factors at the bottom of the list.

We also wanted to know how the project and certain features of the project were influenced by the generational background of the respondents. Of the factors examined, only six were not influenced by the generation of the respondent. This means that almost two thirds of the project scope characteristics examined are strongly influenced by the age of the respondents. Where we did not see a correlation based on the significance value is the future focus, relevance, feasibility, usability, public interest and uniqueness of the project. All other factors were clearly affected by generational affiliation (see Table 1).

Table 2. Perception of the Store of the Future project scope elements by age group of respondents

		Average	Source
Novelty	X. gen.	4,000	0,000
	Y gen.	3,548	0,667
	Z gen.	3,478	0,774
	Total	3,550	0,720
of interest	X. gen.	4,000	0,000
	Y gen.	3,387	0,833
	Z gen.	3,391	0,822
	Total	3,450	0,803
sustainability	X. gen.	3,273	0,451
	Y gen.	2,806	0,862
	Z gen.	2,841	0,775
	Total	2,874	0,785
profit orientation	X. gen.	3,636	0,650
	Y gen.	3,710	0,522
	Z gen.	3,478	0,716
	Total	3,559	0,668
cost savings	X. gen.	3,000	0,863
	Y gen.	2,516	0,801
	Z gen.	2,638	0,799
	Total	2,640	0,815
environmental awareness	X. gen.	3,000	0,747
	Y gen.	2,484	0,879
	Z gen.	2,420	0,807
	Total	2,495	0,838
trendiness	X. gen.	3,727	0,624
	Y gen.	3,742	0,508
	Z gen.	3,420	0,732
	Total	3,541	0,682
visibility	X. gen.	3,182	0,724
	Y gen.	3,452	0,616
	Z gen.	3,087	0,777
	Total	3,198	0,746
sample value	X. gen.	3,182	0,724
	Y gen.	2,645	1,037
	Z gen.	2,812	0,840
	Total	2,802	0,900

Source: own research, 2023, N = 399

This has also led us to look at which generations tend to value the characteristics of scope more highly. Given the ground-breaking nature of the project in terms of digitisation, we would expect that Generation Z in particular will be the generation that will value the initiative. Conversely, we found that it was Generation X members who rated the majority of factors the highest. They are the ones most likely to have the highest average values for novelty, interest, future focus, sustainability, relevance, usability, uniqueness, cost savings, and environmental awareness. For Generation Z, we only saw high scores for public interest, which the project does not really represent. For Generation Y, profit orientation, trendiness and familiarity dominated with the highest average value (Table 2).

Gucci Town

Gucci Town is creating a new kind of retail community in the metaverse. Not content with simply dominating the world of fashion, Gucci has also set its foot in the metaverse with this project, making the Italian company somewhat unexpectedly known as a pioneer of digital transformation and an incubator of discovery. The 101-year-old fashion house first entered the virtual online world with Gucci Garden. Gucci Town opened its virtual doors in May 2022. The space, designed around a central piazza, features Gucci-inspired games, avatar selfies with models from fashion shoots. In the Gucci Shop, avatars can purchase limited edition and archive-inspired virtual accessories and collectibles. Gucci Town has attracted more than 34.6 million visitors in just a few months, including a sensational debut by Miley Cyrus. In August, the pop star emerged as the brand's first celebrity avatar personality, playing with fans and taking selfies while promoting one of the brand's fragrances. Gucci also allows users to purchase a metaverse bottle of the fragrance for around $5 and wear it as a backpack. It's certainly chump change for the high-end retailer, but it's a clever way to inspire early loyalty in the next generation of consumers, especially as more retailers from Nike to Burberry open stores in metaverse.

In the case of the Gucci Town project, we first looked at the averages in detail. In this case, the highest score was also given to profit orientation, followed by trendiness and feasibility. Sustainability and environmental awareness also ranked lower in this project, but slightly higher than in Store of the Future. The lowest average score was given by respondents to the project sample. This is slightly better than the public interest and environmental awareness, which is a slightly more positive and nuanced picture than for the previous project.

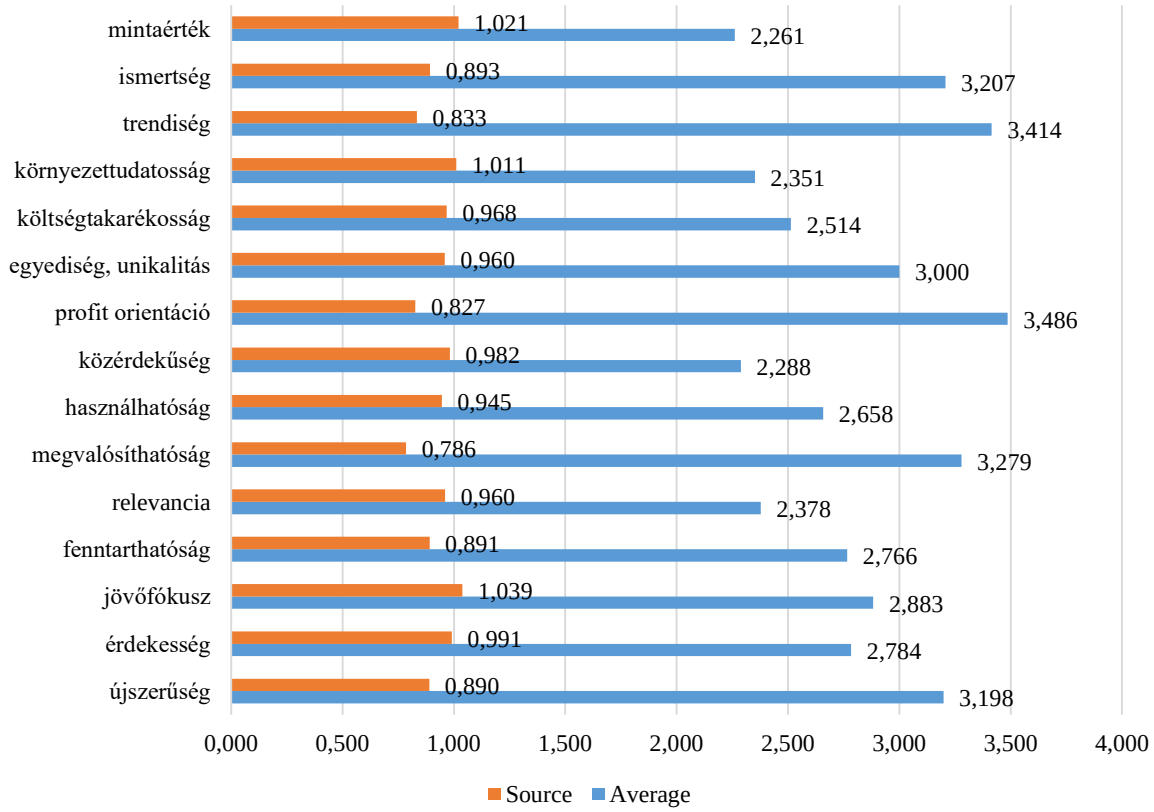

Figure 3. Evaluation of the elements of the Gucci Town project scope
Source: own research, 2023, N = 399

Table 3. Correlation of Gucci Town project scope elements with respondents' age

		Sum of Squares	df	Mean square	F	Sig.
Novelty	Between Groups	20,321	2	10,160	13,568	0,000
	Within Groups	330,238	441	0,749		
	Total	350,559	443			
of interest	Between Groups	18,483	2	9,241	9,779	0,000
	Within Groups	416,761	441	0,945		
	Total	435,243	443			
future focus	Between Groups	12,682	2	6,341	6,011	0,003
	Within Groups	465,228	441	1,055		
	Total	477,910	443			
sustainability	Between Groups	11,686	2	5,843	7,580	0,001
	Within Groups	339,953	441	0,771		
	Total	351,640	443			
relevance	Between Groups	15,351	2	7,675	8,611	0,000
	Within Groups	393,082	441	0,891		
	Total	408,432	443			
Feasibility	Between Groups	2,535	2	1,267	2,064	0,128
	Within Groups	270,835	441	0,614		
	Total	273,369	443			
usability	Between Groups	0,484	2	0,242	0,270	0,764
	Within Groups	395,480	441	0,897		
	Total	395,964	443			
public interest	Between Groups	7,331	2	3,666	3,851	0,022
	Within Groups	419,768	441	0,952		
	Total	427,099	443			
profit orientation	Between Groups	1,526	2	0,763	1,117	0,328
	Within Groups	301,392	441	0,683		
	Total	302,919	443			
uniqueness, uniqueness	Between Groups	4,434	2	2,217	2,423	0,090
	Within Groups	403,566	441	0,915		
	Total	408,000	443			
cost savings	Between Groups	24,318	2	12,159	13,728	0,000
	Within Groups	390,601	441	0,886		
	Total	414,919	443			
environmental awareness	Between Groups	8,176	2	4,088	4,051	0,018
	Within Groups	445,013	441	1,009		
	Total	453,189	443			
trendiness	Between Groups	4,796	2	2,398	3,490	0,031
	Within Groups	302,952	441	0,687		
	Total	307,748	443			
visibility	Between Groups	4,796	2	2,398	3,037	0,049
	Within Groups	348,141	441	0,789		
	Total	352,937	443			
sample value	Between Groups	18,447	2	9,223	9,177	0,000
	Within Groups	443,247	441	1,005		
	Total	461,694	443			

Source: own research, 2023, N = 399

Using analysis of variance, we also examined the extent to which the age of the respondents influences the perception of certain factors of the scope of the project. In this case, there were only four factors where no significant effect was found between the perception of the given characteristic and the age of the respondents. These were feasibility, usability, profit orientation and uniqueness of the project. In other words, the positive perception of certain factors of the project is also reflected in this case, in contrast to the previous Project. As with the previous project, we have looked at the factors where certain generations stand out. Here again, we found that Generation X was the generation most likely to consider the project novel, interesting, future-focused, sustainable, relevant, in the public interest, cost-effective, environmentally conscious and exemplary. There was not a single factor where Generation Z came out on top. What was also noticeable was that Generation Y stood out in terms of trendiness and awareness.

Table 4. Perception of the elements of the Gucci Town project scope by age group of respondents

		Average	Source
Novelty	X. gen.	3,636	0,650
	Y gen.	2,903	0,966
	Z gen.	3,261	0,847
	Total	3,198	0,890
of interest	X. gen.	3,364	0,780
	Y gen.	2,613	0,977
	Z gen.	2,768	0,997
	Total	2,784	0,991
future focus	X. gen.	3,364	0,650
	Y gen.	2,742	1,051
	Z gen.	2,870	1,064
	Total	2,883	1,039
sustainability	X. gen.	3,000	0,747
	Y gen.	2,516	0,760
	Z gen.	2,841	0,944
	Total	2,766	0,891
relevance	X. gen.	2,909	0,802
	Y gen.	2,226	0,978
	Z gen.	2,362	0,949
	Total	2,378	0,960
public interest	X. gen.	2,636	0,990
	Y gen.	2,161	0,923
	Z gen.	2,290	0,996
	Total	2,288	0,982
cost savings	X. gen.	3,000	0,863
	Y gen.	2,194	1,001
	Z gen.	2,580	0,925
	Total	2,514	0,968
environmental awareness	X. gen.	2,727	1,065
	Y gen.	2,226	1,011
	Z gen.	2,348	0,992
	Total	2,351	1,011
trendiness	X. gen.	3,545	0,901
	Y gen.	3,548	0,758
	Z gen.	3,333	0,847
	Total	3,414	0,833
visibility	X. gen.	2,909	0,910
	Y gen.	3,290	0,961
	Z gen.	3,217	0,851
	Total	3,207	0,893
sample value	X. gen.	2,818	1,040
	Y gen.	2,065	1,018
	Z gen.	2,261	0,989
	Total	2,261	1,021

Source: Own research, 2023, N = 399

Conclusions

Overall, respondents were realistic and positive about the two project initiatives. It can be seen that their novelty and uniqueness is less striking to respondents than their profit orientation. Factors that are key issues of the 21st century, such as sustainability or environmental awareness, were very much in the background for both projects. The same could be said for innovativeness and future focus. However, it can be said that both projects have significant novelty value that could revolutionise the retail shopping experience. As economic growth in the 21st century is difficult to achieve without breakthrough innovation, both projects can clearly be held up as examples for the retail sector to follow. From the respondents' point of view, however, it is important to see the factors that are important to them but which do not appear in the evaluation of the projects. This can be achieved either through awareness-raising, a targeted marketing campaign or by better highlighting certain factors, even at the

planning stage. It is important to create projects in the future that can reach as wide a range of consumer groups as possible, paying attention to the call words that 21st century organisations are clearly trying to answer and address.

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The Impact of Artificial Intelligence on the Service Industry and Consumer Behavior: A Bibliometric Analysis

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Abstract: This study aims to reveal, through a bibliometric analysis, more information about the transformation and impacts of artificial intelligence on the service industry and consumer behavior transformation and development over the last 32 years. Articles were collected from three databases using keyword combinations (artificial intelligence, service industry, consumer behavior, marketing, machine learning, etc.). Then, inclusion and exclusion criteria for the field were applied to obtain the final sample. The final sample consisted of 50 peer-reviewed articles. Three separate analyses were conducted to test the sample. A performance analysis identified the publication years of the articles, contributions per country, and the output of the relevant journals. The data analysis analyzed the articles in-depth and provided insights into the evolution of relevant scientific production. The study's findings provide a broad perspective on research to date and identify potential research gaps. This research endeavors to contribute to the marketing field by undertaking a bibliometric analysis of research concerning the impact of artificial intelligence on consumer behavior and the service industry, spanning the period from 1991 to 2024. It offers suggestions to academics and researchers for future research.

Keywords: Artificial intelligence, Service industry, Bibliometric analysis

Introduction

Marketing departments historically leveraged data analytics and key performance indicators to assess their advancement toward revenue and customer growth objectives (Morgan et al., 2002). Nevertheless, these endeavors challenge the growing volume of data, intricate landscapes, intensified competition, and swiftly evolving customer preferences. Digital technologies have opened up possibilities for revealing insights regarding customer needs and behaviors, from individuals to businesses and governmental bodies (Zaki, 2019).This has changed the way businesses connect with clients, comprehend their needs, and give esteem (Bednar & Welch, 2020). Different variables have driven the requirement for a modern-promoting worldview. Advanced innovations have gigantic control and can offer profitable experiences from tremendous amounts of information.

The way machines and humans interact is being changed by artificial intelligence. Artificial intelligence collects and analyzes real-time data to meet customers' needs. Marketing is one of the industries that has seen significant changes due to the rapid growth of artificial intelligence. Artificial intelligence techniques are used to reveal classified information. They help organizations generate real-time revenue growth and strengthen their customer relationships.

The advent of artificial intelligence (AI) in the corporate world holds the potential to significantly impact the economy and employment, much like the industrial and digital revolutions of the past (Bock et al., 2020). This type of automation affects not just manual tasks but also those that require analytical, intuitive, and empathetic abilities (Huang & Rust, 2021). Automation is being used to directly and efficiently interact with customers in

various industries, including banking and finance (Belanche et al., 2019), travel and tourism(Akdim et al., 2021; Belanche et al., 2020; Byrd et al., 2021; Romero & Lado, 2021), service operations (Ivanov & Webster, 2021), and healthcare (Wirtz et al., 2021).

Innovative technologies such as automated interactions in certain services have the potential to greatly impact customer choice, experience, service quality, and productivity. According to (Van Doorn et al., 2017), these types of interactions may even influence consumer behavior. Meanwhile, (Bock et al., 2020)suggest that AI has the power to disrupt services. While automation has clear benefits in some areas, such as the transportation of goods, its impact on social interaction and its ability to replace human interaction in service settings remain uncertain.

The development of big data analysis and AI led to the development of predictable analytics, including machine learning and data mining solutions. AI has transformed marketing by providing an advanced way to analyze and process data and make decisions. Business leaders who understand its potential see its use as an asset. AI can provide significant advantages in terms of data processing and prediction accuracy. In marketing, AI tools have proven useful in predicting consumer behavior. The brand spends time and money to understand customers' needs better, highlight their products or services, and define their market share. Companies use AI tools to analyze web metrics and optimize transportation and transformation strategies to increase customer satisfaction. To achieve our business objectives of enticing new customers and anticipating their purchasing habits, we utilize various forms of AI, including machine learning, natural language processing, expert systems, audio and visual recognition, planning, and robotics. Our aim is to enhance customer satisfaction, loyalty, and sales forecasts by leveraging smart systems that personalize and anticipate demands, while reducing decision-making risks and boosting sales.

This study aims to explore the expansion and impact of artificial intelligence within the service industry. By posing a series of research questions, valuable insights can be gained by companies. To accomplish these objectives and tackle the research questions, a bibliometric research approach has been adopted. In order to obtain a thorough understanding of the subject, various aspects, such as the co-occurrence of keywords, performance by decade, contributions by country, and academic journal publications, are analyzed.

Method

Bibliometric analysis is a valuable statistical tool utilized to analyze publication patterns within a field. By employing this method, researchers can efficiently identify current trends and gaps in research, thereby providing direction for future studies (Guo et al., 2019). This approach is especially beneficial for academics keen on exploring a specific area of study as it offers a rapid comprehension of the field. The main bibliometric analysis tools are performance analysis and science mapping. Performance analysis assesses scientific impact by analyzing journals, authors, and citations. Meanwhile, science mapping creates a visual representation of the structure and progression of scientific research through co-word and co-citation analyses (Feng et al., 2017). This study's methodology focuses on four primary areas, including a four-step process that entails selecting bibliometric databases, identifying keywords, refining initial results, and developing a data analysis plan.

Selecting the Bibliometric Databases

The first step was a comprehensive search of three databases: Google Scholar, Scopus, and Web of Science. This method made it possible to analyze articles from a larger range of nations and sources. The Web of Science is a widely used and well-known research database worldwide. The Google Scholar database was utilized to obtain a range of viewpoints from different researchers, and the Scopus database offered access to more than 20,000 peer-reviewed journals from multiple publishers (Verma et al., 2021). This made it easier to conduct a thorough analysis of the body of literature that was available, which advanced our understanding of the topic at hand.

Defining the keywords and identification of key outcomes

The initial search used keywords included in the research questions, ‘artificial intelligence’, ‘service industry’ and ‘consumer behavior’. These keywords were entered into the three databases using the ‘all fields’ search function. As can be seen in Table 1, this methodology was used with all three databases. While Scopus and

Google Scholar returned a higher number of articles, some were not closely related to the primary subject matter of the research. From all these possible combinations, 40,716 articles were collected. The review was conducted in April 2024.

Table 1. Keyword combinations

Database	Number of studies
Web of Science	10.729
Scopus	542
Google Scholar	29.445
Total	40.716

A broad search was conducted, but the results were filtered based on two main factors relevant to the research topic. First, publications had to be in English. Second, out-of-field studies, such as those in engineering and psychology, were excluded. However, studies in business were included in the research results. Thus, 50 peer-reviewed articles on artificial intelligence in marketing were identified as suitable for the field.

Conducting Data Analysis

Once the final sample was identified, the data was analyzed. To obtain a cluster-oriented organization of a sample and show visual links between keywords, the researchers used VOSviewer software (Van Eck & Waltman, 2010). VOSviewer is a tool that creates and visualizes bibliometric networks by generating a cloud map based on various relevant factors such as authors, journals, and keywords (Srivastava & Sivaramakrishnan, 2021).

The study aimed to analyze keywords related to artificial intelligence and customer behavior in the service industry. The analysis included the number of studies conducted by year, country-based contributions, and journal-based publications. The initial research exploring the intersection of artificial intelligence and marketing dates back to 1991. Since then, a growing number of studies have been conducted, with a notable increase in publications during the 2020s, particularly in the area of customer behavior and the service industry. Findings suggest a significant uptick in studies during the 2010s compared to the 1990s with 10 studies conducted in 2022, 8 in 2023, and 4 in 2024. A total of 50 studies that were subject to the research and met the basic separation criteria, published in English and the field of business administration, and published in peer-reviewed journals were conducted. The studies published every year are shown in Figure 1.

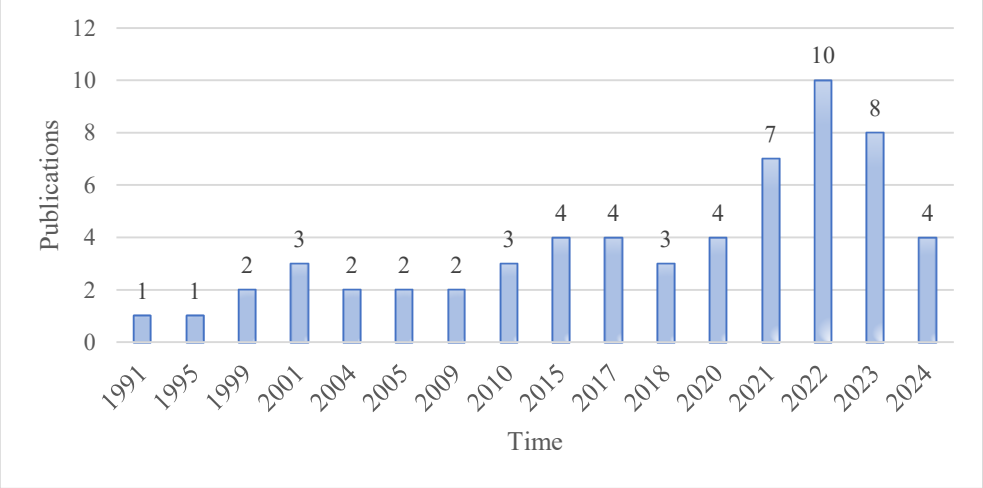

Figure 1. Number of publications by year

Determining Country-Based Contribution

The research identifies the top-producing countries in a field based on the authors' country of origin. The map shows the country with the highest number of publications. The top 10 contributing countries were identified. The map is shown in Figure 2.

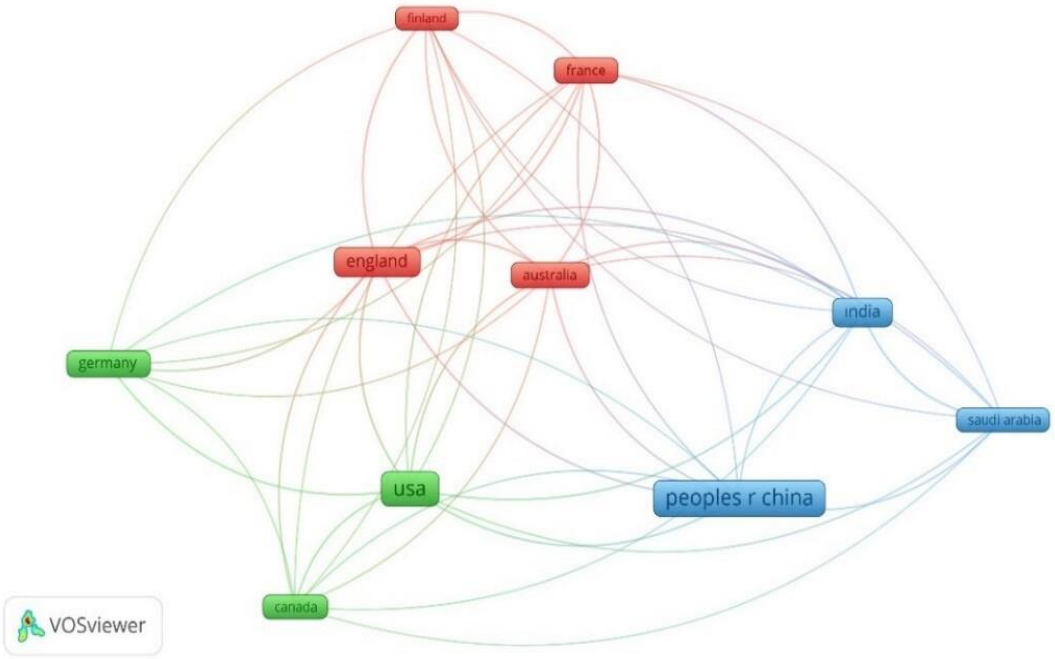

Figure 2. Map of the most prolific authors.

Source: VOSviewer

Studies that revealed the relationship between artificial intelligence and marketing analyzed the findings of which authors contributed the most to the field and identified the countries of the most productive authors. The country map shows that authors from a wide range of countries have contributed to the field. A map of countries by origin of the most prolific authors was created and is shown in Figure 3.

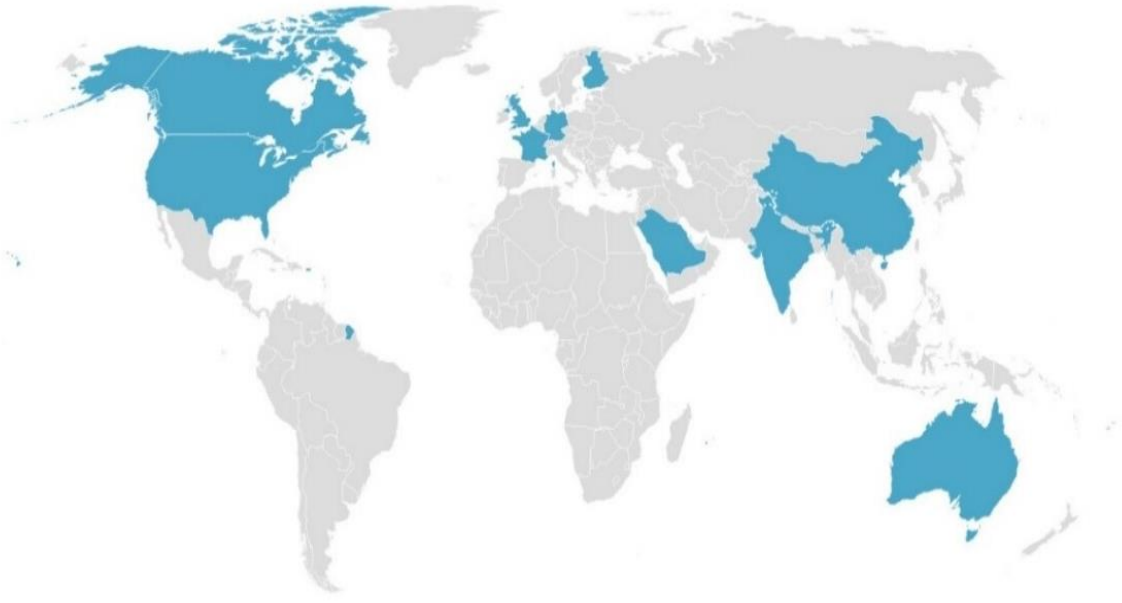

Figure 3. Map of the most prolific countries

Source: VOSviewer

Several studies have been conducted regarding the influence of artificial intelligence on customer behavior and the service industry. The findings reveal that the United Kingdom, China, and the United States of America are the top three countries with the highest number of published research papers on the subject. Table 2 outlines the top 10 countries with the most publications.

Table 2. The 10 most productive countries (based on author origin)

Number	Country	Number of articles
1	China	206
2	USA	193
3	England	108
4	India	99
5	Germany	63
6	Australia	60
7	France	58
8	Saudi Arabia	44
9	Canada	40
10	Finland	27

Determining the Number of Publications according to Journals

The 17 articles were published in 15 journals: the statistics show that the articles were not concentrated on just a few journals but were published over a wide variety. Table 3 lists the 15 most featured academic journals. Since customer behavior and the service industry are related to the business field and, more specifically, to marketing, most of the journals are associated with marketing in some way. Academic studies within the scope of artificial intelligence, service industry, and customer behavior are still very new, and there are still few studies in this field.

Tablo 3. Fifteen of the most prominent academic journals

Name of the journal	Number of articles
International Journal of Bank Marketing	2
Sustainability	2
Entrepreneurship and Sustainability Issues	1
Global and National Business Theories and Practice: Bridging the Past with the Future	1
International Journal of Entrepreneurial Behavior & Research	1
Journal of Asia Business Studies	1
Journal of Hospitality and Tourism Technology	1
Journal of Service Management	1
Journal of Theoretical and Applied Electronic Commerce Research	1
Marketing and Management of Innovations	1
Market-Tržište	1
Pacific Business Review International	1
Technology Innovation Management Review	1
Tourism Management Perspectives	1
Tourism Review	1

Publication Performance of Academic Journals

An analysis was carried out for the keywords used in the studies conducted within the scope of artificial intelligence. In the analysis, the studies conducted in the field of business administration were determined in accordance with the purpose of the study. The keywords used in the journals in which these articles were published were determined, and various clustering results were obtained regarding the scope of the studies conducted so far. The results for keywords are shown in Figure 4.

Results

The VOSviewer tool was used for keyword analysis. The results showed the presence of 8 clusters. Network visualization is shown in Figure 4. Given the different colors, groups can be easily distinguished, and keywords have different sizes depending on the size of the production concerned. This helped us to differentiate between clusters and made it easy to answer the question of which areas of work under top-layer visualization and

artificial intelligence were concentrated. Although there are a total of 8 clusters, some groups have been merged because of very close keywords, and therefore, a whole of 5 clusters will be studied. The clusters generated by means of keywords are shown in Figure 5.

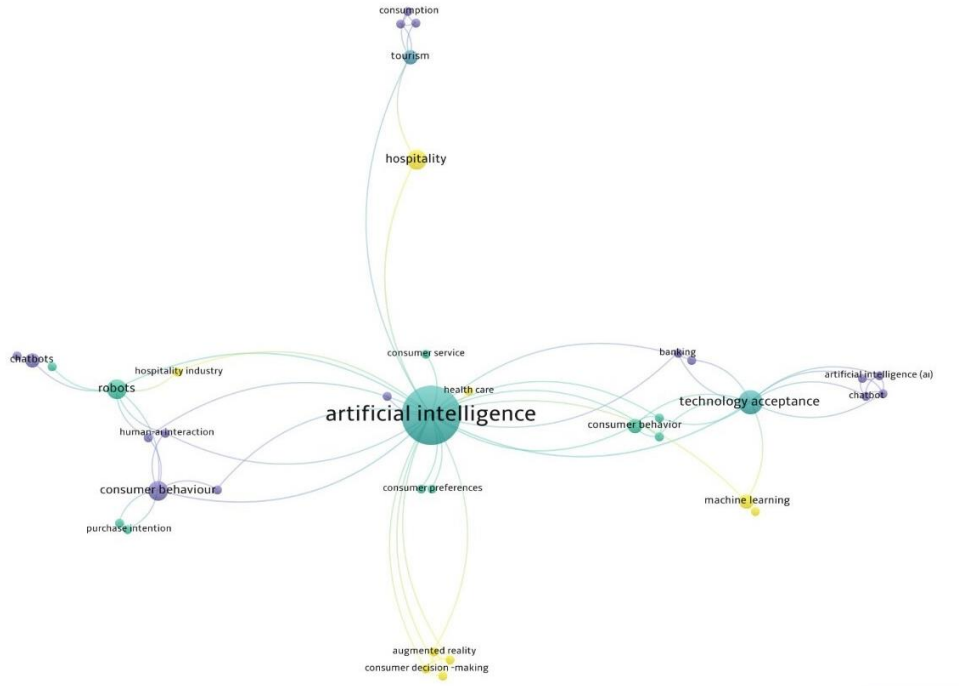

Figure 4. Visualization of keywords

Source: VOSviewer

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
• Digitalization in the service industry	• Adoption of new technologies	• Changes in consumer behavior	• Using Artificial Intelligence to engage customers	• Artificial intelligence applications on social media

Figure 5. Grouping of clusters

Cluster 1. Digitalization in the Service Industry

In the first cluster, more services include human-computer interaction, thus highlighting digitization. It has been concluded that research on the implementation of robots in the service industry has focused on exploring the connection between consumer behavior and buying patterns. Particularly in the travel sector, changes in consumer behavior have been observed with the adoption of artificial intelligence applications. Research into the tourism and accommodation sector is highlighted in this group. Considering that unexpected crises, natural disasters, or epidemics affect whatever sector, it can be said that the existence of alternative instruments can reduce the losses by preventing the disadvantages from being experienced. With changing consumer needs, the importance of using new technologies in marketing is highlighted. It can be said that human and artificial intelligence applications will be more intrinsic in the coming years and will contribute to shaping consumer needs and behavior.

Cluster 2. Adoption of New Technologies

In the second cluster, more emphasis is placed on the adoption of new technologies. Studies include how artificial intelligence applications are used in determining the customer segment. In this context, the banking sector appears to be at the forefront. With the introduction of chatbot applications in the banking sector, the

differences in consumer behavior are also highlighted. In the field of AI-driven transformation, robots have found relevance in various sectors, including the hospitality industry. Recent developments have led to the deployment of robots in hotels and resorts to improve customer experiences. These autonomous machines can perform a range of tasks, such as delivering room service, assisting concierges, or even acting as guides around the property. Research indicates that the integration of robotic services in the hospitality industry can enhance guest perception and operational performance (Alboqami, 2023). In addition to traditional methods, applications that provide more flexible transportation for consumers are preferred, but the critical point here is that consumers accept new technologies.

Cluster 3. Changes in Consumer Behavior

This cluster includes changing consumer behavior and artificial intelligence applications. In this context, with changing consumer behavior, it can be said that there are new service offerings, especially in the accommodation and tourism sector, especially online. Artificial intelligence applications, especially virtual reality and augmented reality applications, are increasing. Businesses do not have to lag behind current practices to adapt to rapidly changing consumer demands. Consumers seeking services without time and space constraints are now choosing easier access. The consumer is faced with many alternatives in the decision-making process, and the key point here is that it can offer the consumer a faster and more differentiated service experience. Therefore, the study emphasizes the importance of providing consumers with virtual experiences that create a unique sense of physical environment in order to save more time.

Cluster 4. Using Artificial Intelligence to Engage Customers

Studies on the service sector and consumer behavior are highlighted in this cluster. In the service sector, it was concluded that there was a trend towards the banking and financial sectors. Banking is one of the most prominent sectors for AI applications. In this context, consumer behavior and consumer satisfaction are seen to play an important role. Given that today's consumers do more than mobile applications, should take account of this change in behavior. Studies in this area show that the two most important factors in consumer behavior are quality perception and satisfaction with service procurement.

Artificial intelligence is utilized in the banking sector to enhance operational effectiveness, safety and the customer experience. It automates repetitive actions such as data collection and fraction recognition, reducing operational expenses. AI-powered chatbots provide round-the-clock customer assistance. Machine learning algorithms assess client data to customize services and identify uncommon operations, improving safety. AI is a versatile technology that combines machine learning, natural language processing, and computer visualization to analyze data, make decisions, and automate operations. The banking industry utilizes AI to enhance customer care and security while also developing tailored financing solutions. The increasing use of artificial intelligence applications in the financial sector and in the banking sector, confirms the increase in research in this area.

Cluster 5. Artificial Intelligence Applications on Social Media

This cluster includes social media and artificial intelligence applications. With the shaping of consumer behavior, social media in particular has become a means for businesses to obtain much more data. In today's digital age, huge amounts of data are produced every day. Artificial intelligence (AI) plays an important role in large social networks to help manage this data. The integration of artificial intelligence (AI) with social media has revolutionized marketing operations and elevated user experiences. AI-powered tools facilitate text and visual content creation, influencer research, advertising management, social media monitoring, and brand awareness campaigns. Brands can leverage AI to personalize content, optimize influencer marketing strategies, and track ad performance, leading to increased engagement and improved marketing outcomes. As AI technology advances, it will continue to offer more advanced and refined tools, transforming the social media landscape even further.

Conclusion

Artificial intelligence has quickly evolved over the past few years and is changing the way we perceive and understand marketing. Proper employment of AI provides significant advantages. The main benefit is how well

the technology has impacted marketers' ability to study and understand consumer behavior. Marketers are researching online behavior to improve their strategies. In recent years, artificial intelligence (AI) and marketing have been collaborating strongly. Many sectors, including marketing, are rapidly adopting artificial intelligence and machine learning. Undoubtedly, technology is constantly evolving, and AI has changed the face of marketing.

The most fundamental outcome of the literature study is that very few studies have been conducted on the impact of artificial intelligence on customer behavior and the service industry. The current study provides a contribution to marketing by filling a gap, i.e., with a biometric analysis that studies the impact of AI on customer behavior and the service industry. The visualization performed with VOSviewer identified 5 clusters associated with the central theme of the study:

- Digitalization in the service industry
- Adoption of new technologies
- Changes in consumer behavior
- Using Artificial Intelligence to engage customers
- Artificial intelligence applications on social media

The study also identified future research directions. After the clustering, it was concluded that the most intensive research areas were "artificial intelligence, consumer behavior, digitalization, banking and travel sector and chatbot" through the following keywords. In the realm of digital marketing, artificial intelligence applications have become increasingly prevalent. Specifically, there has been an emphasis on the use of AI in the tourism and banking industries to engage with customers beyond physical service provision. As a result, the use of robots and chatbots has become a popular tool in the service sector.

Recommendations

Within the scope of the studies carried out, research gaps in the field have been identified for future research, and it is important to carry out more studies in this field both to ensure progress in the academic field and to benefit businesses. The keywords and research areas identified to guide future studies are shown in figure 6.

Figure 6. Content analysis visualization

The content analysis, which was created to provide guidance for future research, consists of three main headings. These three main topics, with artificial intelligence and marketing at the core, are as follows: service industry, machine learning and customer orientation. In the studies on the impact of artificial intelligence applications on the service sector, it is seen that the banking, finance and tourism sectors are mostly investigated. It is suggested that logistics and supply chain, health and retail sectors can also be the subject of future studies. Since there is a literature gap in the field regarding these sub-fields, it is thought that future studies will be beneficial.

Artificial intelligence has demonstrated significant potential in a variety of fields, including healthcare, consumer analytics, financial services and marketing. The use of AI is increasingly supported by both businesses and academics. In healthcare, AI helps in recording and processing documents and providing medical support. Artificial intelligence is improving many sectors, including healthcare, and especially differentiating the customer experience. It is changing the way healthcare-related services are delivered. An example of this is the use of surgical robots in the healthcare sector.

AI chatbots can assist patients with a range of health problems. In this digital era, we cannot disregard the fact that consumers expect quick gratification. Virtual assistants can provide effective treatment for health issues and symptoms, eliminating the need for a patient's doctor to travel to a distant hospital for an appointment or response. In order to provide patients with a special experience, healthcare staff and bots need to connect.

The logistics and supply chain sector is a popular area of research for AI applications. Artificial intelligence is becoming increasingly important in global logistics and supply chain management. It offers significant advantages over competitors and opportunities to reduce costs in areas such as demand forecasting, demand management, manufacturing scheduling, transportation, and delivery planning. Artificial intelligence has the potential to significantly increase effectiveness and aid in making intelligent decisions.

Its applications in logistics and supply chain processes, such as autonomous vehicles, route optimization, and smart roads, are particularly noteworthy. Given the benefits in terms of cost and time, it is crucial for academic and business professionals to conduct further research in this area.

Online businesses are utilizing artificial intelligence to connect with customers. With the assistance of modern AI and online business platforms, vast amounts of data related to consumer behavior and usage patterns can be utilized. This allows for personalized purchasing experiences for online shoppers through computer-assisted computation and self-learning tools. AI-powered online shopping provides features such as visual tracking, voice search, and selection intelligence tools. The use of AI in online shopping facilitates a more effective sales process by providing a customer-centric approach and a new level of personalization. Emerging marketing techniques are supported by new technologies, including AI systems, which are designed to effectively reach target consumers and deliver enhanced consumer experiences.

It is seen that the impact of artificial intelligence applications on the service sector is very important, it saves time and cost, and most importantly, it is one of the critical tools to provide more personalized and faster service to customers. In this context, the fields of healthcare, logistics and supply chain, and online retail are recommended for researchers who want to study the service sector. Another area of research proposed for future research is machine learning. An AI system that incorporates machine learning will increase your client's experience and help you to significantly improve conversion, revenue and profit. Businesses that provide online services can decrease their workload by implementing AI on their e-commerce sites. This will enable them to respond more quickly to evolving trends than a human can, especially when it comes to executing business operations.

In particular, the use of chatbots in e-commerce and the use of augmented reality applications in online purchases will provide a flexible application service against changing customer behavior. Virtual reality, three-dimensional visualization applications will allow consumers to have a different experience. Chatbots are a valuable tool for online customers. They provide information about product availability and suggest options, as well as updates on delivery and order progress. They provide information about product availability and suggest options, as well as updates on delivery and order progress. Additionally, they can suggest products related to the customer's search.

For future research, studies can be conducted including how artificial intelligence applications, especially augmented reality and machine learning, affect customers' online purchasing behaviors and the impact on firm performance within the scope of firm and customer interaction in e-commerce transactions. Another concept

suggested for future research is customer orientation. Nowadays, companies are increasingly using artificial intelligence (AI) to improve customer experience and engagement. AI technology has the potential to revolutionize the way companies interact with customers, providing new opportunities to personalize applications, streamline processes, and enhance outcomes.

Digital transformation can improve customer experiences and engagement by utilizing technologies such as AI, machine learning, and data analytics to help businesses meet these expectations. Businesses can improve customer experience by using chatbots and virtual assistants to provide prompt, personalized customer assistance through these implementations. These systems can help organizations simplify customer service procedures and reduce response times. For future research, it is recommended to conduct studies on how customer-oriented artificial intelligence applications affect customer experience and customer engagement. In addition, studies can also be conducted to determine whether this results in customer loyalty.

In this study, the impact of artificial intelligence applications on changing customer behavior and its applications in the service sector were discussed. In this context, it can be said that the study is very important because it analyzes the studies conducted so far in the field, reveals the gaps in the field and identifies keywords and concepts that can be used for future research. As a result, the information provided and analyzed in this research will be a great service to practitioners and the field for researchers involved in the relationship between AI and consumer behavior and the service industry.

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Scientific Ethics Declaration

The author declares that the scientific, ethical, and legal responsibility of this article published in EPSTEM Journal belongs to the author.

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Performance Analysis of Encryption Algorithms in Named Pipe Communication for Linux Systems

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Abstract: In modern computing environments, inter-process communication (IPC) plays a pivotal role in facilitating seamless interaction between software components. Named pipes, a form of IPC mechanism in Linux systems, offer a straightforward means of data exchange between processes. However, ensuring the confidentiality and integrity of data transmitted via named pipes is essential, particularly in environments where sensitive information is handled. This paper presents a comprehensive investigation into the performance characteristics of various encryption algorithms applied to named pipe communication within Linux systems. The efficiency of six encryption algorithms such as Caesar cipher, RSA, DES, AES-128, AES-192, and AES-256 is examined in terms of their impact on data throughput, latency, and resource utilization within the named pipe communication. Through a series of systematic experiments, encompassing diverse datasets and transmission scenarios, the trade-offs between security and performance inherent in each encryption algorithm are analyzed. Our findings shed light on the relative strengths and weaknesses of different encryption techniques, providing valuable insights for system administrators and developers in selecting appropriate encryption methods based on specific application requirements and security considerations. This study contributes to the broader understanding of secure IPC mechanisms in Linux environments, offering a nuanced perspective on the interplay between encryption algorithms and system performance in the context of named pipe communication.

Keywords: Inter-process communication, Encryption algorithms, Linux systems, Named pipe

Introduction

In the realm of digital security, cryptographic encryption methods serve as the cornerstone for safeguarding sensitive information and ensuring secure communication channels. This paper delves into a comparative analysis of encryption methods applied specifically to named pipes within the Linux environment. Named pipes, also known as FIFOs (First In, First Out), offer a means of inter-process communication (IPC), facilitating data exchange between unrelated processes.

In the past, the performance of encryption methods has been examined and compared with each other many times. There are dozens of studies on these in the literature. In particular, AES and DES are the 2 standards that are most compared. In the study conducted at Galgotias University in 2015, performance calculations and comparisons of AES and DES were made, and in this study, the variation and simulation time of these 2 encryption algorithms were focused on (Bhat et al., 2015). In another paper comparing AES and DES, the encryption times and CPU usage of these algorithms were discussed in the same way as this study (Rihan et al.,

2015). The originality of this study is that Caesar cipher is included in the comparison and the system is tested using named pipe in inter-process communication in Linux structure.

The study methodically investigates the performance of three encryption algorithms: Caesar Cipher, Data Encryption Standard (DES), and Advanced Encryption Standard (AES). These algorithms are scrutinized across three key phases: research and comprehension of cryptographic methods, implementation within the named pipe infrastructure, and comprehensive performance measurements. Additionally, the RSA algorithm has been chosen as the key determination method in all these encryption methods. In practical applications, all key generation is done using the RSA algorithm.

The research phase entails a thorough exploration of each encryption and decryption method, including key generation techniques. This foundational understanding forms the basis for subsequent algorithm development and integration into the Linux environment's named pipe structure.Subsequently, the study focuses on the practical implementation of the encryption algorithms within the named pipe framework. This phase involves the successful execution and evaluation of RSA, Caesar Cipher, DES, and AES algorithms, highlighting their applicability and efficiency in the Linux environment.

Finally, comprehensive measurements are conducted to assess the performance of the encryption methods. Time measurements provide insights into the encryption duration of each algorithm, while CPU utilization measurements offer a glimpse into the resource consumption during encryption operations. By systematically examining the performance of these encryption methods within the Linux environment's named pipe infrastructure, this study aims to provide valuable insights into selecting suitable encryption algorithms for ensuring secure communication channels in digital systems.

Material

Named Pipe

Inter-process communication (IPC) forms the cornerstone of effective multitasking in operating systems. Named pipes, also known as FIFOs (First-In-First-Out), offer a well-established method for IPC, particularly within Unix-like systems (Gaikwad,2023). They build upon the traditional pipe concept by introducing a crucial distinction: persistence.

Unlike standard, anonymous pipes that vanish with their creator process, named pipes exist as named entities within the file system. This characteristic allows them to transcend the lifespan of their originating process, enabling communication between processes that might not be running concurrently. Named pipes function as special files, accessible by processes through familiar file operations like opening, reading, writing, and closing (Adegeo, n.d.), A defining feature of named pipes is their adherence to the FIFO principle. Data written to the pipe by one process is retrieved by another process in the exact order it was written. This ensures the integrity of messages and streamlines communication flow.

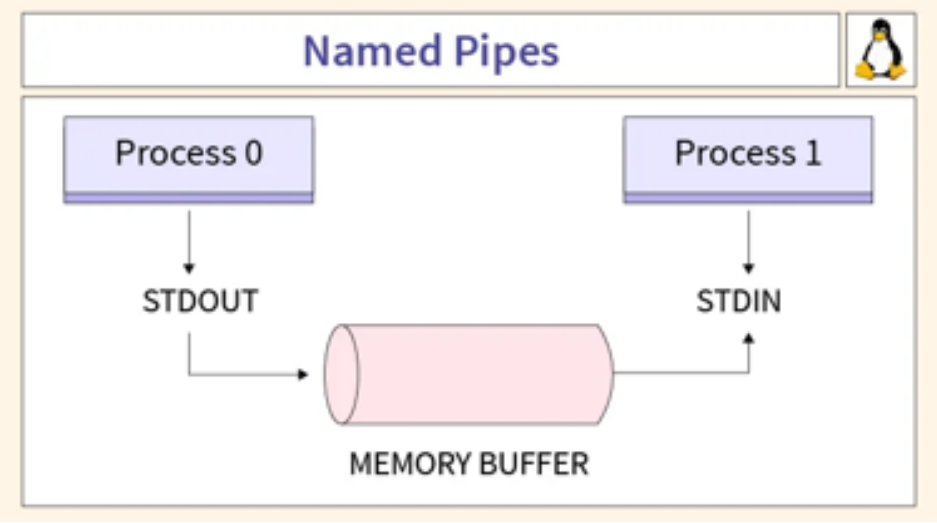

Figure 1. A representation of named pipe (Gaikwad, 2023)

The specific implementation details of named pipes vary across operating systems. In Unix-like environments, commands like mkfifo create named pipes, while functions like open and read/write handle data exchange (linux manual page, n.d). In conclusion, named pipes provide a robust and user-friendly mechanism for inter-process communication. Their persistence, adherence to FIFO principles, and ability to bridge communication between independent processes make them a valuable tool for various IPC applications.

Development and Test Environment

The encryption algorithms with named pipes were developed, compiled, and executed on a single computer to maintain consistent and precise comparisons. This computer operates on a Linux-based virtual machine running Ubuntu-20.04.1, utilizing a 64-bit architecture with x86_64 and a 5.15.0-101-generic kernel. All of the developments such as creating named pipe, RSA, DES, AES cryptosystems were developed with C programming language and compiled using gcc version 9.4.0.

Method

The methodology of this study, in which the performances of the encryption methods used on the named pipe are compared, is carried out in 3 main steps. The first of these is to research and learn these encryption and decryption methods in the field of cryptology. These also include generating keys. Following this research, we will develop and successfully run these encryption algorithms on the named pipe structure established in the Linux environment. Finally, several measurements are made on these structures for performance observation, which is the main purpose of the study.

Cryptographic Encryption Methods

Rivest, Shamir and Adleman (RSA) Cryptosystem

The RSA method is a frequently used asymmetric encryption technology for safe data transport. RSA, named after its founders Rivest, Shamir, and Adleman, encrypts data with a public key that can be freely transmitted, whereas decryption requires a private key that the receiver keeps secret. RSA's security is predicated on the practical difficulty of factoring the product of two large prime numbers, making it a key component of digital security in applications such as safe online browsing, email, and corporate data protection.

RSA encryption uses two keys: a public key for encryption and a private key for decryption. Its security arises from the difficulty of factoring huge numbers into primes, which is computationally expensive for large numbers. RSA is used to ensure secure data transmission, digital signatures, and key exchange. Its effectiveness is determined by key size, with longer keys providing higher security but needing more processing resources. RSA's use in SSL/TLS protocols for secure web connections demonstrates its importance in current cryptography.

Considering one letter sized plain text, letter B to be encrypted. The number representation of B is 2. Let public key for encryption is defined as (5, 14). Thus, cipher text is calculated $2^5 \pmod{14} \equiv 4$ in this case. Then, the letter equivalent of this is D. Also, private key for decryption is chosen as (11, 14). When back-propagation is applied, original text can be reconstructed. $4^{11} \pmod{14} \equiv 2$ (B).

In RSA, keys are generated by selecting two large prime numbers (p and q), calculating their product (n), and then determining a number (e) that is coprime with (n) and the product of the primes' decrements. The public key consists of (n) and (e), but the private key is composed of (n) and a number (d) that solves a certain modular equation involving (e). The procedure assures that public and private keys are mathematically connected, allowing for secure encryption and decryption processes.

Let us choose p= 2 and p= 7. n= p*q= 14 in this case. This value will be the modulo in encryption and decryption keys. Remainder numbers which are coprime with n (sharing no common factors with n) which are 1, 3, 5, 9, 11 and 13 in this case. In real scenario, p and q might be enormous, so calculating coprime would be difficult. The number of remainder numbers is equal to Ø(n)= 6. This term can be also obtained as Ø(n)= (p-1)*(q-1). Then, choosing number e under two conditions:

- $1 < e < Ø(n)$
- Coprime with n, $Ø(n)$

5 can be chosen from four options (2, 3, 4, 5), because only 5 is coprime with n and $Ø(n)$. Then the next step is determining number d for private key. Choosing d: $d*e \pmod{Ø(n)} \equiv 1$. In this case, 11 can be chosen from all options (4, 11, 18, 25…). Finally, public, and private keys for RSA cryptosystem is generated.

Caesar (Shift) Cipher

The Caesar cipher is one of the most simple and well-known encryption methods. It is a type of substitution cipher in which each letter in the plaintext is shifted a set number of positions down or up the alphabet. For example, with a shift of one, 'A' would be replaced by 'B', 'B' by 'C', and so on. Also, spaces and punctuations are reserved. This approach is named after Julius Caesar, who allegedly used it to communicate with his generals. The Caesar cipher's simplicity makes it easy to comprehend, but equally easy to break, restricting its practical relevance to modern security requirements.

For an n-letter alphabet; P, C, K ∈ Zn, encryption $EK(P) = P + K \pmod{n}$, decryption $DK(P) = C – K \pmod{n}$. Let consider the K (shift key) is 4, and plain text is “This is an encrypted message.”, cipher text can be created from the alphabet table in the figure above. For example, the letter T becomes X since the key is 4, so cipher text becomes: “XLMW MW ER IRGVCTXIH QIWWEKI.”.

The Caesar cipher's simplicity is also its primary drawback. It is vulnerable to frequency analysis, which involves an attacker comparing the frequency of letters or groups of letters in the ciphered text to known frequencies in the original message's language. Because the cipher does not dramatically modify these frequencies, it is quite simple to calculate the shift and decrypt the message. Furthermore, because there are only 25 potential shifts in the English alphabet, an attacker can easily try all combinations to decrypt the message.

The Caesar cipher is quite simple to decipher. The original data can be accessed by methods such as analysis of the most repeated characters, determining other characters by selecting one character as plaintext, or vice versa. Caesar cipher was chosen as the simplest encryption method in this study. The performance of Caesar encryption, which has a very simple structure compared to Advanced Encryption Standard (AES) and Data Encryption Standard (DES), has been observed.

Data Encryption Standard (DES)

The Data Encryption Standard (DES) is a symmetric-key block encryption algorithm created by IBM in the 1970s and later standardized by NIST. Its principal function is to encrypt and decrypt digital data with a common secret key. DES encrypts and decrypts plaintext blocks, which are typically 64 bits in size, using a 56-bit key. Although DES has been mostly replaced by more secure algorithms such as AES, knowing its operation provides insight into the fundamentals of modern encryption.

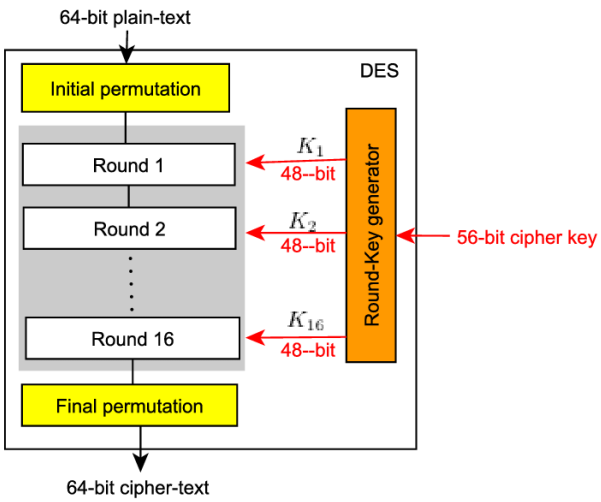

Figure 2. DES structure (Shorman & Qatawneh, 2018)

The first stage in DES is key generation, which converts the 56-bit key into 16 subkeys, each 48 bits long. The procedure starts with an initial permutation and then separates the key into two 28-bit halves. Circular left shifts are made to each half, and subkeys are formed by selecting specified groups of bits using a technique known as key scheduling. These subkeys are subsequently used for further encryption and decryption operations (Schneier & Diffie, 2015).

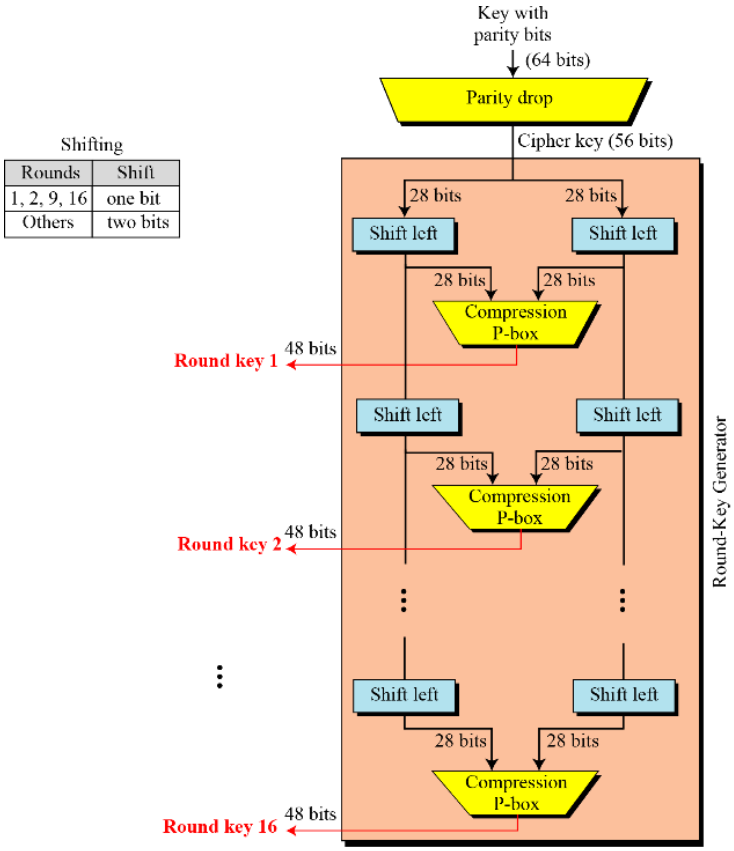

Figure 3. Key generation for DES algorithm (Sharmal & Garg, 2016)

DES encryption involves 16 rounds of processing for each plaintext block. Each round includes multiple operations such as substitution, permutation, and key mixing. The plaintext block is first permuted, then transformed in a sequence of rounds. Each round, the block is divided into two halves, expanded, XORed with a subkey, substituted using S-boxes, permuted, and XORed with the other half. This procedure scrambles plaintext into ciphertext in a reversible manner using the proper key.

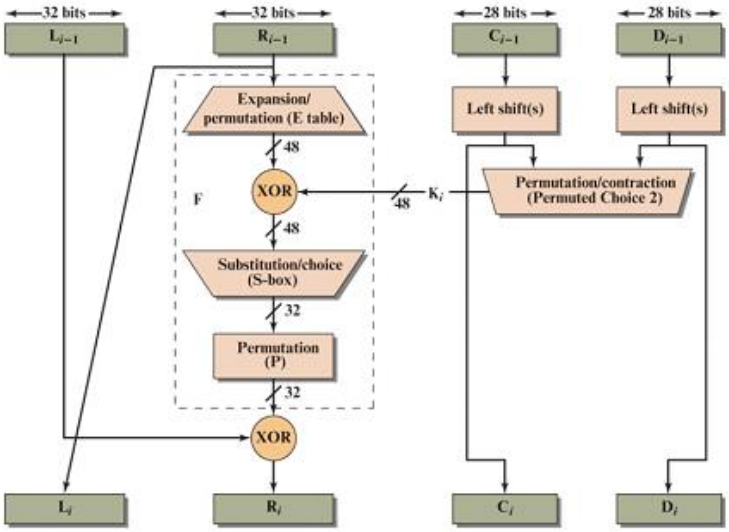

Figure 4. Single round of DES algorithm (Takieldeen et al., 2012)

DES decryption is the same as encryption, but in reverse. The ciphertext is initially permuted, then the subkeys are applied in reverse order across 16 rounds of processing. Each round involves the identical operations as encryption, except the subkeys are used in the reverse order. After the final round, the ciphertext block is treated to an inverse initial permutation, yielding the original plaintext block. Despite its historical relevance, DES has a number of flaws that make it unsuitable for modern cryptography applications. Its small key length renders it vulnerable to brute-force assaults, in which all potential keys can be checked within a reasonable timeframe. Furthermore, developments in cryptanalysis have revealed flaws in the DES algorithm, reducing its security. As a result, DES has been replaced by more powerful encryption protocols such as AES, which provide higher security assurances and improved performance.

Advanced Encryption Standard (AES)

AES (Advanced Encryption Standard) is a symmetric encryption algorithm that has become an essential component of modern cryptographic protocols. AES was developed to replace the outdated Data Encryption Standard (DES) and was adopted as a standard by the United States National Institute of Standards and Technology (NIST) in 2001 following a rigorous selection process. Unlike asymmetric encryption algorithms, which use separate keys for encryption and decryption, AES uses a single key for both operations, resulting in a symmetric encryption method. This key is shared by the communicating parties and must be kept secure in order to ensure the secrecy of the encrypted data (Hioureas, 2023).

AES's processing on data blocks is crucial to its functionality. Each block is made up of 128 bits, or 16 bytes, and if the plaintext is not a multiple of this block size, padding is used to ensure consistency. AES provides key sizes of 128, 192, and 256 bits, with bigger key sizes providing more security at the expense of computational complexity. The algorithm uses a substitution-permutation network (SPN) to perform its operations. These procedures take place over numerous rounds, with the number of rounds varied according to the key size: 10 rounds for AES-128, 12 rounds for AES-192, and 14 rounds for AES-256.

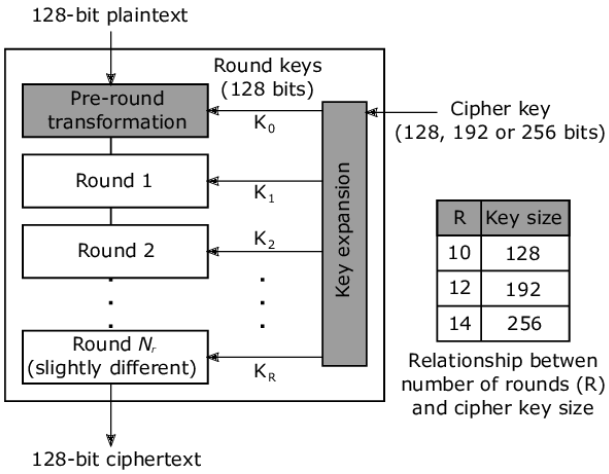

Figure 5. AES structure (Abdelrahman et al., 2017)

The AES encryption process begins with key expansion, which converts the initial key into a series of round keys, one for each round of encryption. Each round of AES encryption consists of four major steps: SubBytes, ShiftRows, MixColumns, and AddRoundKey. In the SubBytes step, each byte in the input block is replaced with a corresponding byte from a substitution table, introducing non-linearity into the encryption process. ShiftRows is the process of cyclically shifting the bytes within each row of the block, which contributes to data diffusion. MixColumns treats the block's columns as polynomials and multiplies them with fixed polynomials modulo an irreducible polynomial. Finally, AddRoundKey applies bitwise XOR to merge the state and round key (Daemen & Rijmen, 2002).

SubBytes are the first stages in each round of AES encryption. It aims is to replace each byte in the input block with a corresponding byte from a prepared substitution table, known as the S-box. This replacement is a nonlinear process that causes confusion in the data. The S-box is a fixed 16x16 matrix with pre-computed values. Each byte in the input block is replaced with the value from the relevant row and column in the S-box. This transformation ensures that even minor changes in the input block cause huge changes in the output, making it difficult for attackers to identify patterns.

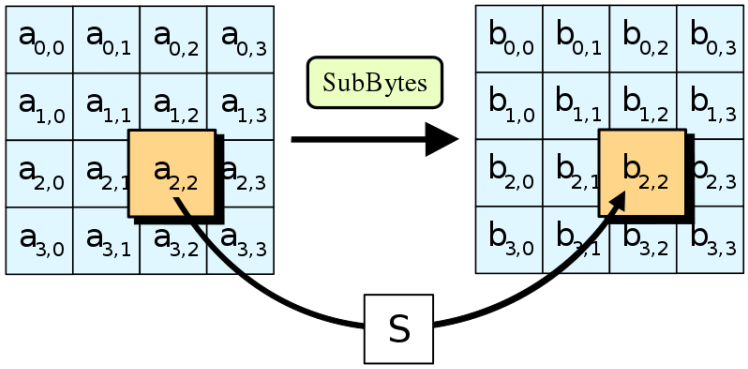

Figure 6. SubBytes act on the individual bytes of the state (“SubBytes”, 2024)

ShiftRows is the next stage in each round of AES encryption. This procedure consists of cyclically shifting the bytes within each row of the block. The bytes in the second row are shifted one position to the left; those in the third row are shifted two places to the left; and those in the fourth row are shifted three positions to the left. This phase adds to data diffusion by spreading each byte's influence across numerous columns. ShiftRows ensures that neighboring bytes interact with one another during successive encryption steps, hence improving the algorithm's overall security.

MixColumns follows ShiftRows with the exception of the final round of AES encryption. This procedure treats the block's columns as polynomials over the finite field GF(2^8). MixColumns multiplies each byte in a column by a fixed polynomial modulo an irreducible polynomial. The result replaces the original byte, yielding a linear transformation of the data. This process further distributes the data and ensures that each byte of the output is dependent on multiple bytes from the input. By creating this reliance, MixColumns improves the overall security of AES encryption, making it more resistant to cryptanalytic attacks.

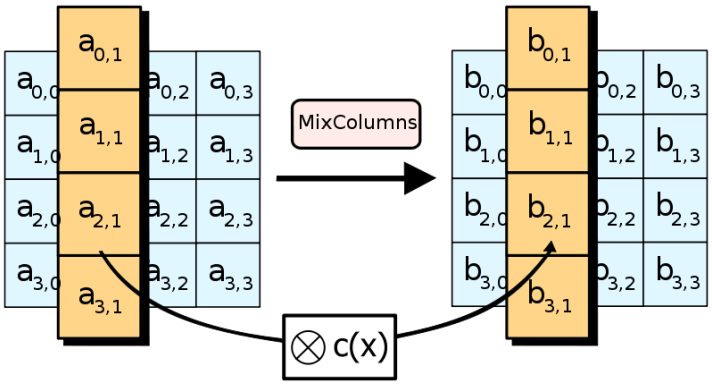

Figure 7. MixColumns operates on the columns of the state (“MixColumns”, 2024)

The last step in each round of AES encryption is AddRoundKey. In this stage, the block's current state is joined with a round key generated from the main encryption key. Each byte of the state is bitwise XORed with its matching byte from the round key. The round key created during key expansion is unique to the current round of encryption. AddRoundKey ensures that each round of encryption is separate and depends on the key by introducing the round key's unique effect into the state. This phase further obscures the relationship between the plaintext and the ciphertext, which improves the security of AES encryption.

AES is a symmetric key algorithm, which means it uses the same key for encryption and decoding. This differs from asymmetric key methods, which use two separate keys (public and private) for encryption and decryption. Symmetric key methods are often faster and more efficient for large volumes of data; nevertheless, key management can be difficult because securely communicating the key with the intended recipient is critical.

AES operates on fixed-size data blocks (128 bits). Different modes of operation can be used to encrypt data that does not fit into a single block, or to encrypt numerous blocks with increased security, such as Electronic Codebook (ECB), Cipher Block Chaining (CBC), or Galois/Counter Mode (GCM). These modes specify how the plaintext is divided into blocks and how the encryption process is performed on each block. Electronic Codebook (ECB) encrypts each block separately with the same key, which can reveal patterns in the ciphertext

if the plaintext contains repeated data. It is typically regarded as less secure and not recommended for most purposes. On the other hand, Cipher Block Chaining (CBC) creates a dependency between blocks by XORing the previous block's ciphertext with the current block's plaintext prior to encryption. The first block uses an Initialization Vector (IV) to add randomization. This mode offers more security than ECB, but it is vulnerable to certain attacks if the IV is predictable or overused.

AES is regarded extremely secure and is widely used in a variety of applications, including government, military, and commercial use. The algorithm's security stems mostly from its key size, which makes it resistant to brute-force attacks. Brute-force attacks attempt to decrypt the ciphertext by trying every conceivable key combination; however, with AES key sizes (128, 192, or 256 bits), the number of possible possibilities is so huge that it is currently deemed impossible to break AES encryption using this technique.

AES is a cornerstone of digital security, with use ranging from government communications to commercial transactions nowadays. Its exceptional resilience against brute-force attacks, combined with key size versatility (128, 192, and 256 bits), ensures strong defense mechanisms for sensitive information protection. AES's efficiency and security have won it a key role in global standards and protocols, making it a must have tool in the fight against cybersecurity threats. As we traverse the digital age, AES's importance grows, emphasizing its important role in protecting digital assets and communications around the world.

Development of the Named Pipe and Encryption Algorithms

Linux Inter-Process Communication with Named Pipe

In C programming on Linux systems, named pipes, often known as FIFOs (First In, First Out), provide a means for inter-process communication (IPC) that allows unrelated programs to share data. Unlike anonymous pipes, which are commonly used for parent-child process communication, named pipes exist independently of the processes that utilize them and persist in the file system, offering a path for communication between any processes that have access to the filesystem. To create a named pipe, use the mkfifo system function or command. This method creates a FIFO special file with the specified name in the filesystem. The required C libraries for mkfifo command are ‘types.h’ and ‘stat.h’ in the sys directory (Stevens & Rago, 2014).

The mkfifo command in the C programming language has an integer return value and 2 arguments. These arguments are the ‘pathname’ as a constant char pointer and ‘mode’ with the type of ‘mode_t’. The pathname represents the name of the directory of the FIFO to be created and “mode” specifies the permissions for the FIFO. The “mode” is specified as an octal (base-8) number and represents the file’s permission bits. It’s similar to the permissions used for regular files and directories. The “mode” is influenced by the process’s ‘umask’, which may restrict the permissions set during the creation of the FIFO. The “mode” parameter is composed of three groups of permissions:

- Owner permissions: What actions the owner of the file can perform.
- Group permissions: What actions users who are members of the file’s group can perform.
- Other permissions: What actions all other users can perform.

Each group can have permissions for reading (r), writing (w) and execution (x), represented by octal numbers:

- 4 (100 in binary) stands for read permission.
- 2 (010 in binary) stands for write permission.
- 1 (001 in binary) stands for execute permission.
- 0 stands for no permission.

These permissions are added to together to get the total permission value for each group. The final mode is a concatenation of these values for the owner, group and others in that order.

Opening the Named Pipe

Once created, processes can open the named pipe using open(.), just as they would with regular files. A process can open the FIFO in read-only (RDONLY) or write-only (WRONLY) mode, depending on its role. The writer

process, which sends data into the FIFO, opens it for writing. Also, the reader one opens it for reading. When a process is done with the FIFO, it can close it using close(.), similar to files.

Reading from and writing to a named pipe are accomplished with the read(.) and write(.) system methods, respectively. These calls halt the calling process: a read(.) call on an empty FIFO will block until there is data to read, and a write(.) call on a full FIFO will block until there is space to write new data. This blocking feature allows the producer and consumer processes to synchronize without the need for additional coordination code.

Caesar, RSA, DES, and AES Algorithm in C

Overview of the OpenSSL

The OpenSSL project, a powerful, commercial-grade, and feature-rich toolkit for the Transport Layer Security (TLS) and Secure Sockets Layer (SSL) protocols, has expanded dramatically over time. One critical component of its evolution is the creation and improvement of its cryptography library, which includes a diverse set of cryptographic algorithms and capabilities like as AES, DES, and RSA. In subsequent releases, OpenSSL has continued to evolve, improving its support for these methods via its digital envelope library.

Digital Envelope Library

The digital envelope technique secures a communication by using asymmetric encryption to encrypt a symmetric key, which is then used to encrypt the message or data. This method combines the effectiveness of symmetric encryption algorithms (such as AES and DES) for large-scale data encryption with the security of asymmetric encryption algorithms (such as RSA) for safe key exchange (Viega et al., 2002).

The EVP (Envelope) interface serves as the foundation for OpenSSL's digital envelope capabilities. The EVP interface provides a higher-level abstraction of the different cryptographic methods. It provides a uniform method to encryption and decryption, hashing, and digital signature operations using diverse algorithms. By abstracting the complexities of each cryptographic technique, the EVP interface makes it easier to integrate encryption into programs while also ensuring that the algorithms are utilized appropriately and securely.

Usage in C and Named Pipes

When implementing cryptographic operations in C with OpenSSL, developers use the EVP interface to execute encryption and decryption. This method enables a seamless transition between multiple algorithms (AES, DES, RSA) without requiring significant changes to the codebase. For example, developers can encrypt data with AES for efficiency and then use RSA to encrypt the AES key, resulting in a secure digital envelope (Stallings, 2017).

As it mentioned before, cryptography is essential in scenarios involving inter-process communication (IPC), such as when employing named pipes (FIFOs), to ensure the confidentiality and integrity of the data being transmitted. In Unix-like operating systems, named pipes can be built and accessed using functions such as mkfifo to simplify communication between processes running on the same machine. Developers can use OpenSSL's cryptographic capabilities to encrypt data before sending it via the pipe and decrypt it upon receipt. This method assures that even if the data is intercepted while in transit over the designated pipe, it is protected and unreadable without the correct decryption key.

This combination of OpenSSL with named pipes for safe IPC is especially useful in applications that require secure transport of sensitive information between various components or services running on the same system. Using OpenSSL's digital envelope features ensures that data enclosed within a secure envelope is efficiently encrypted and securely sent, combining the strengths of symmetric and asymmetric cryptography.

OpenSSL's digital envelope library, which supports the AES, DES, and RSA algorithms, is a powerful and versatile toolset for performing cryptographic operations in C, including secure inter-process communication via named pipes. By abstracting the intricacies of cryptographic operations and assuring secure key and data handling, OpenSSL allows developers to create more secure applications that can confidently protect sensitive information from interception and unwanted access.

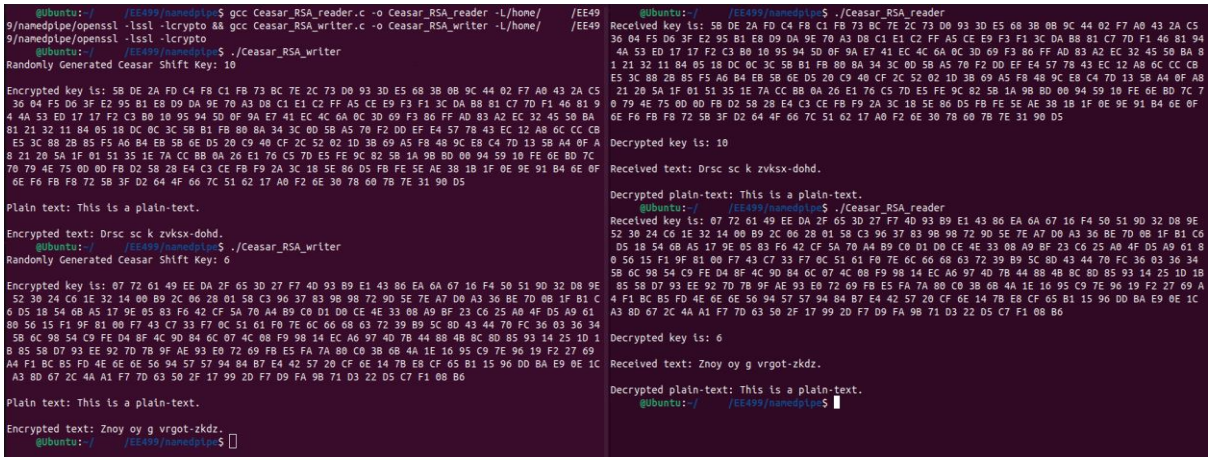

Figure 8. Caesar encryption with RSA secured key

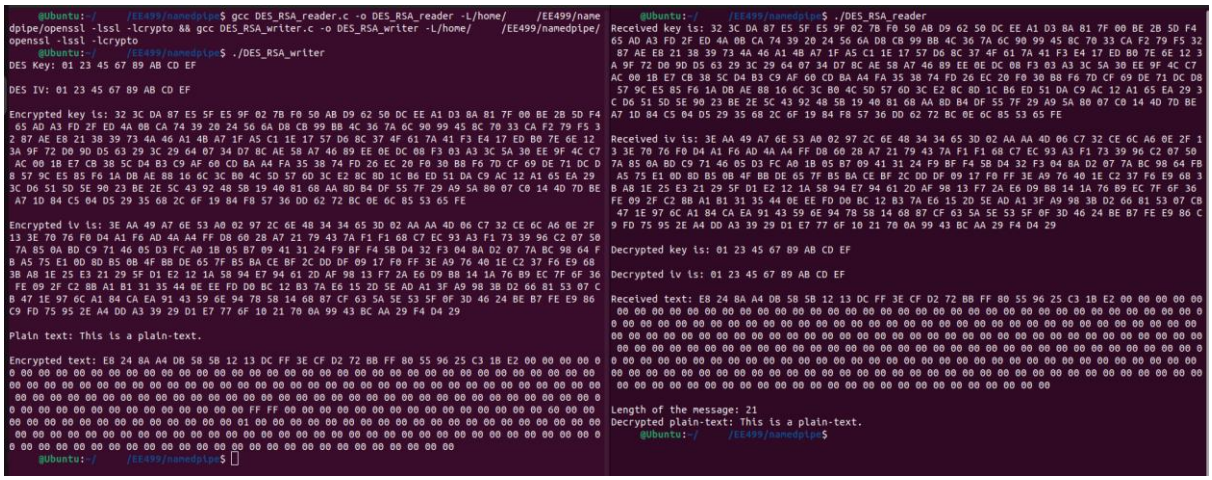

Figure 9. DES encryption with RSA secured key

Figure 10. AES encryption with RSA secured key

Measurements and Comparison of Algorithms

After the encryption algorithms are researched, developed and compiled, the last stage in the study is to run the programs with these algorithms in a Linux environment and make the necessary measurements. The running times of the developments in this study and the resource consumption at run time are recorded and a comparison is made between the encryption algorithms.

Time Measurement

The first measurement is to measure the time each cryptographic method spends on encryption. In order to measure this, 'time', a built-in function in the Linux environment, was used. The 'time' command expresses the time, in seconds, from the start to completion of the application run with it. On the other hand, although measuring an encryption process with the time command can give a value, a single value for comparison will be weak in terms of consistency. During this process, operations such as other applications running in the background, I/O waits, and network states cause deviations in the current time and performance. For this reason, a script was developed and run 1000 times for each encryption algorithm separately and averaged after saving each time output value in a file. In this way, the effect of deviations due to external factors is significantly reduced and consistency is increased. This script runs 1000 times for Caesar Cipher, DES and AES and transfers the results to a csv file. Then, a separate application called 'averager' presents the mean of these values as an output.

CPU Utilization Measurement

Another factor to be evaluated in the study is the CPU usage of the algorithms while they are running. Although all the algorithms in the study use RSA for key generation, the operations and structures they perform in each cycle are completely different, as explained above. For this reason, observing and comparing the use of resources will have an important role in the use of these algorithms. Just like in time measurement, data taken for a single trip will be insufficient in terms of consistency and accuracy. Both the difference in the resources the device allocates and uses for other processes at that moment and the difficulty of obtaining CPU values in a very short time have led to the need to take measurements during repetition many times. Each encryption algorithm was run 1000 times respectively with a prepared script and the values were saved in a csv file. The built-in function that this script uses to monitor CPU utilization is 'ps'. This command shows the list of processes actively running on that computer. By running the 'ps -p <pid> -o %cpu' command, the CPU usage of the process whose 'pid', that is, the process ID, is given among the processes listed with 'ps' can be observed.

Results and Discussion

Time Measurement Results

Time measurements were noted through scripts as described in the method section. Afterwards, the averages of each 100 iterations were taken and graphed using a Python script. On a single graph, the time spent by AES, DES and Caesar encryption methods during encryption can be observed. Values in this measurement are in milliseconds.

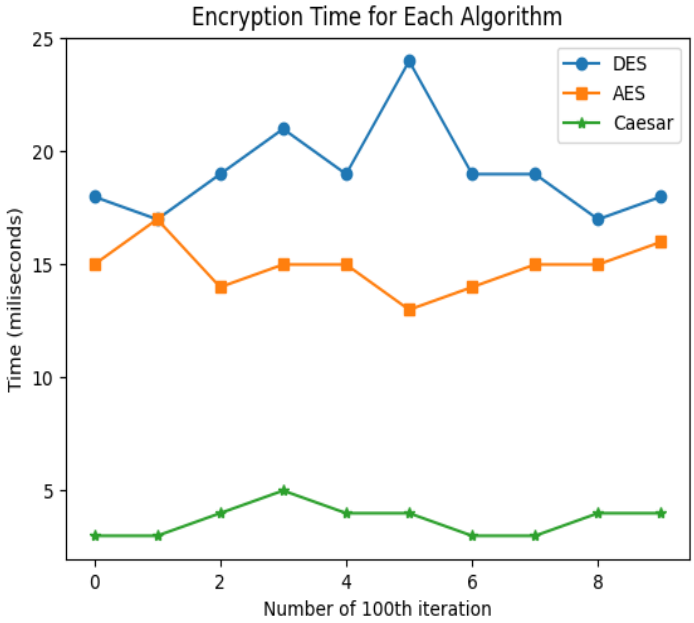

Figure 11. Time measurement graph

Table 1. Time measurement result recordings

	Caesar Cipher	DES	AES
Average of 1st 100 runs	3 ms	18 ms	15 ms
Average of 2nd 100 runs	3 ms	17 ms	17 ms
Average of 3rd 100 runs	4 ms	19 ms	14 ms
Average of 4th 100 runs	5 ms	21 ms	15 ms
Average of 5th 100 runs	4 ms	19 ms	15 ms
Average of 6th 100 runs	4 ms	24 ms	13 ms
Average of 7th 100 runs	3 ms	19 ms	14 ms
Average of 8th 100 runs	3 ms	19 ms	15 ms
Average of 9th 100 runs	4 ms	17 ms	15 ms
Average of 10th 100 runs	4 ms	18 ms	16 ms

According to the observed results, the Caesar encryption algorithm, which has a very simple working structure, completes transactions in 4-5 times shorter time compared to AES and DES. Data that can be easily encrypted can also be decrypted very easily through cyber-attacks. On the other hand, although the AES algorithm makes encryptions that are more difficult to decipher than DES, the running time of the DES algorithm is longer than AES, although there are not big differences. The small difference also varies depending on the size of the data to be encrypted. If very large data will be encrypted, it is appropriate to choose the AES algorithm.

CPU Utilization Measurement Results

CPU usage measurements were noted through scripts as described in the method section. Afterwards, 10 different measurements are done and the results are taken notes. Then, a Python script is used to visualize them. On a single graph, the utilized CPU by AES, DES, and Caesar encryption methods during encryption can be observed.

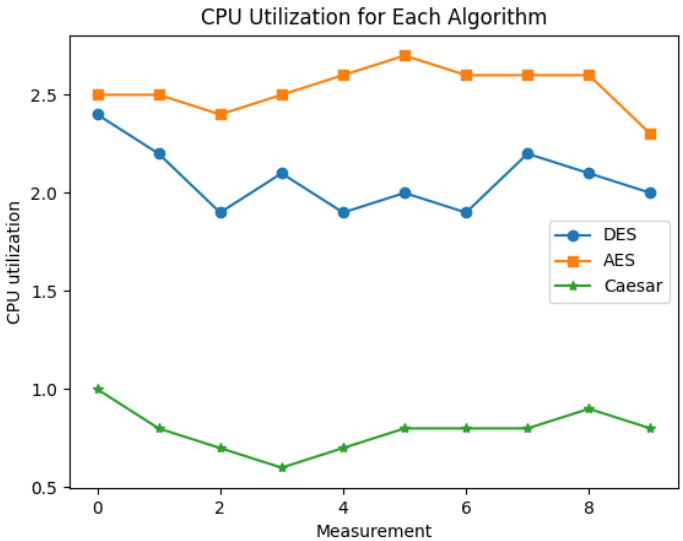

Figure 12. CPU utilization measurement graph

Table 2. CPU utilization measurement result recordings

	Caesar Cipher	DES	AES
1st measurement	1.0%	2.4%	2.5%
2nd measurement	0.8%	2.2%	2.5%
3rd measurement	0.7%	1.9%	2.4%
4th measurement	0.6%	2.1%	2.5%
5th measurement	0.7%	1.9%	2.6%
6th measurement	0.8%	2.0%	2.7%
7th measurement	0.8%	1.9%	2.6%
8th measurement	0.8%	2.2%	2.6%
9th measurement	0.9%	2.1%	2.6%
10th measurement	0.8%	2.0%	2.3%

According to the CPU usage measurement results, the Caesar encryption method uses minimum resources with its very simple structure, just like time measurements. It completes operations using less than half the CPU of AES and DES algorithms. To compare in terms of CPU usage, there is a difference of almost similar proportions to that in time measurements. The AES algorithm consumes slightly higher CPU during operations than DES, with a slight difference. This may determine the preference for platforms with very limited processing power.

To summarize the results, these algorithms that encrypt communication on named pipes responded as expected. The Caesar algorithm, which can be solved very easily, has the highest performance in terms of resource consumption and time, but provides a very low level of security. AES and DES can be preferred in different ways according to different restrictions when they want to be used in inter-process communication.

Conclusion

In conclusion, this study has provided a comprehensive analysis of encryption methods applied to named pipes within a Linux environment, focusing on RSA, Caesar Cipher, DES, and AES algorithms. Through meticulous examination and performance measurements, several key findings have emerged.The RSA algorithm, renowned for its asymmetric encryption capabilities, demonstrates robust security features suitable for various applications, including secure data transmission and digital signatures. Its reliance on complex mathematical operations, such as prime number factorization, ensures high levels of encryption strength. However, RSA's computational demands are notable, impacting performance metrics such as encryption time and CPU utilization.

Contrastingly, the Caesar Cipher, while simple and easy to implement, lacks the sophistication necessary for modern security standards. Its straightforward substitution method makes it vulnerable to frequency analysis and brute-force attacks. Nevertheless, the Caesar Cipher exhibits the lowest resource consumption and fastest encryption times among the algorithms studied, albeit at the expense of security.

The Data Encryption Standard (DES), a symmetric-key block encryption algorithm, offers historical insights into encryption fundamentals but falls short in contemporary security contexts. Its small key size and susceptibility to brute-force attacks render it obsolete compared to more robust alternatives like AES. Advanced Encryption Standard (AES), heralded as a cornerstone of modern cryptography, emerges as the preferred choice for secure communication over named pipes. AES balances strong encryption with efficient performance, making it suitable for diverse applications ranging from government to commercial use. With key sizes of 128, 192, and 256 bits, AES provides flexible security options tailored to specific needs while maintaining resistance against brute-force attacks. Performance measurements confirm AES's superiority in both encryption time and CPU utilization, albeit with marginal differences compared to DES. The Caesar Cipher, while significantly faster and less resource-intensive, lacks the requisite security for most applications.

The measurements in the study overlap with the inferences found in similar studies in the literature. Very similar results were obtained with the results in the study comparing AES and DES, not only on named pipes. In this study, which considers both time and resource consumption, it was concluded that AES is faster and uses more CPU than DES (Rihan et al., 2015). Obtaining similar results with this study conducted without a named pipe indicates that the named pipe has no relative impact on the algorithm performance.

In summary, the selection of encryption algorithm for named pipe communication hinges on a nuanced evaluation of security requirements, computational resources, and performance considerations. While the RSA algorithm offers unparalleled security, its computational overhead may limit practical applications. Conversely, the Caesar Cipher, while efficient, lacks the requisite security for modern encryption needs. DES, though historically significant, is overshadowed by AES's superior performance and security. Ultimately, AES emerges as the optimal choice, striking a balance between robust encryption and efficient resource utilization, ensuring secure communication over named pipes in Linux environments.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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The Role of Digitalization, Industrialization and Green Innovation in the Green Growth Process: A GMM Panel VAR Approach

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Abstract: This study aims to investigate the influence of digitalization, industrialization and green innovation development, along with economic and environmental determinants on the green growth process. A dataset containing OECD countries from 2000 to 2022 utilizes a generalized method of moments (GMM) Panel VAR approach. This study also employs the panel Granger causality test. The findings of this study indicate that there is a significantly positive effect of green innovation development on the green growth process. There exists a significant positive association and causality between digitalization, industrialization and green growth. These findings carry substantial policy implications for the development and implementation of strategies that promote green growth and environmental-friendly innovation. Consequently, policymakers should prioritize integrating green innovation and adaptive measures in their sustainable development agendas to foster a greener, more resilient future. Therefore, this study offers important insights into the dynamic interplay among digitalization, industrialization, green innovation, and green growth, thus providing policymakers with actionable strategies to navigate the intersection of technological advancement and environmental sustainability toward a greener future. Moreover, this study also contributes to the existing literature by providing a nuanced understanding and actionable policy recommendations for policymakers and stakeholders seeking to navigate the evolving landscape of green growth amidst rapid technological and industrial transformations.

Keywords: Green Growth, Green innovation, Digitalization, Industrialization, GMM P-VAR model.

Introduction

In recent years, the global community has increasingly recognized the importance of sustainable development to secure a viable future for future generations. Central to this pursuit is the concept of green growth, which harmonizes economic expansion with environmental preservation. This balance is not only desirable but necessary, given the pressing challenges posed by climate change, resource depletion, and ecological degradation.

Green growth extends beyond merely balancing economic expansion with environmental conservation. It emphasizes a high-quality, low-carbon, energy-efficient growth model that prioritizes value creation through clean technologies, natural infrastructure, and market innovation in environmental goods and services. As stated by the widely recognized Porter hypothesis (Porter, 1991), the advancement of green growth and green technology is closely tied to the enforcement of environmental protection regulations. Nonetheless, the evolution of green technologies and climate change adaptation is affected by a range of factors including economic, social, and political influences (Agan & Balcilar, 2022; Allan et al., 2013; Bilal et al., 2022; Hotte, 2020; Hussain et al., 2022; Lv et al., 2021a, 2021b; Nguyen et al., 2022; Song et al., 2024). The process of green growth is intricately linked to the evolving landscape of technology and industry.

Digitalization, industrialization, and green innovation play pivotal roles in shaping the pathways to sustainable development, as outlined in a recent study by Adeshola et al. (2023). Digitalization, marked by the integration of digital technologies across industries, drives efficiency and innovation. It fosters the creation of smart,

interconnected systems that can lead to more sustainable practices and the optimization of resource use. Digitalization plays a critical role in this process, as it facilitates the transformation of traditional industries through the adoption of smart technologies. The integration of digital solutions in areas such as manufacturing, logistics, and energy management has been shown to improve efficiency and reduce waste. For instance, Murray et al. (2020) highlight how digitalization in the manufacturing sector can streamline production processes, optimize resource use, and ultimately contribute to more sustainable practices.

In the same vein, industrialization, traditionally associated with economic expansion, has been redefined in the context of green growth. Modern approaches emphasize cleaner, more sustainable industrial practices that incorporate circular economy principles. Studies such as Gao et al. (2024) and Raihan et al. (2022) demonstrate how industrial processes can be redesigned to minimize waste, reduce carbon emissions, and enhance resource efficiency, thereby aligning with the goals of green growth.

Furthermore, green innovation is another key driver of green growth, encompassing the development of products, technologies, and processes that minimize environmental impact while supporting economic advancement. (Song et al., 2024) investigate the asymmetric nexus between green technology innovation and energy efficiency, and the findings show that green technology innovation improves energy efficiency. Another study by Xu et al. (2021) analyzes the effects of environmental regulation and foreign direct investment on green technology innovation based on the 13 Chinese manufacturing sectors. Their findings indicate insights into shaping environmental regulations and managing foreign direct investment (FDI) inflows into China to enhance green technology innovation. Similarly, Kuang et al. (2022) examine the relationship between green technology innovation, renewable energy, and CO2 emissions and conclude that the creation of green technology innovation has positive externalities. In this extended introduction, examples of studies in the literature such as those by Appiah et al. (2023), He et al. (2023), Khan et al. (2023), Liu et al. (2023), Pérez-Suárez & López-Menéndez (2015), Wang et al. (2023) provide a contextual foundation for your research. These references illustrate the current trends and advancements in digitalization, industrialization, and green innovation within the broader framework.

Numerous studies have increasingly focused on micro-level green technology innovations. For instance, Cai & Zhou (2014) examine the key factors influencing green innovations in Chinese firms. Their findings suggest that a firm's integrative capability, or its ability to implement effective and eco-friendly strategies, plays a significant role in green innovation. Similarly, Xue et al. (2023) investigate the regional variation and distribution of green patents in Chinese cities, discovering that regional disparities in urban green innovation are minimal and contribute to economic differences across cities. Additionally, another study by Khanh Chi, (2022) analyze on farm households in Vietnam explores the factors driving green agricultural innovation and finds that environmental awareness is a crucial motivator for enhancing green production innovation. Additionally, Wang et al. (2023) investigate the impact of eco-innovation on CO2 emissions and its associated causal factors using the quantile regression method. Their results indicate that eco-innovation leads to a reduction in CO2 emissions in OECD countries. This aligns with the findings of Yu and Du (2019), whose empirical analysis also supports the notion that innovation significantly lowers emission levels.

Against this backdrop, this study employs a Generalized Method of Moments (GMM) Panel Vector Autoregression (VAR) approach to investigate the dynamic relationships between digitalization, industrialization, and green innovation development with economic and environmental determinants of the green growth process. This methodological framework enables a detailed examination of how these factors interact and influence one another over time. By investigating these relationships, the study aims to provide valuable insights for effective policies and strategies that promote sustainable development while fostering economic prosperity. The empirical findings of our study underscore the role of digitalization, industrialization, green innovation development, CO2 emissions, economic growth, and the environmental tax in OECD countries. This study proceeds with the data description and methodology are presented. Later, this study reports the empirical results and discussion. Lastly, this study ends with the conclusions and recommendations.

Data and Methodology

Data

This study utilizes annual data from 2000 to 2022 for 38 OECD countries. These countries and periods are chosen based on the data availability. The objective of this study is to investigate the effects of digitalization, industrialization, green innovation development, and carbon dioxide (CO2) emissions with causal factors of

economic growth and environmental-related tax on the green growth process. In the field of environmental economics, the Environmental Kuznets Curve (EKC) framework emerges as a crucial empirical model for exploring renewable energy and eco-friendly technology, as demonstrated by research undertaken by Gu et al. (2023), Khan et al. (2021), Kostakis et al. (2023), Shah et al. (2023a), (2023b), Voumik et al. (2022), Xu et al. (2024), Zhang et al. (2022). Table 1 presents the definition and sources of the variable considered.

Table 1. Data descriptions

Variable	*Definition*	*Source*
Green Growth Index (GGI)	The ratio of GDP per capita to total primary energy consumption	World Development Indicators (WDI)
Digitalization (DIG)	Individuals using the Internet (% of population)	WDI
Industrialization (IND)	Industry (including construction), value added (current US$)	WDI
Green Innovation Development (GTD)	Development of environment-related technologies, % all technologies (%)	OECD statistics
Carbon dioxide emissions (CO2)	CO2 emissions (metric tons per capita)	WDI
Economic Growth (GDP)	GDP per capita (current US$)	WDI
Environmentally related tax (TAX)	Environmentally tax revenues	OECD statistics

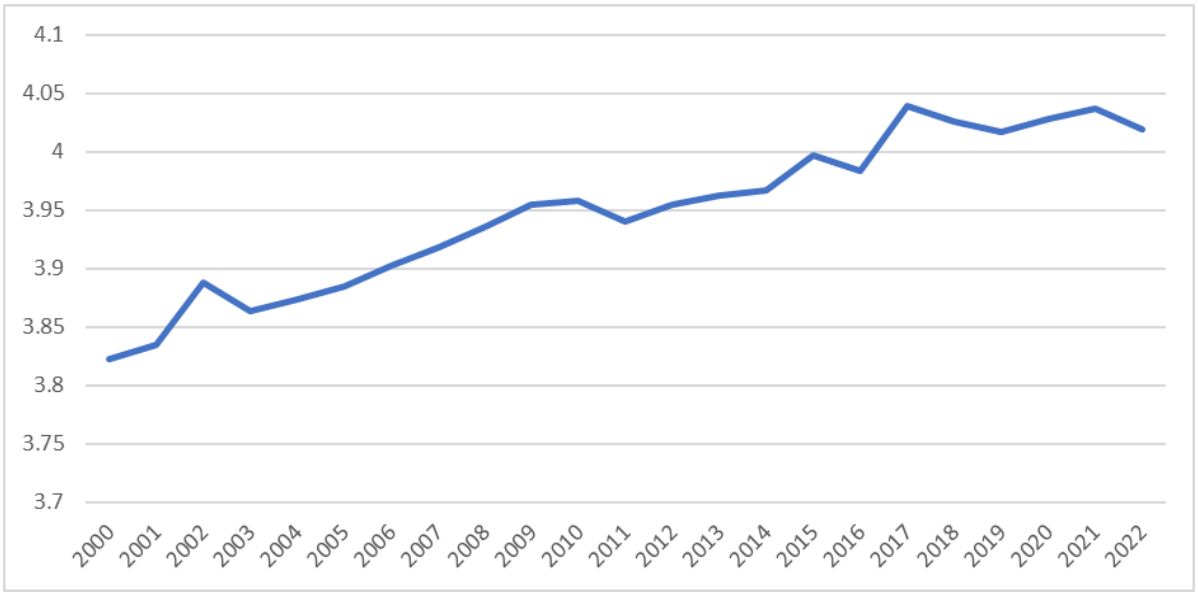

Figure 1. Time series plot of the average green growth index, 2000–2022.

Figure 1 illustrates a time series plot of the average green growth index across 38 OECD countries from 2000 to 2022. The global sustainable competitiveness index reaches a high level in the US, Japan, and Germany in 2022.

Methodology

In this study, we investigate the impact of digitalization, industrialization, green innovation development, and carbon dioxide (CO2) emissions on green growth process in OECD countries using a panel vector autoregression (PVAR) model within the Generalized Method of Moments (GMM) framework. Since Sims (1980) introduced time-series vector autoregression (VAR) models as an alternative to multivariate simultaneous equation models in macroeconomic econometrics, they have become prominent. In a VAR system, all variables are typically treated as endogenous.

The PVAR methodology, introduced by Love and Zicchino (2006) and Holtz-Eakin et al. (1988), combines the conventional VAR approach with a panel-data approach that incorporates unobserved individual heterogeneity. This allows for recognizing dynamic differences within the groups of countries being studied. Utilizing the PVAR approach enables comprehensive capturing of temporal variations in both coefficients and shock variances. Given the dataset's properties, which involve multiple entities observed across various time periods, PVAR modeling is more appropriate for our analysis.

Previous literature has predominantly focused on investigating the influence of green growth process on sustainable development. Several empirical studies (Chen et al., 2019; Mamkhezri & Khezri, 2023; Mitić et al., 2023; Mongo et al., 2021; Rahman et al., 2022; Sezgin et al., 2021; Shahzad et al., 2020; Tsimisaraka et al., 2023; Yao et al., 2020) aim to investigate the correlation between green growth, CO2 emissions, renewable energy sources and their potential repercussions on sustainable development objectives. We employ an empirical model to investigate the effects of digitalization, industrialization, green innovation development, carbon dioxide (CO2), economic growth, and environmental-related tax on green growth process. Our extendend model is estimated as follows:

$$LGGI_{it} = \alpha_i + \beta_{1i}LDIG_{it} + \beta_{2i}LIND_{it} + \beta_{3i}LGTD_{it} + \beta_{4i}LCO2_{it} + \beta_{5i}LGDP_{it} + \beta_{6i}LTAX_{it} + \varepsilon_{it}$$

where GGI represents the green growth index. DIG denotes digitalization, while IND is the industrialization. GTD represents green innovation development, while CO2 shows carbon dioxide emissions, GDP is the economic growth, and TAX is the environmental-related tax. All variables are taken their natural logarithm level. The error term is denoted by ε, where i and t respectively represent countries and time.

Empirical Results

The main descriptive statistics for all variables are displayed in Panel A of Table 2. It shows that environmental-related tax exhibits the smallest mean value, whereas industrialization has the highest annual mean. The green innovation developments are more volatile. In a normal distribution, the skewness is expected to be approximately zero, and the kurtosis should be close to three. Therefore, the distribution of LGGI and LGTD series is positively skewed, while LDIG, LIND, LCO2, LGDP, and LTAX are negatively skewed. Also, the distribution of all series shows excess kurtosis as leptokurtic. The Pearson correlation estimates are represented in Panel B of Table 2. There is a positive correlation coefficient between the variables. However, the variable pairs of LTAX and LGGI is negatively correlated.

Table 2. Descriptive statistics and correlation coefficients

Panel A: *Descriptive Statistics*							
	Mean	Std. Dev.	Max.	Min.	Skewness	Kurtosis	
LGGI	3.948	0.5568	5.5087	2.8321	0.39749	3.8063	
LDIG	1.776	0.2510	1.9991	0.3424	-2.1597	8.3602	
LIND	10.907	0.7145	12.620	9.1507	-0.1085	3.6079	
LGTD	4.223	2.1860	10.696	0.2337	0.19498	3.7374	
LCO2	0.834	0.2522	1.3948	0.0797	-0.5597	3.4011	
LGDP	4.432	0.2696	5.0825	3.4385	-0.8215	3.8028	
LTAX	0. 331	0.2017	0.7291	-1.0012	-1.7568	8.7773	
Panel B: *Correlation Matrix*							
Probability	LGGI	LDIG	LIND	LGTD	LCO2	LGDP	LTAX
LGGI	1.0000						
LDIG	0.2138*	1.0000					
LIND	0.9494*	0.2631*	1.0000				
LGTD	0.0930*	0.6557*	0.2013*	1.0000			
LCO2	0.1115*	0.5581*	0.1251*	0.2462*	1.0000		
LGDP	0.6766*	0.3176*	0.7231*	0.3030*	0.3870*	1.0000	
LTAX	-0.3280*	0.2043*	-0.2512*	0.1531*	0.1151*	-0.1431*	1.0000

Note: * denotes significance at 5% level.

As an initial assessment, the outcome of the Pesaran (2004) cross-sectional dependence (CSD) test for our benchmark model reveals no cross-sectional dependence among the variables. Therefore, we proceed with analyzing panel unit root tests conducted by Levin et al. (2002) and Breitung (2000) to ascertain the stationarity characteristics of the variables.

The results of the panel unit root tests are presented in Table 3. We determine that there are no unit root concerns in either test at both constant and constant with trends levels. The subsequent step in the analysis involves presenting the impulse response functions and variance decomposition obtained from the panel VAR. Selecting the appropriate lag length is critical in panel VAR analysis, and it is determined based on selection criteria in the estimated models.

Table 3. Panel unit root test results

Series	Model	LLC[a]	LLC[b]	Breitung[a]	Breitung[b]
LGGI	Constant	-6.9701***	-10.5767***	-8.3541***	-10.4307***
	Constant&Trend	-3.0833***	-7.7591***	-4.8607***	-0.7711
LDIG	Constant	-28.309***	-18.646***	-8.9998***	-3.8188***
	Constant&Trend	-56.337***	-12.2051***	-1.5471*	-8.4858***
LIND	Constant	-10.056***	-12.6755***	-5.6241***	-13.0285***
	Constant&Trend	-7.0204***	-11.8109***	-0.3676	-11.2639***
LGTD	Constant	-4.3442***	-11.2547***	-7.6748***	-12.1344***
	Constant&Trend	-3.6181**	-10.0119***	-0.1237	-13.8957***
LCO2	Constant	-1.7217*	-12.3041***	0.1986	-10.5039***
	Constant&Trend	-1.8681**	-10.1146***	-3.1867***	-11.4534***
LGDP	Constant	-9.7883***	-3.9929***	14.7395	-11.2859***
	Constant&Trend	-2.4391***	-3.5908***	6.7461	-1.5589*
LTAX	Constant	-3.1270***	-10.7369***	-2.0762***	-11.0274***
	Constant&Trend	-5.6571***	-8.8714***	-1.1748***	-10.0457***

Note: A refers to unit root test model at level and b refers to unit root test model at first difference. *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

Table 4 displays the overall coefficient determination (CD), Hansen J-statistic of over-identifying restrictions, and three information criteria proposed by Andrews and Lu (2001). These criteria include a moment selection criterion for GMM estimation and adaptations of the commonly used Akaike, Bayesian, and Hannan-Quinn information criteria, denoted as MAIC, MBIC, and MQIC, respectively. The results in Table 4 indicate that at a lag order of 3, the null hypothesis that over-identified restrictions are valid cannot be rejected at the 5% significance level. Consequently, we proceed with fitting a third-order panel VAR model.

Table 4. Lag order selection criteria

Lag	CD	J-statistic	P-value of J stat.	MBIC	MAIC	MQIC
1	0.86926	208.2998	1.32e-09	-430.7243	8.299771	-162.6546
2	0.93618	107.6251	0.008065	-371.6429	-42.37489	-170.5907*
3	0.94853	49.2187	0.504677	-270.2933*	-50.7813*	-136.2585
4	0.80627	24.57642	0.486301	-135.1796	-25.42358	-68.16218

Note: The asterisk * denotes the selected optimal lag order.

Before estimating Impulse Response Functions (IRFs) and Forecast Error Variance Decompositions (FEVDs), we assess the stability condition of the estimated PVAR model. The results confirm the model's stability, as all roots are found to be within the unit circle. Figures 2 and 3 display the impulse response functions of benchmark model, and extended model, respectively. Based on the GMM Estimation, the effects of IRF of digitalization on green growth index has a positive, but insignificant shock. Likewise, the results of the IRF show that industrialization reacts positively to a shock to green growth index. Also, the IRF shows that CO2 emissions react positively to a shock to green growth index. Concerning the IRF of shows that economic growth react positive and significantly to a shock to green growth index. Similarly, the IRF of environmental-related tax reacts positively but insignificant shock to green growth index. Moreover, the results of IRF indicate that the positive shock to green innovation development leads to an insignificant increasing in green growth index.

The IRF plots in Figure 2 and 3 also reveal that the IRF impacts of green growth index on digitalization is postive and statistically insignificant over the whole horizon considered. Furthermore, the green growth index response is negative and insignificant to shocks in industrialization over the whole horizon considered. Also, the green growth index responds positively when faced with a stock in green innovation development, except for the third lag which has a negative stock. Similarly, the green growth index responds positively when faced with a stock in CO2 emission, except for the first lag which has a negative stock. On the contrary, the green growth index response is positive and insignificant to shocks in economic growth over the whole horizon considered, while green growth index response is negative and insignificant to shocks in environmental-related tax.

Table 5 presents the findings of the Granger causality test in the extended model. The test evaluates Granger causality using a Wald test based on the GMM estimates. In addition to we perform to Granger causality at the optimal lag order of three. According to the Wald test results, we are able to reject the null hypothesis indicating that *LIND* does not cause to *LGGI* at the 1% significance level. Similarly, we find that *LGDP* also granger causes to *LGGI.* However, all other variables do not causes to *LGGI* at any significance level.

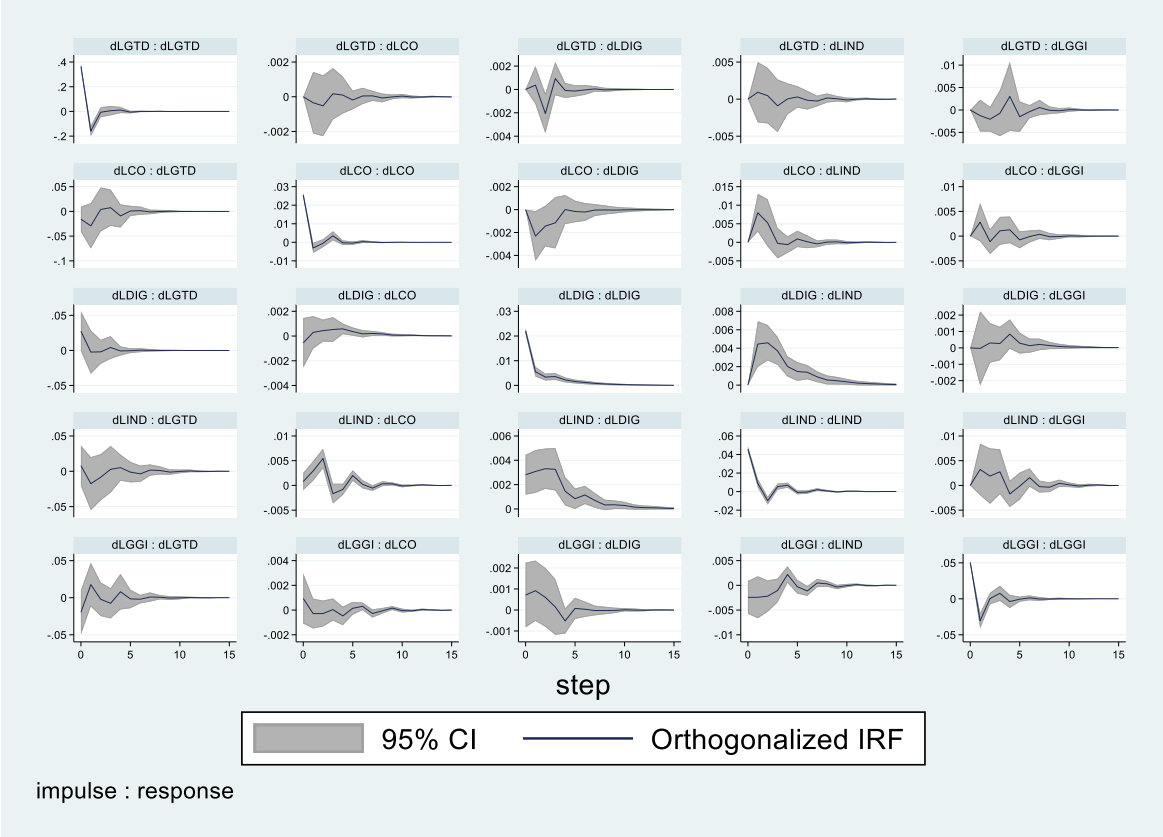

Figure 2.Impulse response with the benchmark model is estimated of dLGGI dLDIG dLIND dLCO dLGTD. Note: The optimal lag order is 3.

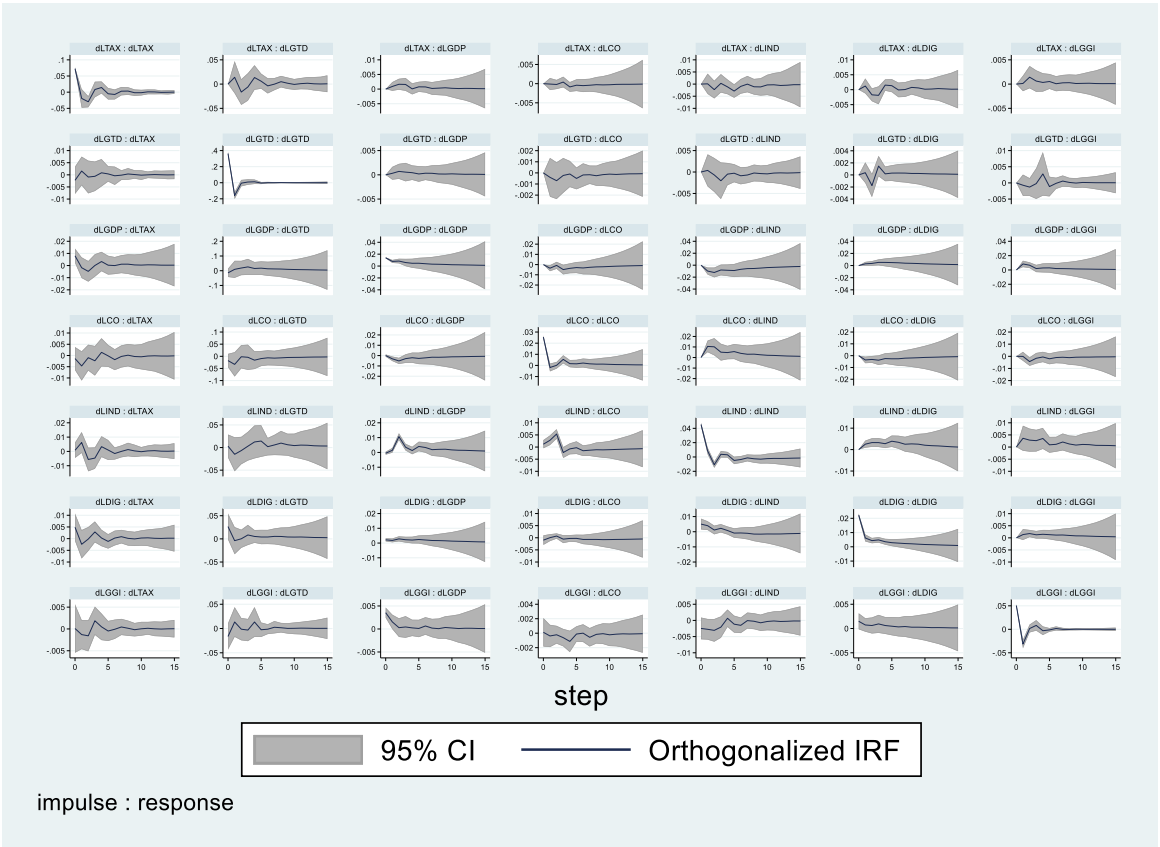

Figure 3. Impulse response with the extended model is estimated of dLGGI dLDIG dLIND dLCO dLGDP dLGTD dLTAX. Note: The optimal lag order is 3.

On the other hand, the findings indicate that *LIND, LGTD, LCO2, LTAX,* and *LGDP* granger cause to *LDIG*. Also, we conclude that *LDIG, LGDP,* and *LCO2* granger cause to *LIND* at the 1% and 5% significance levels. The findings of granger causality test indicate that *LDIG, LIND, LCO2, LTAX,* and *LCO2* granger cause to *LGDP*, while *LIND, LGDP* granger cause to *LCO2*. Lastly, there is granger causality from *LCO2* to *LTAX* at the 10% significance level. On the contrary, we are unable to find a granger causality from all variables to *LGTD* at any significance level.

Conclusion

Green growth is vital for sustainable development and the well-being of current and future generations. It promotes economic expansion while minimizing negative environmental impacts, and protecting ecosystems and natural resources. Furthermore, green growth plays a crucial role in driving digitalization, industrialization, and green innovation towards a sustainable future. By fostering the adoption of digital technologies in various industries, green growth enhances efficiency and productivity while minimizing resource consumption and waste. This digital transformation supports cleaner production methods and facilitates the use of renewable energy sources, leading to a reduction in carbon emissions and other pollutants.

In terms of industrialization, green growth promotes the development of eco-friendly industrial processes and practices. By encouraging the integration of green technologies and innovations into manufacturing and production, industries can improve their environmental performance and competitiveness. This, in turn, helps create sustainable supply chains and supports the transition to a low-carbon economy. Moreover, green growth stimulates green innovation by driving research and development in sustainable technologies. This leads to the creation of new products and services that address environmental challenges while contributing to economic growth. Through green innovation, businesses can gain a competitive edge, create new market opportunities, and contribute to global efforts to combat climate change.

The main objective of this study is to examine the potential role of digitalization, industrialization, green innovation development, CO2 emissions, economic growth, and the environmental tax on the green growth process in OECD countries using a GMM Panel VAR approach from 2000 to 2022. Through this methodology, the research reveals the significant roles each of these factors plays in promoting sustainable development and fostering green growth.

The empirical findings based on the GMM Panel VAR approach indicated that the IRF impacts of the green growth index on digitalization, green innovation development, CO2 emission, and economic growth are positive and statistically insignificant over the whole horizon considered. In contrast, the green growth index response is negative and insignificant to shocks in environmental-related tax and industrialization. On the other hand, the results of the IRF show that digitalization, industrialization, green innovation development, and CO2 emissions react positively and significantly to a shock to the green growth index. Moreover, the findings of the Granger causality test indicate that there is bidirectional causality between industrialization and the green growth index and economic growth and the green growth index. On the other hand, there is no causal relationship between digitalization, green innovation development, CO2 emissions, and environmental taxes to the green growth index. The findings from this study have important implications for policymakers and industry stakeholders. To facilitate green growth, there is a need to create an enabling environment that supports digitalization, industrial modernization, and green innovation. This may involve investing in research and development, fostering collaboration between the public and private sectors, and establishing regulatory frameworks that incentivize sustainable practices. Likewise, the study underscores the importance of international cooperation and knowledge sharing in advancing green growth. The transfer of technology, expertise, and best practices across borders can accelerate the adoption of sustainable solutions and address global challenges such as climate change and resource depletion.

Recommendations

Based on the findings of this study, several key recommendations can be made to promote green growth through the effective integration of digitalization, industrialization, and green innovation. First, industries should be encouraged to adopt smart technologies such as the Internet of Things (IoT), artificial intelligence (AI), and big data analytics to optimize resource management, reduce waste, and enhance energy efficiency. Additionally, supporting and incentivizing research and development (R&D) in green technologies, including renewable energy and energy-efficient infrastructure, will drive innovation across various sectors.

Table 5. Granger causality tests in Extended Model

Extended specification			
Hypothesis	***p=3***		***p=3***
LDIG⇏ LGGI	1.204	LGGI ⇏ LGDP	3.052
LIND ⇏ LGGI	16.621***	LDIG ⇏ LGDP	6.365*
LGTD ⇏ LGGI	3.947	LIND ⇏ LGDP	131.295***
LGDP ⇏ LGGI	21.610***	LGTD ⇏ LGDP	0.804
LCO2 ⇏ LGGI	1.925	LCO2 ⇏ LGDP	17.635***
LTAX ⇏ LGGI	1.476	LTAX ⇏ LGDP	9.462**
LGGI ⇏ LDIG	0.566	LGGI ⇏ LCO2	1.158
LIND ⇏ LDIG	16.466***	LDIG ⇏ LCO2	0.373
LGTD ⇏ LDIG	11.270**	LIND ⇏ LCO2	36.392***
LGDP ⇏ LDIG	12.779***	LGTD ⇏ LCO2	0.659
LCO2 ⇏ LDIG	11.119**	LGDP ⇏ LCO2	9.068**
LTAX ⇏ LDIG	9.239**	LTAX ⇏ LCO2	3.868
LGGI ⇏ LIND	4.152	LGGI ⇏ LTAX	2.505
LDIG ⇏ LIND	42.892***	LDIG ⇏ LTAX	2.450
LGTD ⇏ LIND	0.176	LIND ⇏ LTAX	3.967
LGDP ⇏ LIND	10.986**	LGTD ⇏ LTAX	0.364
LCO2 ⇏ LIND	12.762***	LGDP ⇏ LTAX	0.062
LTAX ⇏ LIND	3.641	LCO2 ⇏ LTAX	6.654*
LGGI ⇏ LGTD	2.367		
LDIG ⇏ LGTD	0.715		
LIND ⇏ LGTD	0.684		
LGDP ⇏ LGTD	1.331		
LCO2 ⇏ LGTD	3.161		
LTAX ⇏ LGTD	3.003		

Note: *, ** and *** indicate significance at 10%, 5% and 1% level, respectively.

Moreover, policies and incentives should promote environmentally friendly manufacturing processes and circular economy principles, investing in cleaner production technologies and waste reduction initiatives. Facilitating partnerships between businesses, governments, and academic institutions can foster collaboration and knowledge sharing, accelerating the adoption of sustainable practices. Creating supportive regulatory frameworks with standards for emissions, energy efficiency, and incentives for sustainable practices can drive industry compliance and innovation. Investing in education and training programs is also essential to building a workforce skilled in digital and green technologies, supporting the transition to a low-carbon economy.

Furthermore, establishing systems to monitor and evaluate the progress of green growth initiatives is crucial, including tracking key performance indicators (KPIs) and conducting regular assessments to measure the effectiveness of policies and strategies. Engaging in international collaboration can facilitate the transfer of green technologies, expertise, and best practices across borders, accelerating the adoption of sustainable practices globally.

Lastly, green growth initiatives must be equitable and inclusive, benefiting all segments of society, with targeted support for vulnerable communities and industries transitioning to green practices. Encouraging continued research into the dynamic relationships between digitalization, industrialization, and green innovation will provide deeper insights and guide future policy and strategy formulation. By following these recommendations, stakeholders can effectively leverage digitalization, industrialization, and green innovation to drive sustainable development and achieve a resilient, prosperous future.

Future research may build upon the insights gained from this study by exploring the nuanced interactions between these factors across different sectors and regions. Such investigations will contribute to a deeper understanding of how to harness the potential of digitalization, industrialization, and green innovation to achieve sustainable development goals.

In conclusion, the study makes a substantial contribution to the body of knowledge on the intersection of digitalization, industrialization, and green innovation in the context of green growth. It highlights the need for

an integrated approach that leverages these elements to drive sustainable development and create a prosperous, resilient future for all.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

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Advancements in Bifacial Photovoltaics: A Review of Machine Learning Techniques for Enhanced Performance

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Abstract: Bifacial photovoltaics have gained a lot of popularity in recent years given their ability to utilize scattered and reflected solar radiation from both sides of the panel. Although the price of a Bifacial module is generally higher than conventional mono-photovoltaic panel, it compensates for the higher energy generation per unit area. Even though the potential of Bifacial photovoltaics market is promising, their applications are still limited compared to mono-photovoltaics. However, researchers have been experimenting with Bifacial photovoltaics to exploit their capabilities in different applications and working scenarios, especially with Artificial Intelligence (AI) models. This study will focus on reviewing different Machine Learning (ML) algorithms that have been exploited and modified in order to be used with Bifacial system applications in the last three years of literature. Moreover, most popular ML algorithms are presented and discussed with respect to different Bifacial system parameters. Finally, a conclusion of future prospects and the potential of ML in bifacial photovoltaic industry and applications is presented.

Keywords: Bifacial, Photovoltaics, Machine learning, Renewable energy

Introduction

Green and sustainable power generation plants have become a necessity in almost every country around the world. The most popular and reliable type of renewable energy plants is photovoltaic systems (Renewables, 2018). Solar photovoltaic power plants can be found almost everywhere around the globe. Their efficiency, ease of installation, and reliability made the photovoltaic industry one of the most growing renewable energy industries. In fact, the collective installed photovoltaic systems are expected to reach 1.5 TW of capacity by 2030 (GlobalData, 2019). These numbers might increase with the continuous growth and advancements that we witness in photovoltaics technologies. The average power conversion efficiency of conventional solar photovoltaic panels is hovering over the 20% benchmark in the market (Zheng et al., 2019). However, with the current type of photovoltaics being utilized, the large areas which these systems cover will become a problem in the near future. Therefore, floating photovoltaic plants have become an alternative solution in certain regions with limited land areas (Haas, et.al, 2020; (Scavo et al., 2021).

To compensate for the area problem, a new bifacial solar photovoltaic module was introduced in the market lately. A typical bifacial solar photovoltaic panel consists of two layers of photovoltaic cells, one on the top face,

like a conventional panel, and one on the back of the panel (Manasrah et al., 2023). The design allows the panel to exploit the solar irradiance from both sides, taking advantage of the scattered and reflected radiation in the process. This feature gives bifacial solar photovoltaic panels up 30% power gain over conventional mono-facial panels with the same panel area (Jang & Lee, 2021). Typically, bifacial photovoltaic systems cost more than conventional ones, however, the price gap is decreasing every year. Nevertheless, researchers have started to experiment with bifacial photovoltaic panels to exploit their capabilities and potential in energy generation. These studies included investigating alternative or modified materials (Yang et al., 2020; Vimala et al., 2023) and formfactors (Choi et al., 2023) with different configurations.

Another type of experimentation with bifacial photovoltaics is the application of Artificial Intelligence (AI) models in such systems. AI technologies provide computational devices that have the ability to receive information, understand it, and respond to it intelligently. Machine Learning (ML) algorithms are considered a subset of AI that can actually improve its responses from experience. These algorithms, namely, can be a powerful tool that is able to detect and predict future events in the performance of bifacial photovoltaic systems. Many recent studies can be found in the literature about this topic, therefore, there is a need to collectively analyze and compare the different approaches in these studies. However, very little research papers have reviewed the different ML algorithms that were investigated with bifacial photovoltaic systems. In this study, a miniature review is presented to summarize the latest advancements in bifacials with ML for the last three years in literature. The goal of this review is to shed light on the most popular ML algorithms that are implemented with such systems and their effect on the performance of bifacials. This study will also discuss the prospects and future of predictive models that are used in bifacial solar photovoltaic applications.

On Bifacial Solar Photovoltaics

The concept of bifacial solar module was first introduced in 1983 (Eguren, 2022) where the technology has been around since the 1960s. However, the technology did not pick up in the market until 2016-2017 (Kopecek & Libal, 2021) when the prices of crystalline silicon (c-Si) wafers dropped dramatically. Figure 1 shows the accumulated power of bifacial systems in the world in the past 10 years. The working principle of a bifacial cell is simple and takes advantage of light passing through it. A typical bifacial cell works just like a mono-facial cell where a portion of the direct sunlight is absorbed and converted into electricity by the cell. However, the bifacial cell also converts reflected and scattered light into electricity from both of its faces in what is known as the albedo effect (Riedel-Lyngskær et al., 2022). Figure 2 illustrates the concept of bifacial and mono-facial panels.

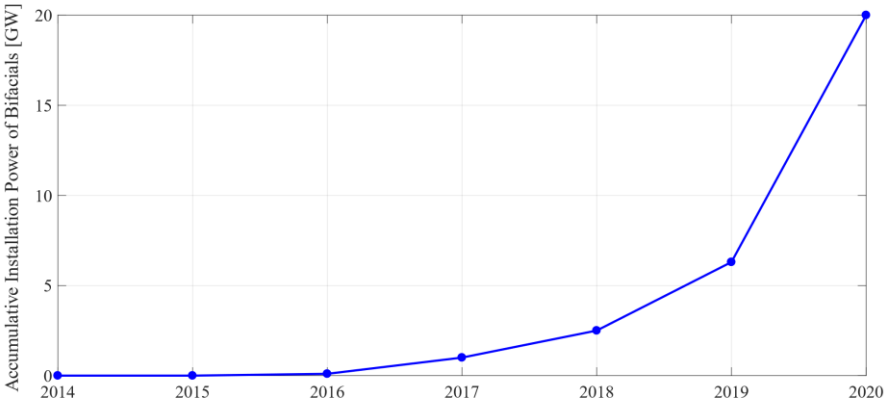

Figure 1. Accumulated power of bifacial systems in the world (Kopecek & Libal, 2021).

While mono-facial module systems can be installed in a “fixed” mode, facing one direction (Manasrah et al., 2021), or in a “tracking” mode, bifacial photovoltaic systems can be installed vertically, horizontally, or on a slant (facing either South, or North) if the system is in a “fixed” mode. However, bifacial systems can also be installed in “tracking” mode to maximize the generated power gain. Figure 3 shows the output power of fixed and tracking bifacial system setups against the time of the day.

A bifacial power gain is the amount of extra energy generated from the backside of a bifacial module which is always a fraction of the conventional energy generated from the front side (Gu et al., 2020) which is referred to as “bifacial ratio”. Power gains in bifacial modules can reach up to 30% of the maximum rated power if it was a mono-facial module with the same size and number of cells. Therefore, it is safe to assume that a bifacial system can generate up to 30% more power than a mono-facial system within the same covered area and modules size.

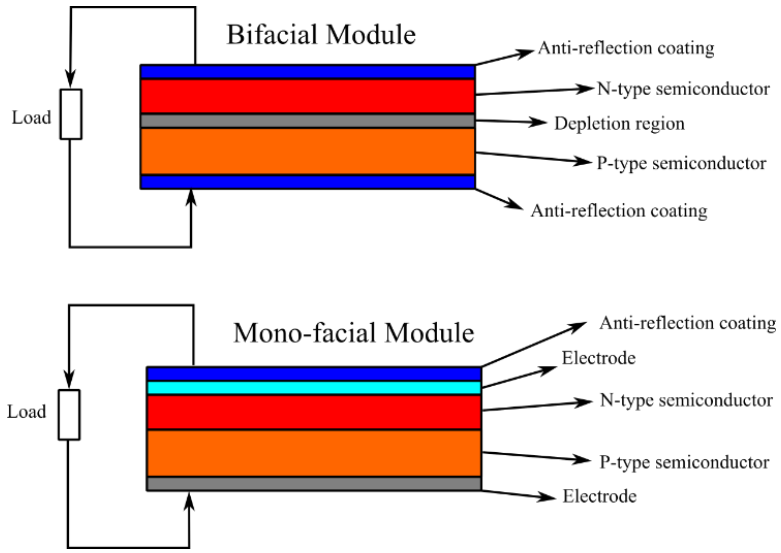

Figure 2. Working principle of mono-facial and bifacial cells (Gu et.al., 2020).

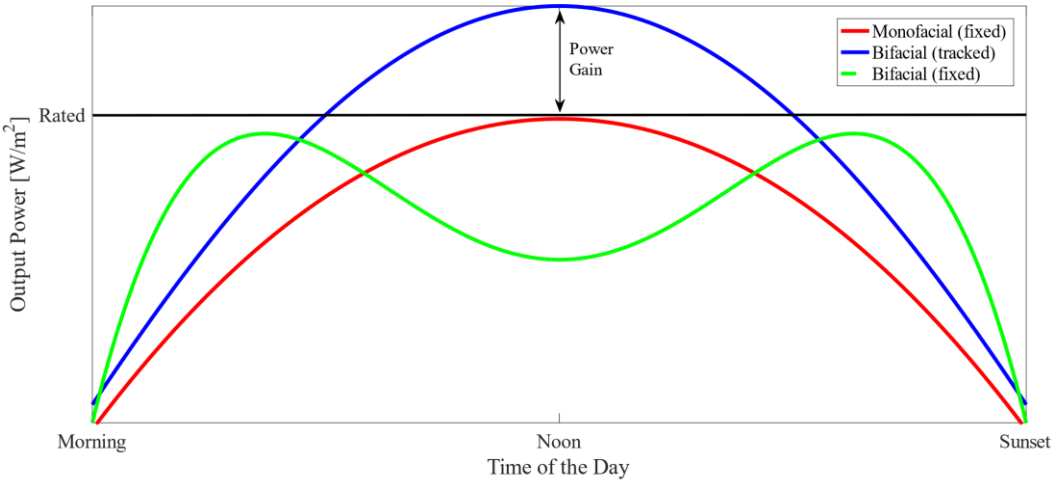

Figure 3. Output power of two bifacial setups (Kopecek & Libal, 2018).
[Curves not based on experiments data]

Of course, when talking about reflected sunlight, it is assumed that the bifacial system should be well above the ground. Increasing the height of the system could increase the installation cost. However, there is a simple approach to determining the optimal height of a bifacial system above the ground which is called in the industry as the "normalized height" (Raina et al., 2022). This will be the ratio between the width of the system and its actual height above the ground. As the system gets larger (i.e., width of the system), its height above the ground should be increased as well to maintain a normalized height. Hence, the reflected irradiance remains the same no matter how large the system is.

On Machine Learning (ML)

There is no doubt that AI and ML products have bloomed in the last decade. The technology entered almost every field of the industry from smartphones (Masoud et al., 2019) through business (Masoud et al., 2021) and communication networks (Jannoud et al., 2021), all the way to even water disinfection technologies (Bashayreh et al., 2021), e-commerce (Loukili et al., 2023), healthcare (Alanazi, 2022), and manufacturing (Kumar et al., 2023). However, there is a common misconception about the differences between AI and ML. Artificial intelligence (AI) is a broad field that refers to the technologies used to build machines that are able to mimic the human intelligence (i.e., receive, understand, and respond). On the other hand, Machine Learning (ML) is a subset of AI that gives the system the ability to learn and improve with time and experience. The learning process depends on many algorithms that are used to analyze input data. In other words, ML is considered to be the application of AI that allows a system to learn and improve.

Machine learning (ML) can be divided into three main branches: supervised learning, unsupervised learning, and reinforcement learning. Each branch has many algorithms that can be implemented in the forms of mathematical formulas that can be trained. For instance, supervised learning consists of algorithms that deal with input-output data samples called pairs. These pairs need to be "labeled" by a human supervisor, hence the name. This labeling process could be time-consuming or complex if we are dealing with large sets of data (Jaskie et al., 2021). The predicted results are then compared to the labeled pair and the error is used as feedback to improve the prediction based on the mathematical model. Unsupervised learning, on the other hand, does not require data labeling in the process. Instead, the generated models learn on their own to discover patterns in the data structure (Alloghani, et al., 2020). Clustering and reducing data dimensionality are very common examples of this type. In reinforcement learning, ML algorithms provide an "agent" from data that performs an "action" based on the state received from the environment. If the action of the agent is not accurate, it gets a "punishment" in a reward shaping process. This technique is designed to encourage or discourage agents to take more accurate decisions or not repeating previous ones, respectively. Figure 4 shows all three main types of ML with a few examples from each of them.

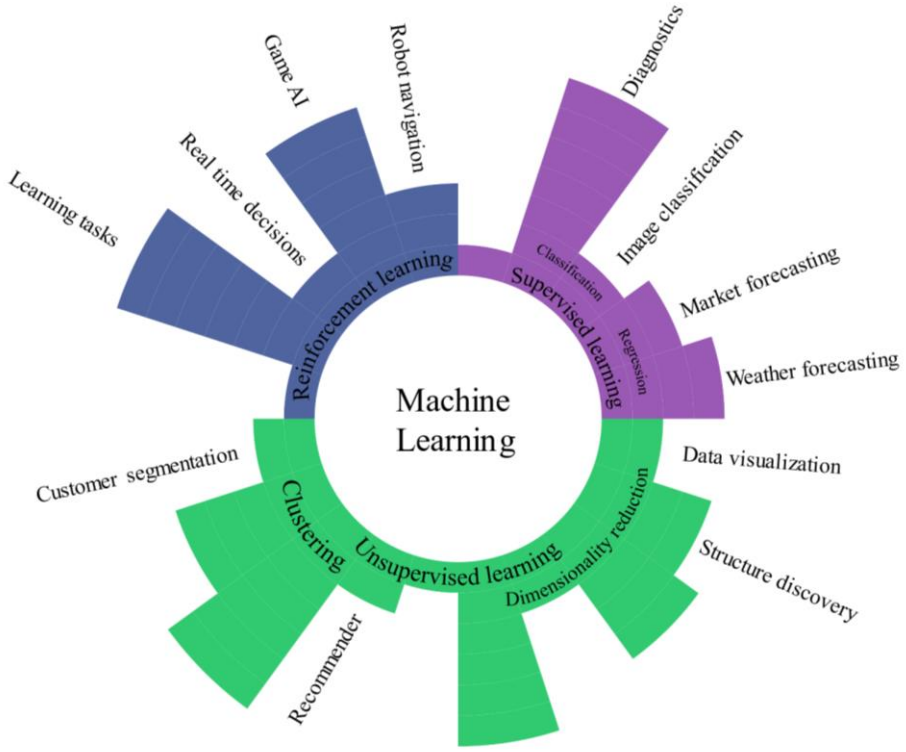

Figure 4. Machine learning types with examples (Sarker, 2021).

Advancements in Bifacial Photovoltaics with ML

Many ML algorithms were implemented with bifacial photovoltaic system, mainly for performance predictions and economical purposes. This miniature review discusses studies that investigated different ML algorithms with bifacials in the last three years. Many prediction models have been developed for bifacials recently to study their performance and energy production. For example, a previous study implemented a type of recurrent neural networks (RNN) to predict the output power of bifacial systems (Yunqiao &Yan, 2023). The study utilized real data from power stations and used many weather parameters like wind speed, temperature, clouds, irradiance, and ground type. Results showed that the predictive model depends on the weather characteristics which were heavily dependent on the accuracy of weather stations. Another study implemented Artificial Neural Networks (ANN) to forecast the generated energy from bifacial systems (Ghenai et al., 2022). Results showed that ANN accurately predicted improvements in power generation with the increase of surface albedo with R values of more than 99%. Real-time decomposition method was also used to calculate the performance ratio of bifacials with reliable and accurate results (Dobos et al., 2021). A more recent study deployed an autoencoder convolutional neural network model with mean absolute error and data filter layers (Manasrah et al., 2023) to predict the performance of bifacial modules under partial shading. Results showed accuracies of 91% in predicting and locating shades.

Machine learning techniques were also utilized to predict optimal tracking angles for bifacial systems (Tsuchida, et al., 2022). Deep reinforcement learning was deployed to learn in real time with the tracking system. The features of the model included global irradiance, generated power, time, and tilt angle. The results showed that the proposed model achieved up to 9% more electricity yield with high albedo. A similar approach was implemented in an older study where convolutional neural networks CNN model was used in a solar tracking system (Carballo, 2019). Adaptive real-time tracking was also used with bifacial systems (Sun et al., 2024). Improvements in energy production were presented up to 7.5% compared to conventional tracking algorithms. Table 1 summarizes the previously mentioned studies.

Table 1. Summary of previous ML studies on bifacial systems.

Last name	Year	Approach	Purpose	Results
Yunqiao	2023	RNN	Power prediction	Accuracy depends on weather data.
Ghenai	2022	ANN	Power prediction	R=99%.
Dobos	2021	Real-time decomposition	Performance ratio	Reliable accuracy in real data performance.
Manasrah	2023	Autoencoder CNN	Anomaly and shade detection	91% accuracy in detecting and locating shade.
Tsuchida	2022	Deep reinforcement learning	Tracking	9% improvement in power.
Sun	2024	ARTT	Tracking	Up to 32% improvement over conventional tracking.

By taking a deeper look at the literature, only very few research papers have investigated machine learning algorithms with bifacial systems specifically. Nevertheless, there has been an exponential increase in publications on bifacial technology (Gu et al., 2020). However, many studies presented similar machine learning methods on conventional mono-facial photovoltaics (Tina et al., 2021). This raises a question of whether there is an actual potential of bifacial photovoltaic systems in the near future on the market. Even though bifacial systems can be an interesting technology to investigate with ML models, the topic is still not very popular among scholars even with real experimental data. Perhaps the performance gain of bifacials over conventional systems is enough in a way that does not necessarily require complex algorithms for improvement purposes. However, machine learning algorithms are taking over real-world applications in almost every research field as discussed earlier. Therefore, there is much room for model development especially in the applications of bifacial systems.

Conclusion

In this paper, a miniature review is conducted on the deployment of different machine learning algorithms with bifacial photovoltaic systems. The technology of bifacial solar modules has been developing rapidly and getting less expensive with time. The paper reviewed different machine learning algorithms that were used to improve the performance or generated power of bifacials. Many of the previously presented studies relied on real experimental data to predict performances. However, even though bifacials have been around for years now, applying machine learning models on such systems is still not that popular. The most rational reason could be that bifacial systems (either fixed or tracked) are already superior over conventional mono-facial ones. Hence, there is much potential for development in this area especially for bifacial photovoltaic applications.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Conversational Agents: An Exploration into Chatbot Evolution, Architecture, and Important Techniques

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Abstract: A chatbot is a computer software that mimics a user interaction. It is often referred to as a dialogue system or conversational agent. Developers and academics are increasingly focused in designing and implementing Chatbots. This in-depth look focuses on the ever-changing realm of chatbot technology, concentrating on chatbot evolution, architecture, and techniques that drive the most recent breakthroughs. We begin with a brief history and then follow the progress of Chatbots, emphasizing major milestones. The review focuses on the many architectures used in chatbot creation, ranging from classic rule-based systems to cutting-edge machine learning (ML) and natural language processing (NLP) approaches. We analyze the present status of chatbot technology and its breakthroughs, which include advances in NLP and interpersonal interactions. While demonstrating effective industry practices, we also discuss the architecture of software. Recommendations are made for academics, developers, and enterprises, identifying possible areas for future investigation and development in this quickly changing industry. The paper finishes by projecting future trends and developments in chatbot development.

Keywords: Chatbot, Artificial Intelligence (AI), Natural language processing (NLP), Machine learning (ML)

Introduction

A chatbot is a computer program that mimics and interprets spoken or written human communication, enabling people to engage with digital gadgets in the same way they would with a real person (Berry, 2023) . Chatbots can be simply defined as one-line programs that respond to basic questions, or they can be as complex as digital assistants that learn and develop over time to provide ever-more-personalized services as they collect and analyze data (Kalla, 2023). Chatbots are being used in a range of industries and applications, ranging from entertainment to education, e-commerce, and healthcare. chatbots, like jessie humani, and mitsuku can offer both support and fun to users (Joseph, 2023) . these "small talk" chatbots may encourage a sense of social connection. chatbots appear to be more engaging than static frequently asked questions (faq) pages on websites. chatbots are more efficient and cost-effective than human customer assistance since they can help several users at once. chatbots can provide customer service, entertainment, and connection to the end user (Lin, 2023).However, users' engagement and confidence in Chatbots are influenced by their amount of embodiment

(human-likeness) and disclosure (how and when the bot's presence becomes apparent to the user) (Alabed, 2023; Suhaili, 2021).

Chatbots have become more popular in recent years due to increased processing power and open source technology. Advancements in Artificial Intelligence (AI) and NLP have made Chatbots more user-brotherly (Kar, 2016) , adaptable, and capable of mimicking human conversation (Suhaili, 2021) . Chatbots have become more popular in recent years due to higher computational capacity and open-source technological advances. Chatbots use conversation systems to efficiently manage tasks including gathering information, directing requests to the appropriate channels (Gandon, 2018) , and delivering customer service (Dhola, 2021). Some Chatbots utilize sophisticated NLP (Arora, 2016) and word classification algorithms to understand and interpret user input Amodu et al. (2023) . These Chatbots comprehension the context and complexities of the conversation, leading in more accurate and detailed responses. Some Chatbots, on the other hand, employ a simpler method of searching for generic keywords and constructing responses from pre-defined terms in a library or database Cho Wang et al. (2023). Virtual assistants and website popups are the primary methods for contacting Chatbots online Ashari et al. (2014). Virtual assistants, such as voice-activated Chatbots, provide engaging conversational experiences on smartlaptop s and smart speakers Shamir and Gilad (2023).

Website popups, on the other hand, are chatbot interfaces that display on websites and allow users to have text-based discussions Nirala, et al. (2019).These two communication strategies have a wide range of applications, including business (for example, e-commerce help), education, entertainment, finance, health, news, and productivity Grudin et al. (2019) . Chatbots can be classed in several ways depending on certain characteristics. Here are some popular chatbot categories. *Rule-based* Chatbots are those that obey a set of rules or scripts and are hence referred to as "rule driven" Chatbots. They generate predefined replies based on phrases or patterns found in user inputs. Rule-based Chatbots are basic and have limited functionality because they can only answer to a specific set of preset questions Caldarini et al. (2022) . Chatbots based on machine learning evaluate and respond to human input using AI and NLP techniques. They can refine their replies over time by observing user interactions. *ML-based Chatbots* are more complex and can answer a wider variety of questions than rule-based Chatbots Maher et al. (2020) . *Retrieval-based Chatbots* answer using predetermined responses stored in a database. They do not generate new replies, but instead select the most appropriate one depending on user input. Retrieval-based Chatbots are commonly used for certain activities or places where predetermined replies are available Horacek, Helmut. "Natural language processing, 1990 . *Generative Chatbots* generate their own replies rather than depending on preprogrammed ones. They may exhibit innovative, interactive behaviors in response to human stimulation. Generative Chatbots give more flexible and unique replies than retrieval-based Chatbots, but they are more complex to design and train Miller (2024). *Task-oriented Chatbots* are Chatbots that are trained to do certain tasks, such as organizing appointments, providing customer service, or making bookings Al-Amin et al. (2024). . They have a limited functional range and are focused on completing a certain task. Conversational Chatbots are meant to converse with humans in an open-ended manner. They may not have specific jobs or responsibilities because their primary goal is to encourage conversational interactions. Conversational Chatbots are commonly used for amusement, customer engagement, and social interaction Dsouza et al. (2019) . The rest of this article is organized as follows: Section 2 provides some background on Chatbots and their evolution through time, Section 3 describes the Chatbots architecture, Section 4 presents an analysis of the state of the art in terms of Chatbots techniques, in Section 5 we will discuss the challenges and we conclude the paper in Section 6.

Evolution of Chatbots

The term "chatbot" may have gained popularity recently, but the idea has been around since people began creating computer-mediated communication methods. Chatbots have a history dating back to the 1960s, when the first such technology assistant was developed. Joseph Weizenbaum created ELIZA in 1966 1 . It could recognize certain phrases and reply accordingly, simulating a conversation with a person. Since 2000 more and smarter bots have been created. They use natural language processing to 'understand' human speech and respond appropriately. Conversational systems have grown alongside advancements in computing and NLP techniques. The first chatbot, ELIZA, was developed in 1966 and used linguistic rules and pattern-matching algorithms (Berry, 2023; Nirala & Kumar, 2022). It can converse with users using a keyword-matching system. The algorithm looks for a suitable transformation rule to reformulate the input and return an answer to the user. Eliza was a milestone system that encouraged additional research in the field. Elıza's knowledge was limited due to its reliance on basic context identification and the inflexibility of pattern-matching rules for implementing new domains Seering, Joseph et al, 2019 . Chatbots are a type of AI that interpret and converse with users by using NLP Tulshan et al. (2018). They are often used in a variety of platforms and apps to interact with users, respond

to inquiries, and offer automated support. Over the years, Chatbots have had a remarkable transformation, progressing from simple pattern-matching algorithms to complex conversational agents utilizing cutting-edge technology. Their past reveals an amazing development in NLP and AI. Fig. 1, shows the major stages of chatbot development.

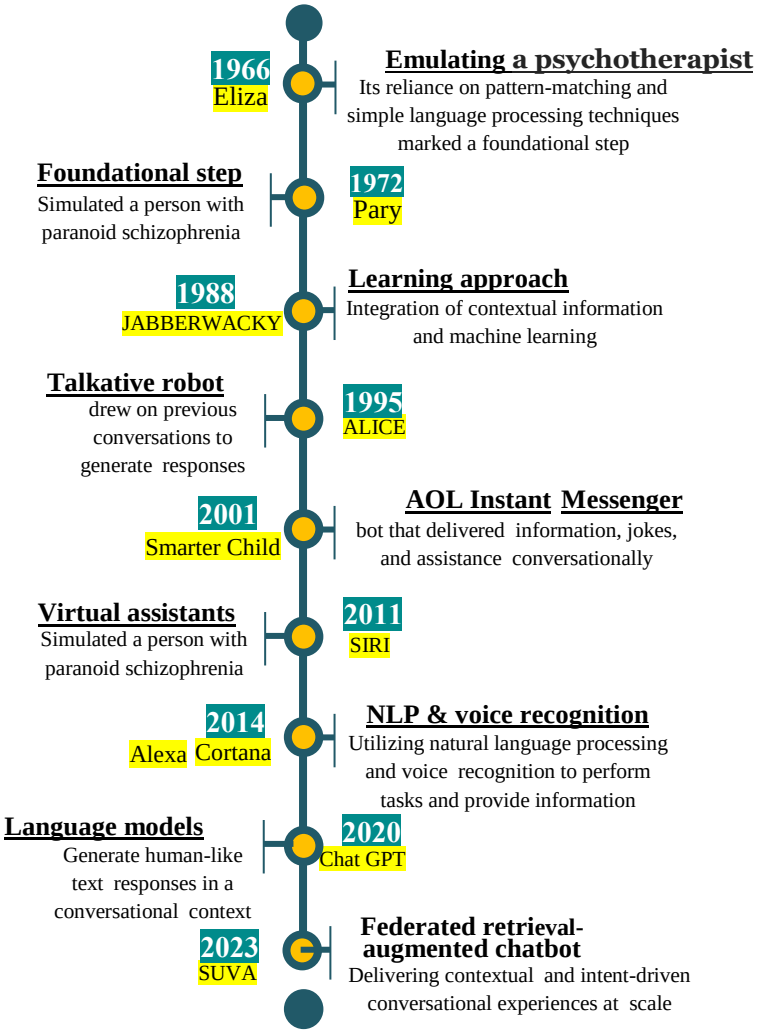

Figure 1. Chatbots through time

In the mid-1960s, the first bot ELIZA appeared as an early NLP software that mimicked a psychiatrist. Its focus on pattern-matching and basic language processing techniques was a critical advance Hadi, Muhammad Usman, et al, 2023 . In 1972, the PARRY software emulated a person with paranoid schizophrenia, providing insight on the difficulty of replicating complicated human cognitive processes Yogesh et al, 2021 . The learning methodology gained prominence in 1988 with JabberWacky, which used previous talks to create replies, demonstrating the combination of contextual knowledge with ML Han et al. (2021) . In the middle of 1990, A.L.I.C.E., a talking robot, used pattern-matching and rule-based approaches to simulate conversation Luo et al. (2022) . In 2001, CHILD, an AOL Instant Messenger bot that gave knowledge, jokes, and assistance conversationally, made its debut Horacek, Helmut, 1990 . Then, the following years introduced virtual assistants like SIRI (2011), Cortana (2014), and ALEXA (2014), each built by big tech firms, using NLP and voice recognition to do tasks and offer information Miller, James R, 1981 . ChatGPT made its public release in 2020, marking a big step forward in language models. OpenAI built it on the GPT-3.5 architecture with the goal of producing human-like text answers in a conversational setting Reiter (2007) . By 2023, ChatGPT had advanced significantly, leveraging the capabilities of retrieval augmented generation, ML, NLP, natural language question answering (NLQA), generative AI, and an insights engine. This enabled it to address customer and employee support inquiries 24/7, demonstrating a comprehensive integration of several AI technologies Firdaus et al. (2020) .On June 15, 2023, SearchUnify introduced SUVA. The world's first federated retrieval-augmented chatbot, SearchUnify Virtual Assistant (SUVA), provides contextual and intent-driven conversational interactions at scale. SUVA, which is powered by large language models (LLMs), uses

ML, NLP, NLQA, and retrieval-enhanced generation to provide secure and tailored customer and staff assistance queries Skantze (2007) .

Chatbot Architecture

To improve system design, it's important to first understand its structure and architecture. The architecture is often represented by its components and their interactions Lee et al. (2010) . We did a thorough review of survey papers, publications, and journals. We discovered several conversational agents, each with its unique architecture. For example, the Amazon Alexa bot uses user data, such as speech, to generate Automatic Speech Recognition (ASR) about the Amazon ASR service. Then, process the supplied data about various Amazon Web Services (AWS) and use Amazon DynamoDB to store the conversations and their states Adamopoulou and Moussiades (2020). Google Assistant is the most successful bot of all. Which receives recordings from users and sends them to Google's servers for processing. It breaks down the voices into component sounds and tries to match each sound with the most comparable word's pronunciation. A standard chatbot architecture is made up of five major components, see fig.2. A user interface, a natural language understanding (NLU) component, a dialogue management (DM) component, a backend component, and a response generation (RG) component Khanna and Pandey (2019), as shown in the image below:

- **User Interface** The user interface enables users to converse and engage with Chatbots using messaging apps such as Facebook Messenger, Cortana, and Slack. The operation of a chatbot begins with a user request Khanna, and Pandey (2019) .

- **Natural Language Understanding:** When the system gets a user request, the NLU component extracts information and creates a representation of its meaning for subsequent use Abdul-Kader and Woods (2015) . NLU focuses on three tasks: conversation act categorization, intent classification, and slot filling Arsovski and Osipyan (2019) . Conversational agents reply by giving a semantic representation for user utterances Hahm et al. (2018). , such as logic or class purpose, and extracting the "meaning" of an utterance de Melo and Hose (2013) . Parsing is the primary function of an NLU, which takes a string of words and provides a linguistic framework for the speech. The mechanism used by an NLU to parse input is implementation-dependent, and it can use context-free grammars, pattern matching, or data-driven methods. NLU outputs must be manageable by a conversation manager Bollacker et al. (2008) .

- **Dialogue Management (DM)**: The Dialogue Management component manages information from other components, updates discussion context, and governs the chatbot's activities Sean (2010).

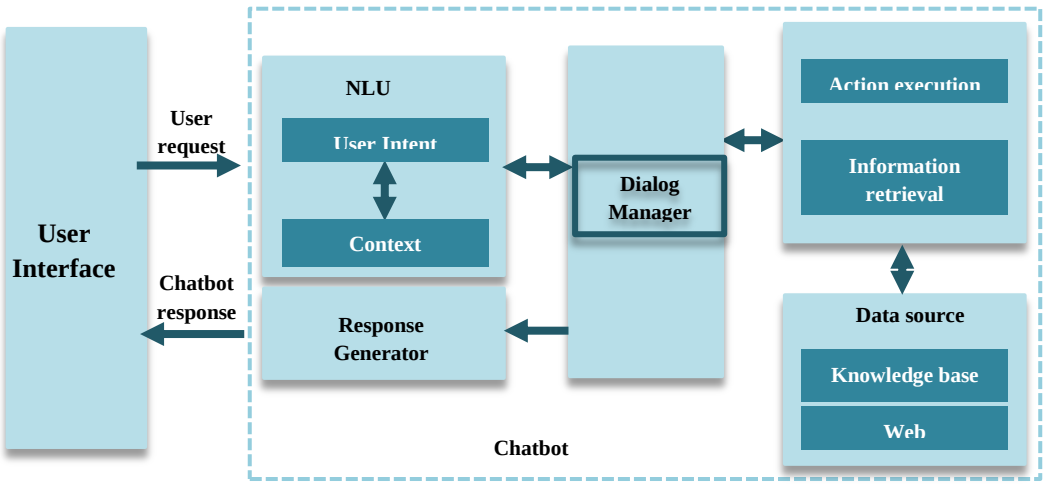

Figure 2. Operational mechanics and architectural components of chatbots

Dialogue Manager is the second key component of every chatbot, and we can distinguish between Chatbots using this component, which has various aspects that may be modified or added in the future if it is discovered to serve the DM. DM accepts user input from the NLU and generates system replies at the concept level for the natural language generation (NLG). The reaction that the DM will pick is determined by the approach that was chosen. Strategies involve preserving a conversational state and modeling the discourse structure beyond a single statement Khanna and Pandey (2019) . The methodologies include rule-based, knowledge-based,

retrieval-based, and generative. The rule-based techniques include background, intent templates, and entity-based templates, which are arranged in order of priority. Because rule-based techniques encode human knowledge into templates, they produce the most accurate results. If one of these tactics recognizes the input, the system will respond with a template. If there is no matching template for the input, the system may attempt to obtain a response from a knowledge-based question answering (Q/A) engine Adamopoulou and Moussiades (2020). Otherwise, the input is processed by a collection of neural network models and information retrieval modules to provide a generic conversation output.

- **Backend:** Chatbots gather information from the backend and send messages to the Dialogue Management and Response Generation components . Rule-based Chatbots require a Knowledge Base (KB) to hold their own rules. To ensure the chatbot's resilience, the Knowledge Base rules should be broad and comprehensive Abdul-Kader and Woods (2015). .A chatbot can utilize a Relationship Data Base (RDB) to retrieve previous interactions. Using past knowledge improves the chatbot's consistency, precision, and reliability Arsovski S., Osipyan H., 2019 . Developing the knowledge base (KB) can be time-consuming and labor-intensive due to manual effort. To address this challenge, engineers created a method for automatically creating a new KB from an existing chatbot Hahm et al. (2018). A software may convert a corpus into an AIML knowledge base Bollacker et al. (2008) . Rule-based Chatbots often employ user replies to direct and fulfill knowledge base questions Motta (2010) . Information is increasingly being saved digitally on the World Wide Web and other online sources. Large repositories contain information in machine-readable and accessible formats Pool, Steven, and Brian Pool, 2007 . Examples of knowledge bases are Google's Knowledge Graph et al. (1955) and DBpedia , Freebase, and Wolfram Alpha . Jacobs and Bean (1963). Knowledge Graphs were launched in 2012. Structured information on a topic or summary is provided by crowd-sourcing and manual duration of data. DBpedia uses structured data from Wikipedia and is accessible online. These repositories often have subject-predicate-object triples and a graphical framework to display them. The nodes represent entities, such as topics and objects, whereas edges represent their relationships.

- **Response Generation:** Once the appropriate information has been retrieved, the next step for the dialogue system is to determine the content of the response and the best way to express it. The Response Generation component is responding for generating responses in user understandable format. The final key component of any chatbot. It gets a communicative act from the DM and produces a corresponding textual representation. The NLG must execute two functions: content planning (Content Filter | Engagement Ranking) and language generation (using only text or speech via Text to Speech). After going through one or more of the DM's techniques, the pipeline moves on to the reply generator Yorozu et al. (1987), This generator will first apply a content filter to exclude incoherent or problematic candidates. If there are several legitimate responses, a ranking procedure is utilized to sort candidate utterances, first by priority, and then by engagement ranking. Finally, the chatbot sends the selected utterance as a text in the final output.

Chatbot Techniques

- Domain Adaptive Pre-training (DAPT): is a simple technique. Pre-training the model on an extremely small corpus or particular task can yield substantial advantages. In addition to working on ever-larger LMs, it can be beneficial to find and employ domain- and task-relevant corpora in tandem to specialize models Baevski and Edunov (2019) . This model can investigate additional adaptability by extending the pre-training of big LM into two types of unlabeled data: (i) huge domain-specific text corpora Beltagy et al .(2019) and (ii) readily available unlabeled data related to a specific task Lewis et al. (2020) .

- Retrieval Augmented Generation (RAG): pre-trained endow, parametric-memory generation models with a non-parametric memory through a general-purpose fine-tuning technique which we refer to as retrieval-augmented generation (RAG) Payal Bajaj, Daniel Campos, 2016 . Using the same retrieved document to generate the entire sequence, technically, the model treats the retrieved document as a single latent variable that is pooled to obtain a probability seq2seq p(yx) using a top-K approximation Devlin and Chang (2019) . Specifically, the top-K documents are retrieved using the retriever and the generator produces the resulting sequence probability for each document, which is then marginalized Hussain et al. (2019) .

- Parsing: In order to ascertain the semantic structure of the text or the relationships between its terms, it transforms the text into a meaningful representation string. Lexical parsing is one type of parsing approach that can be used to facilitate manipulation and extract information from text by breaking it down into simpler atomic words. Following the application of lexical parsing, syntactical and semantic parsing can be used. By translating text into a machine-understandable representation of its meaning, these two parsing approaches ascertain the

grammatical structure of a phrase and extract a particular meaning Cooper (2020) . "Set your eyes on my brother" and "could you see my brother," for instance, would both produce the identical parsed version of "see my brother." Additionally, this method assists in locating the ambiguity so that a user can be asked to restate his input Ramesh et al. (2017). As an illustration, there are two ways you could understand)the line "I saw my brother with my laptop ": 1) Did I see my brother with my laptop ? ; 2) Did I see my brother with my laptop in his hand?

- Matching patterns: Using this method, Chatbots generate responses with patterns when they are created manually, which is a laborious procedure. Even though it speeds up response times, the responses could be monotonous and repetitive, which makes for boring conversations devoid of spontaneity and the human touch Motgeret al. (2022) . The chatbot, for instance, can identify terms such as "books" and "office supplies" in response to the input "Where the stickers are?" It can also identify other inputs like "different types of supplies in the office supplies aisle".

- Artificial Intelligence Markup Language (AIML): Chatbots use a variety of technologies, such as AIML, to use a pattern matching approach syntax to find the best possible response Adamopoulou and Moussiades (2020). Derived from the Extensible Mark-up Language (XML), AIML is an open standard language. Topics and categories are the two components that make up AIML data objects. A category is a rule that matches a template for input and an optional pattern for response. A subject is an optional top-level element that has a group of related categories. AIML files are used to sort the objects. It must offer a pattern for every possible response and update it regularly, which cannot be done automatically, despite its readability, usefulness, and efficient use of response time Sutskever et al.

- RNNs. The chatbot can handle sequential data and take into account the input from the present users thanks to the RNNs. It retains the input from prior users because of the inherent limited memory. Put another way, an RNN allows data to stay, in contrast to a standard neural network. RNNs work on the basic principle of storing an output from one layer and using it as an input for the subsequent layer in order to predict the outcome S. Hochreiter (1993). For certain applications, the unaltered version of RNN is inappropriate because of the vanishing or expanding gradient problem Chung et al. (2022) . Two distinct approaches addressing this issue are Gated Recurrent Units (GRU) Cho et al. (2014) and Ma et al. (2023) , LSTM Jozefowicz et al. (2015).

- LSTM. An unique variety of RNN is the LSTM Jozefowicz et al. LSTM addresses the vanishing or ballooning gradient issue in RNN and is built to manage long-term dependency. Consequently, the LSTM introduces gates. The main element of an LSTM is a gate, which determines which information is remembered. The gates also output a value between zero and one, where zero denotes memorizing nothing and one denotes allowing everything to go to the next stage. In addition, LSTM provides three different types of gates to regulate the information flow: forget gates, output gates, and input gates. The forget gates choose which data should be committed to memory, whereas the input gates handle the state update procedure. The output from the hidden layer is also determined by the output gate. These three gates make up the LSTM memory cell. Gender is among the things the LSTM can remember because it was designed as a short-term memory solution. Thus, the chatbot can use "his/her" based on the previously recalled input. An alternative LSTM architecture called BiLSTM takes into account input coming from the opposite direction as well Vinyals and Le (1964) . In addition, the LSTM and RNN's primary rival is the GRU Cho et al. (2014) and Ma et al. (2023) . Its architecture makes it less complex and more popular than LSTM. One "update gate" is created by combining the input and forget gate.

- Sequence to Sequence: The first design to be developed to tackle translation concerns is the Seq2Seq structure, and its success is encouraging for NLG. Diverse datasets and domains are used to train the seq2seq end-to-end. Additionally, seq2seq is the industry standard structure because of its versatility, ease of use, and generality in solving many NLP tasks Weizenbaum (1966) . In theory, seq2seq is made up of an encoder and a decoder, two RNNs. Word by word, the Encoder interprets the user's input, and word by word, the Decoder creates the response based on previously had discussions. When creating Chatbots, the challenge was to translate user input to the chatbot's response rather than translating across languages. One benefit of seq2seq structure over others is that the lengths of the input and response sequences can also vary. Depending on table 1 below, Papers Makatchev et al. (2010) and Liu et al. (1971) discussed Rules and patterns matching technique as a set of predefined human made rules with pros Easy and less expensive implementation Fast deployment. No overtime to understand the intent of the user. Cons is unable to learn on their own. Unable to react outside its preconceived notion.

- To map words to actual umber vectors, a language modelling and feature extraction technique was used. Kim and Kwon (2020) Combination of generation and retrieval-based approaches which "Xiaolce: more popular

example from Microsoft". In Combination of generation and retrieval-based approaches, Tran and Nguyen (2020) "Proposed PS, GP. And PRFDevlin et al. (2022) and Toutanova (2022) "Develop matching method based on the seq2seq, Radford et al. (2018). "Develop a model using the Twitter LDA model and attention mechanism Song and Wang (2022) "Integrate AIML technique with a SNC model", Albeladi et al. (2023) "Multi-strategy process including LSTM with an attention mechanism beside rule-based technique". Lewis et al. (2020).Domain Adaptive Pre-training (DAPT) technique where text modeling for upcoming tasks inside the domain is enhanced by domain adaptive pre-training, which is the ongoing unsupervised pre-training of a language model on text unique to the domain. Finaly, Retrieval Augmented Generation (RAG) technique where models that blend non- parametric and parametric memory that has been trained beforehand to generate language Lin et al. (2023)

- Also in Rule –based Jia (2009) and Moubaiddin et al. (2015) and Belgaumwala (2019) discussed the Parsing technique is Converting a text to be less complicated terms. The pros is Providing the text's semantic structure or the dependence relationships between terms. The cons is the same guidelines and trends that correspond with drawbacks. The Corpus based the articles Candra (2017) and Noori et al. (2014), describe Pattern matching technique which predefined structures of responses, pros is adequate for basic jobs, Pick insightful answers from the list of candidate answers. Greater adaptability compared to rule-based, cons is providing Chatbots devoid of intelligence and relativity, Repetitive responses and restricted capacities.

Mavridis et al. (2019) describe AIML technique Represents the knowledge as objects which derived from XML, pros is benefits of matching patterns strong in creating a conversational flow, cons are developing every potential motif by hand Very challenging to scale. Generation –based has linear support vector machine (LSTM) technique which the papers Zhang et al. (2022) and Shawar and Atwell (2004) describe the CNN that usually used for learning features automatically by utilizing convolution and pooling processes. Shawar and Atwell (2004), depict GRU is a type of RNN technique related with LSTM. Shawar (2011) , RGDA based on gradient reinforcement learning Stacked LSTM method that teaches computers to make decisions in a way that produces the best outcomes. It simulates the process of learning by making mistakes. Kadeed (2014) , characterize Stacked LSTM that a deeper and more abstract model is produced by stacking many hidden LSTM layers on top of one another in a LSTM. Two concealed LSTM layers in the opposite direction make up a bidirectional LSTM, which uses information from both sides. Ali and Habash (2020) characterize Stacked LSTM and BILSTM which is the input is followed in both directions. Al-Ghadhban and Al-Twairesh (2020) HRED generates context and response.

In hybrid technique Palasundram et al. (2019) paper expressing the “Attention” which is attention method, in which the encoder assigns attention weights to each concealed state. The computation of these weights establishes the relative importance of an encoder state to a decoder state in producing the subsequent state based on the energy associated with each weight. In seq2seq learning based on encoder- decoder architecture, Al-Madi et al. (2021) based on RNNs cell and improved technique of seq2seq learning. Zhang et al. (2019) Mapping a sequence of input words to another representation of response sequence. TNaous et al. (2019) GRU is in compression to LSTM. GRU required fewer parameters training and it not being required for an additional cell state. Hu et al. (2022) paper expresses RNN. Attention mechanisms Improved technique of seq2seq learning based on RNNs cell. Resolve the problem of systems incapability to remember a longer sequence. Prassanna (2020) "Enhancement of RNN-GRU" which "This technique is improved by adding three additional cells which are Refinement, Adjustment, and output cells Zhang and Dinan (2022), Boussakssou and Ezzikouri (2022). Pre-trained GPT-2, DIALOGPT, BoB, aubmindlab, CakeChat, asafaya is

Chabot Challenges and Limitations

Chatbot creation faces numerous challenges, including linguistic, technical, and user experience issues. These include NLU, handling ambiguity, generating responses, preventing user dissatisfaction, supporting multiple languages, managing dynamic contexts, ensuring data security and privacy, enhancing personalization, integrating chatbots with systems, identifying user intent, and managing memory retention Chaves et al. (2021) . Efficient assessment, transplatform coherence, and ethical considerations like bias and fairness are also crucial. Adapting to new information requires robust learning techniques Chiang et al. (2024) . A multidisciplinary approach involving domain-specific knowledge, machine learning, NLP, and user experience design is needed to overcome these challenges. Continuous research and developments in AI technology can help reduce these challenges and enhance chatbot performance. Overall, overcoming these challenges is crucial for the development of chatbots Sudalairaj et al. (2024) . Limited flexibility, inflexible responses, complex scalability, managing ambiguity, dependence on rule quality, absence of learning capabilities, expensive and resource-

intensive maintenance, difficulty managing variability, restricted generalization, scalability problems, user experience issues, reliance on expertise, and limited adaptability are some of the challenges that rule-based chatbots must overcome Naık et al. (2023). Because of these difficulties, rule-based systems are best suited for certain applications with clearly defined domains and predictable user behavior.

Table 1. Approaches and techniques for Chatbot

Approach	Techniques	Description	Advantages	Disadvantages	Articles
Rule –based	Rules and patterns matching	Set of predefined human -made rules	Easy and less expensive implementationFast deployment. No overtime to understand the intent of the user	Unable to learn on their own. Unable to react outside its preconceived notion	Makatchev et al. (2010),Weizenbaum (1966) , Colby(1971)
	Parsing	Converting a text to be less complicated terms	Providing the text's semantic structure or the dependence relationships between terms	The same guidelines and trends that correspond with drawbacks	Jia (2009) , Moubaiddin(1962) , Belgaumwala, (2019)
	(Retrievalbased) Pattern matching	predefined structures of responses	adequate for basic jobs, Pick insightful answers from the list of candidate answers.Greater adaptability compared to rule-based	Providing chatbots devoid of intelligence and reativity.Repetitive responses and restricted capacities.	Candra and Noori(2014)
	AIML	Represents the knowledge as objects which derived from XML	Benefits of matching patterns Strong in creating a conversational flow	Developing every potential motif by hand Very challenging to scale	Mavridis and AlDhaheri, (2011), Roca and Sancho (2020)
	CNN	CNN usually used for learning features automatically by utilizing convolution and pooling processes	LSTMs are beneficial for managing long sequences in time series analysis and natural language processing due to their ability to retain information from previous time steps. They also help solve the vanishing gradient problem by regulating information flow across the network.	Long Short-Term Memory (LSTM) models have drawbacks such as computational complexity, overfitting, hyperparameter tuning, and limited interpretability. They require more computation than feedforward networks or basic RNNs, and are prone to overfitting when there is insufficient training data.	Zhang and Chen (2021), Zhang and Qin (2022), Shawar and Atwell (2004)
	CNN and GRU	GRU is a type of RNN technique related with LSTM .	CNN offers high accuracy in machine learning tasks, while GRU networks are faster and less computationally expensive. They manage long-term dependencies in sequential data selectively.	CNN design is time-consuming and labor-intensive, and GRU models face low learning efficiency and slow convergence rate issues.	Shawar and Atwell (2011), Wang (2022).
Corpus based	LSTM RGDA based on gradient reinforcement learning	method that teaches computers to make decisions in a way that produces the	Reinforcement learning has the following benefits: Performance maximization. Maintain Change for an extended length of time. An excess	It is preferable to use reinforcement learning to solve difficult problems rather than simple ones. It demands a great deal of work and a large amount	Shawar and Atwell (2011) ,Wu et al. (2020), Yu et al. (2019).

Stacked LSTM	best outcomes. It simulates the process of learning by making mistakes.	of states resulting from reinforcement can taint the outcomes.	of data. The cost of maintenance is substantial.	
Stacked LSTM	A deeper and more abstract model is produced by stacking many hidden LSTM layers on top of one another in a stacked linear support vector machine (LSTM). Two concealed LSTM layers in the opposite direction make up a bidirectional LSTM, which uses information from both sides.	To effectively capture intricate patterns and long-term dependencies in sequential data, numerous LSTM layers may be used.	In order to guarantee efficient training and avoid overfitting, it also adds more complexity and calls for cautious tuning and regularization.	T. Kadeed, 2014 , Ma, M., Liu, C., Wei, R., Liang, B., & Dai, J. (2022) , Jørgensen, R. K., Hartmann, M., Dai, X., & Elliott, D. (2021).
Stacked LSTM and BILSTM	BiLSTM: The input is followed in both directions.	Reliable on a bigger dataset and useful for recalling lengthier sequences	makes use of a lot of parameters, more memory size was needed, Extended execution duration and intricate complexity	Ali and Habash (2020)
HRED	HRED generates context and response			Al-Ghadhban and Al-Twairesh (2020)
Attention	using the attention method, in which the encoder assigns attention weights to each concealed state. The computation of these weights establishes the relative importance of an encoder state to a decoder state in producing the subsequent state based on the energy associated with each weight.	Using a BiLSTM network with attention, they map each user statement to an EPA (Evaluation Potency Activity) vector. They then provide a corresponding EPA response vector that is used to condition the response generation.	BiLSTM is a far slower model that takes longer to train. As a result, they advise against utilizing it unless absolutely necessary.	Palasundram et al.(2019)
seq2seq Seq2seq learning	based on RNNs cell and improved	"Same advantages of tachniques that seq2seq	"Same disadvantages of tachniques that seq2seq depending on it"	Al-Madi et al. (2021)

based on encoder-decoder architecture	technique of seq2seq learning Mapping a sequence of input words to another representation of response sequence.	depending on it Support variable-length size of input and response"		Zhang et al . Wang and Koji (2018)
GRU	In compression to LSTM. GRU required fewer parameters training and it not being required for an additional cell state	Uses less training parameter Uses less memory Take less time in execution Less complex structure"	"Not suitable for large Dataset Not suitable for long- distance relations"	Naous et al. (2019)
RNN	"Attention mechanisms Improved technique of seq2seq learning based on RNNs cell. Resolve the problem of systems incapability to remember a longer sequence"	Uses less training parameter Uses less memoryTake less time in execution - Less complex structure"	Suffer from gradient exploding and vanishing problems. Difficult to process very longer sequences"Not suitable forparallelizing or stacking up"	Hu et al. (2022)
"Enhancement of RNN-GRU"	"This technique is improved by adding three additional cells which are Refinement, Adjustment, and output cells"	Uses less training parameter Uses less memoryTake less time in execution - Less complex structure"	Suffer from gradient exploding and vanishing problems. Difficult to process very longer sequences"Not suitable forparallelizing or stacking up"	Prassanna (2020)
Pre-trained GPT-2, DIALOGPT , BoB, aubmindlab, CakeChat, asafaya,	To map words to actual umber vectors, a language modeling and feature extraction technique was used.			Zhang et al. (2018) , Boussakssou, (2020)
Combination of generation and retrieval-based approaches	"Xiaolce: more popular example from Microsoft"	"Easy to select the attributes (relevance) from ranked features list."	If the hybridization technique is not complementary to each other, the performance quality may decrease	Kim and Kwon (2020)
Combination of generation and retrieval-based approaches	"Proposed PS, GP. And PRF" "Develop matching method based on the seq2seq"	"Easy to select the attributes (relevance) from ranked features list."	If the hybridization technique is not complementary to each other, the performance quality may decrease	Tran and Nguyen Devlin et al. (**2022**

	"Develop a model using the Twitter LDA model and attention mechanism"			Radford et al.(2018)
	"Integrate AIML technique with a SNC model"			Song and Wang (2022)
Domain Adaptive Pre-training (DAPT) Retrieval Augmented Generation (RAG)	"Multi-strategy process including LSTM with an attention mechanism beside rule-based technique" Text modeling for upcoming tasks inside the domain is enhanced by domain adaptive pretraining, which is the ongoing unsupervised pretraining of a language model on text unique to the domain. models that blend non-parametric and parametric memory that has been trained beforehand to generate language	focus on adapting to multiple languages within a specific domain. they propose different techniques to compose pretraining corpora that enable a language model to both become domain-specific and multilingual. They present RAG models, in which a pre-trained neural retriever accesses a Wikipedia dense vector index as the non-parametric memory and a pre-trained seq2seq model serves as the parametric memory.	MDAPT is a complex, resource-intensive, and multilingual model that requires careful consideration of linguistic and domain-specific characteristics. It also faces challenges in fine-tuning and requires sufficient data for effective performance across multiple languages and domains. RAG is a resource-intensive model that relies on a large dataset for information retrieval. Its effectiveness depends on the quality of the information retrieved, as missing or erroneous data can lead to generation mistakes. RAG is also dependent on a pre-existing set of fixed retrievals, making it challenging to manage dynamic data.	Albeladi et al. (2023) Lewis et al. (2020) Lin et al. (2023)

Furthermore, they have trouble with a variety of unexpected or diverse user inputs, which makes it challenging to update and maintain the rule base. Moreover, rule-based systems are incapable of learning, which makes it challenging for them to adjust to changing user requirements or shifting linguistic trend Sanders et al. (2023) . To get around these restrictions, hybrid systems that combine learning-based and rule-based strategies have been developed. The challenges faced by generative chatbots, which employ NLG techniques, include handling open-ended questions, avoiding biases and inappropriate content, producing creative but inaccurate responses, handling domain-specific knowledge, and handling lack of context. In addition, they encounter constraints on data efficiency and training sets because of enormous training sets, response time management, unclear user intent, and challenges in responding to user feedback. Another difficulty is achieving real-time responsiveness since some models could take longer to generate. Determining trustworthy measures to assess the caliber of produced answers is still a challenge Spivack et al. (2024) . In order to improve the overall performance and dependability of generative chatbots, advances in NLP, model designs, and ethical considerations are required

Conclusion

This research paper examines the techniques of chatbots, a type of computer software that mimics user interactions. Chatbots are used in various industries, such as entertainment, education, e-commerce, and healthcare. They can be one-line programs or complex digital assistants that learn and develop over time. Advancements in AI and NLP have made chatbots more user-friendly and adaptable. They use conversation systems to efficiently manage tasks, such as gathering information and delivering customer service. Chatbots can be classified into rule-based, machine learning-based, retrieval-based, generative, task-oriented, and conversational chatbots. The evolution of chatbots dates back to the 1960s, with more sophisticated bots created since 2000. Techniques used include parsing, pattern matching, AIML, and RNNs, DAPT where text modeling for upcoming tasks inside the domain is enhanced by domain adaptive pretraining, which is the ongoing unsupervised pretraining of a language model on text unique to the domain, and RAG where models that blend non-parametric and parametric memory that has been trained beforehand to generate language.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

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Mapping the Field of Digital Nomadism: A Bibliometric Analysis Using VOSviewer and R

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Abstract: This study aims to conduct a comprehensive review of research on digital nomads, focusing particularly on open-access articles published in English. The methodology employs advanced bibliometric techniques such as co-citation analysis, keyword co-occurrence, co-word analysis, trend topics, thematic evolution, and scientometric mapping. A total of 116 documents from the Web of Science, spanning the period between 2005 and March 28, 2024, were screened and analyzed using the VOSviewer, MAXQDA, and R programs. For this investigation, we utilized Biblioshiny, an R-based graphical interface of Bibliometrix, renowned for its ability to create clear visualizations of literature through text-mining functionality, revealing the conceptual and intellectual structure of the field. Distinguished by its comprehensive methodology, temporal coverage, and scope on the topic of digital nomadism, this study sets itself apart from previous articles. It traces the evolution of research in this area, offering a nuanced identification of gaps and future research opportunities. Basic findings of our study: The top five most frequently used keywords, with the highest connection power, are digital nomads, digital nomadism, remote work, nomadic work and mobility respectively. Our analysis reveals that the journals with the highest number of articles and citations in this field include World Leisure Journal, Worldwide Hospitality and Tourism Themes, Information Technology \& Tourism, Computer Supported Cooperative Work-The Journal of Collaborative Computing and Work Practices and Sustainability. When considering the number of articles and citations by country, the USA, England, Russia, Australia and Spain emerge as the leading contributors. Through highlighting information gaps and suggesting research opportunities, this study aims to contribute to the shaping of future research paths in the field of digital nomadism.

Keywords: Digital nomad, Nomadism, Nomadic lifestyle, Nomadic work, Digital wanderer.

Introduction

Digital nomadism has emerged as a prominent working model of significance in today's modern work landscape, increasingly preferred by individuals due to economic and technological advancements. This concept allows professionals to move globally while carrying out their work without being tied to a physical office (Hannonen, 2020; Matsushita, 2023). This model offers flexibility, freedom, and the opportunity to work while traveling the world, presenting a lifestyle and work approach distinct from traditional office environments. This

lifestyle is further bolstered by the growing prevalence of mobility and technology in daily life, alongside the flexible and sometimes uncertain conditions of employment (Buscher, 2014; Hannonen, 2023).

Digital nomadism embodies a concept referred to as meta-work, marked by continual and global mobility within the realm of work activities (Aroles et al., 2023). Digital nomads, representing an autonomous lifestyle and working approach (Muller, 2016), typically include professionals such as freelancers, independent consultants, and technology experts engaged in creative fields. This emerging work style, as highlighted by Müller (2016), appeals to individuals who prefer a location-independent lifestyle and seek the freedom to work from anywhere and at any time they desire. The goal of digital nomadism is to transcend the constraints of traditional office settings and achieve a harmonious balance between work and life. Reichenberger (2018) stresses that digital nomads blur the lines between work, travel, and leisure, temporarily integrating with the chosen geographical location or environment. It is reported that digital nomads often utilize local coworking spaces as their working hubs, facilitating interactions with diverse cultures (Richards, 2015).

It is posited that at the heart of digital nomadism lies the aspiration for workers to strike a balance between work and life, to explore the world, and to break free from the constraints of traditional office settings. This work model affords individuals the liberty to carry out their tasks from any location and at any time they prefer, enabling them to attain a seamless blend of work and travel. Digital nomads typically enjoy flexible working hours, seizing opportunities to engage with new cultures and experiences in the places they journey to. Digital nomadism represents an increasingly popular lifestyle that epitomizes the swiftly evolving mobile lifestyle of working and traveling digital nomads (Hannonen, 2020).

Studies investigating the impact of digital nomadism on local communities have shed light on significant aspects of this emerging lifestyle. Literature research underscores that digital nomads increasingly adopt the ethos of location independence, blurring the lines between work and personal life (Müller, 2016). In self-identification, digital nomads often employ terms such as "freedom," "inspiration," and "work-life balance" (Matos & Ardévol, 2021), expressing the ability to work "from anywhere, anytime" (Nash et al., 2021). Digital nomads embrace a lifestyle where distinctions between work, travel, and leisure fade away (Reichenberger, 2018). Understanding how digital nomads harmonize work, travel, and personal growth, along with assessing their impact on local communities, has become paramount (Moravec, 2013). For digital nomads, mobility transcends mere travel; it embodies the potential to relocate (Matos & Ardévol, 2021). The mobility of digital nomads bears environmental and social ramifications (Hannonen, 2022). This dynamic and adaptable workforce acclimates temporarily to their chosen geographic settings, maintaining a personalized lifestyle facilitated by logistics and digital infrastructure (Richards, 2015). Digital nomads frequently engage with local communities, facilitating the exchange of skills and ideas (Richards & Marques, 2012; Starbird & Palen, 2013).

The work practices of digital nomads are being shaped in a cohesive manner through the use of mobile technologies. Nomadic professionals, often managing their work across various online platforms, aim to streamline their workflows by integrating diverse project management tools, communication apps, and cloud storage services (Marx et al., 2023). Studies suggest that these workers capitalize on the flexibility offered by various locations while also ensuring synchronization with team members (Mark & Su, 2010). Furthermore, an investigation into nomadic computing systems delves into how individuals organize their mobile workspaces and conduct tasks using communication platforms (Cotroneo et al., 2007).

Digital nomadism is increasingly becoming a work model that provides individuals with freedom and flexibility to balance work and travel in the contemporary world. This lifestyle is rapidly gaining traction due to the pervasive influence of technology and globalization, thereby giving rise to novel economic frameworks. Ongoing research continues to delve into critical aspects such as job security, social welfare provisions, and strategies for long-term settlement among digital nomads (Aroles et al., 2023).

Digital nomadism remains a pivotal aspect of the evolving landscape of work, underscoring the need for enhanced research and scholarly inquiry in this domain. Concurrently, achieving work-life equilibrium, fostering robust social connections, and optimizing work settings emerge as crucial considerations for digital nomads. Existing studies within the literature offer a comprehensive view of the lifestyle, business dynamics, and ramifications of digital nomadism. It is evident that this phenomenon transcends individual preferences to become a societal and economic force. Governments increasingly recognize digital nomads as integral to policy mechanisms aimed at attracting and supporting highly skilled remote workers (Sánchez-Vergara et al., 2023).

Notably, digital nomads are drawn to specific regions through visa programs tailored to remote work opportunities and tourism-related activities. This underscores the fact that digital nomadism is not merely an

individual pursuit but an integral aspect of destination communities' and states' policy frameworks. The publications on the digital nomad serve as invaluable resources for comprehending digital nomadism and evaluating its ramifications. Nonetheless, it is also acknowledged that research and literature on this subject are fragmented and dispersed (Cook, 2023). In essence, gaining a holistic understanding of digital nomadism and systematically analyzing its variability and impacts necessitate a thorough exploration of the existing literature.

Previous research by Simova (2023) is the most recent and comprehensive study on Digital Nomadism based on bibliometric analysis. We take this study as a starting point and reperform our literature review in April 2024. Our literature review differs from that of Simova in several ways. Table 1 compares Simova's study with ours based on several dimensions.

Table 1. Comparison of Simova's study and our study.

Basis of the Comparison	**Šímová (2023)**	**Our Study**
Time Period:	2006-2022	2005-2024
Keywords:	"digital nomad" or "nomadic work" or "neo-nomad"	"Digital Nomadism" or "Digital Nomad" or "Neo nomad" or "Nomadic lifestyle" or "Technology enabled travel" or "Nomadic Work" or "digital wanderer" or "nomadic technology" and "digital"
Methodology:	bibliometric analysis	Bibliometric, and content analysis
Total studies:	48	116
Records identified from:	Web of Science	Web of Science

In this study, digital nomadism is analyzed through a bibliometric perspective. Within this framework, we define and underscore the significance of digital nomadism, noting its growing prominence in recent scientific investigations. The aim of assessing the development and impact of these themes in the literature is to provide a scientific perspective for understanding this evolving phenomenon. The study employs a quantitative methodology, utilizing bibliometric analysis to delve into the following research questions.

RQ1. What are the general trends in publications concerning digital nomadism?
RQ2. Who are most influential players in the field of digital nomadism?
- **RQ21.** Which countries are leading (Publishing trends)?
- **RQ22.** Which universities/institutions are leading (Publishing trends)?
- **RQ23.** Which publications are the most influential?
- **RQ24.** Which publishers are leading and most influential?

RQ3. How are the conceptual structure and thematic identification of the topics?
RQ4. What are the trendiest topics in digital nomad?
RQ5. What are the factors influencing destination choice of digital nomads?
RQ6. What are the sustainable destination strategies to attract digital nomads?
RQ7. Which theories have been used to explain the phenomenon of digital nomadism?
RQ8. What can be the scope for future research?

Methodology

Database and Research Strategy

Preparing a protocol serves as a cornerstone in systematic literature reviews, ensuring meticulous planning, consistent implementation, and transparency for potential replication. In this review, we adopt the Scientific Procedures and Rationales for Systematic Literature Reviews (SPAR-4-SLR) protocol developed by Paul et al. (2021), which has been widely used by other authors (e.g. Lim et al., 2022; Raman et al., 2022), to guide the tasks of assembling, organizing, and evaluating (Figure 1 and Figure 2).

Analysis and Findings

Publication Trends in Digital Nomadism (RQ1)

Table 2 reports basic summary descriptive analysis 116 articles sourced from the Web of Science.

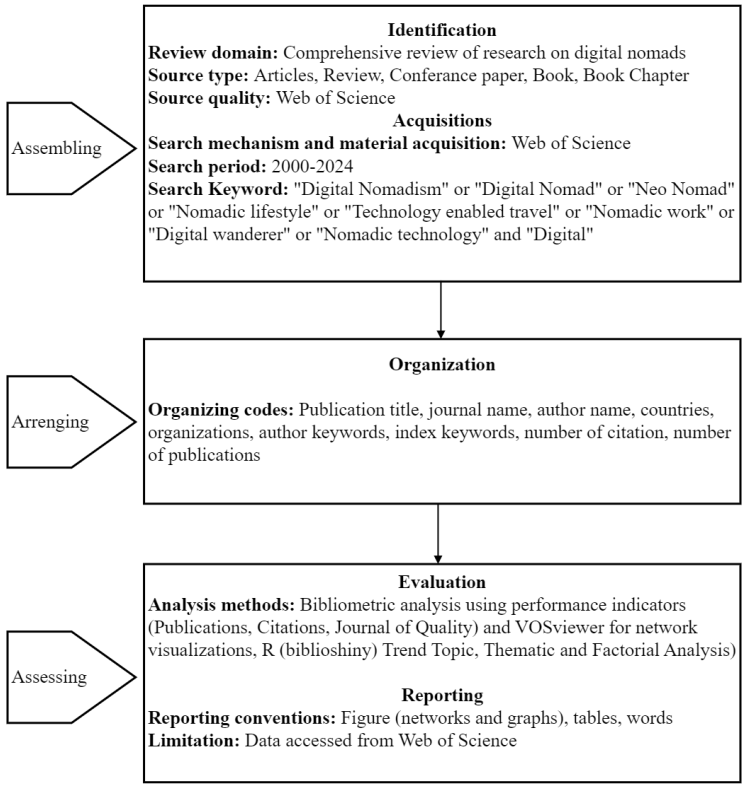

Figure. 1. SPAR-4-SLR protocol-based research design.

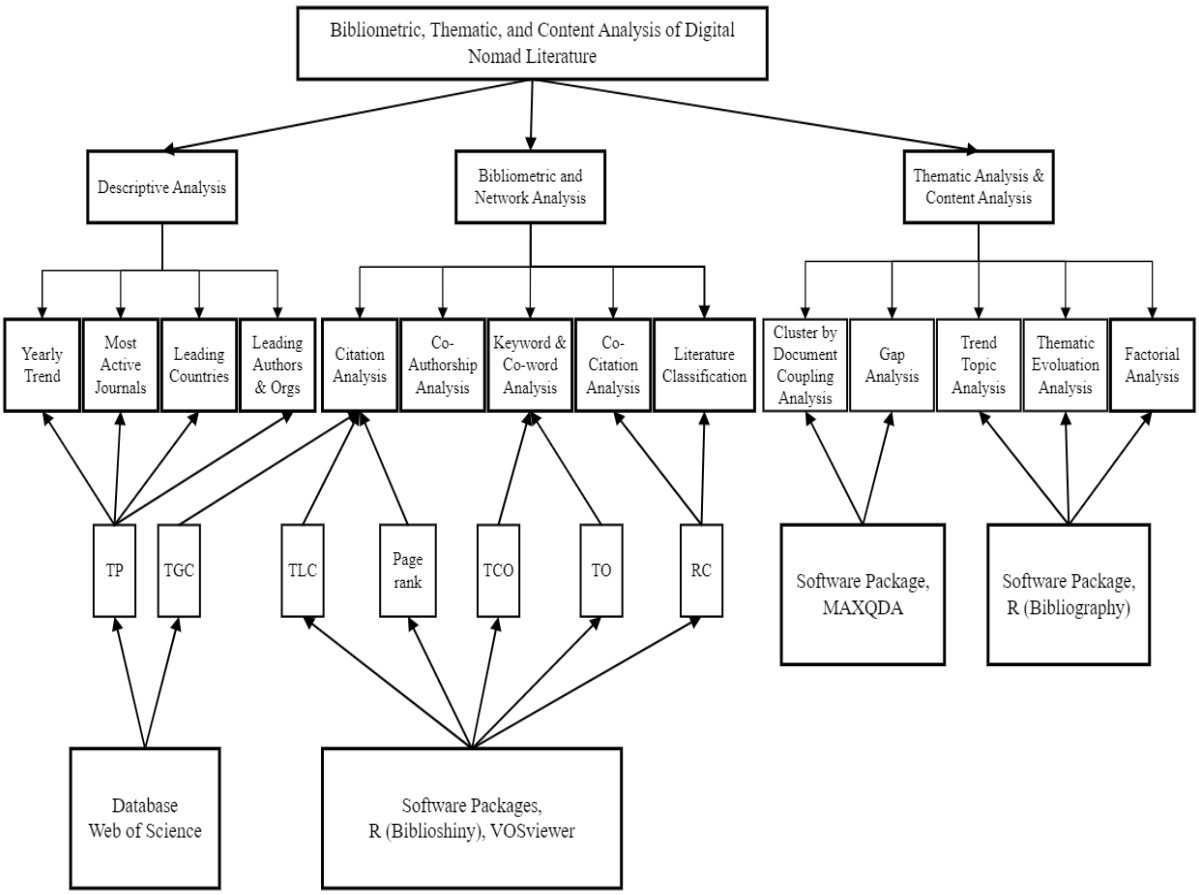

Figure 2. Research structure, the analytical framework utilized in our study, where **TP**=Total Publications; **TGC**=Total Global Citations; **TCO**=Total Co-Occurrence; **TO**=Total Occurrence; **RC**=Research Clustering; **TLC**=Total Local Citations (Adapted from Baker et al., 2020).

Table 2. Basic information about data

Main information	Results	Document information	Results	Author information	Results
Timespan	2005:2024	Keywords Plus (ID)	185	Authors	234
Sources (Journals, Books, etc)	86	Author's Keywords (DE)	463	Authors of single-authored docs	35
Documents	116	Article	78	Single-authored docs	39
Annual Growth Rate %	16.43	Article; Book Chapter	2	Co-Authors per Doc	2,34
Document Average Age	4.57	Article; Early Access	13	International co-authorships %	21.55
Average citations per doc	11.39	Article; Proceedings Paper	1		
References	4962	Editorial material	4		
		Proceedings paper	15		
		Review	3		

To address RQ1 regarding the publication research trends in digital nomadism, we conducted an analysis of the publication trend in digital nomadism using total publications by year, country, journal, contributing author, and organization. The data for this analysis was derived from the bibliographic data collected from the WoS database.

Annual Scientific Production and Average Article Citations

Figure 3a and 3b illustrate the number of annual publications and citations to digital nomadism from 2005 to early 2024. The trend indicates a notable increase in studies in this field, particularly since 2018.

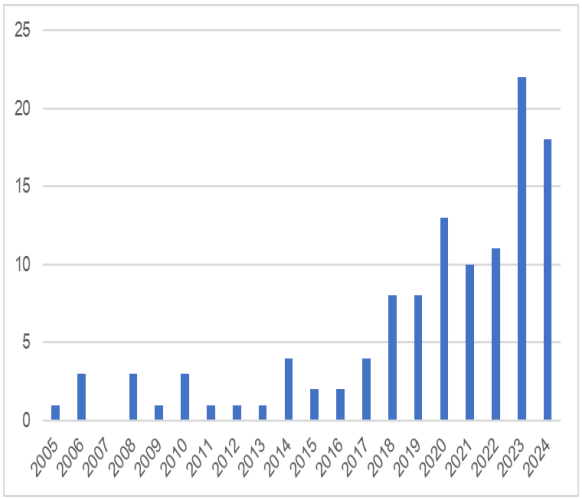

Figure 3a. Annual scientific production

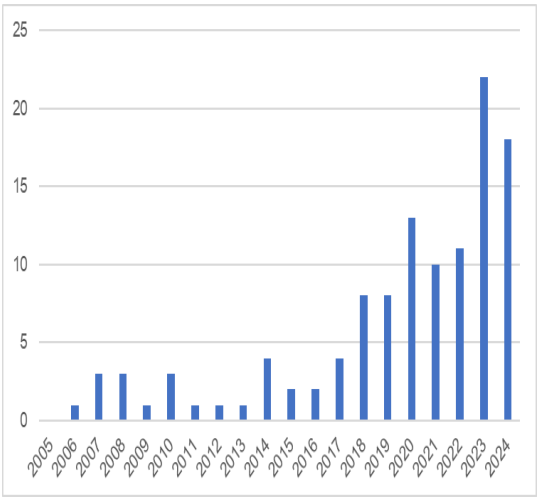

Figure 3b. Average Article citations per year

Table 3. Top 20 publishing countries in digital nomadism (2005-2024)

Rank	Countries	TP	TC	Rank	Countries	TP	TC
1	USA	16	360	11	Portugal	6	32
2	England	15	231	12	Finland	5	77
3	Russia	10	47	13	China	5	32
4	Australia	9	144	14	Canada	4	17
5	Spain	9	97	15	Norway	4	26
6	Germany	8	48	16	Sweden	4	28
7	France	7	66	17	Austria	3	128
8	Türkiye	7	0	18	Brazil	2	9
9	Czech Republic	6	91	19	Croatia	2	0
10	Netherlands	6	70	20	Estonia	2	3

TP=Total publications; TGC=Total global citations

Publishing Activity by Country (RQ21)

Digital nomad has garnered significant attention from researchers worldwide, evidenced by contributions from 108 countries. Table 3 presents the leading publishing countries in the field of digital nomadism, with the top three being the United States, the England, Russia, and Australia.

Universities/Institutions Publishing Trends (RQ22)

The 116 articles appeared in 239 organizations. The most active universities /institutions in the field of digital nomadism are presented in Table 4. The top leading university publishing in digital nomadism topic is found to be the University of Eastern Finland (TP: 8) while three US universities together (ΣTP: 19) dominate the list. The US Universities are followed by two Australian universities (ΣTP: 13), and Russia (TP: 6), Portugal (TP: 6), Türkiye (TP: 4), and Norway (TP: 4) are included in the list with one university from each.

Table 4. Top publishing organization in digital nomadism (2005-2024)

Rank	Organization	TP
1	University of Eastern Finland / Finland	8
2	University of North Carolina Chapel Hill /USA	8
3	Sydney University / Australia	8
4	Tomsk State University/ Russia	6
4	University of Minho/ Portugal	6
4	North Carolina State University/ USA	6
5	Syracuse University/ USA	5
5	University New South Wales/ Australia	5
6	Anadolu University /Türkiye	4
6	BI Norwegian Business School/Norway	4

TP: Total publications

The Most Influential Publications in Digital Nomadism (RQ23)

"RQ23. Which articles have the most influence in the field of digital nomadism?" aims to identify the most impactful publications in the field of digital nomadism. To address RQ2, we conducted an ***analysis of the citation networks*** within the dataset of 116 documents. Table 5 presents the top academic publications based on citations. According to citations, Reichenberger (2018) holds the highest number of citations with 97, followed by Dal Fiore, (2014) with 63 citations. Reichenberger (2018) is also the most locally cited work in the literature.

Table 5. Top 10 articles based on citations and pagerank analysis (2005-2024)

Rank	Publication	TLC	TGC	TGCPY	Rank	Publication	PRS
1	Reichenberger (2018)	39	97	13,8	1	Reichenberger (2018)	0.0353
2	Dal Fiore (2014)	12	63	5,7	2	Mancinelli (2020)	0.0284
3	Cook (2020)	23	59	11,8	3	Nash (2018)	0.0281
4	Mancinelli (2020)	27	59	11,8	4	Cook (2020)	0.0278
5	Nash (2018)	0	55	7,8	5	Orel (2019)	0.0258
6	Bean (2006)	0	50	2,6	6	Hannonen (2020)	0.0245
7	Richards (2015)	17	50	5	7	Richards (2015)	0.0232
8	Olga (2020)	22	47	9,4	8	Dal Fiore (2014)	0,0217
9	Orel (2019)	20	47	7,8	9	Bozzı (2020)	0,0157
10	Wang (2020)	9	42	8,4	10	Green (2020)	0,0117

TCL: Total Local Citations, **TGC:** Total Global Citations, **TGCPY:** TGC per year, **PRS:** Page Rank Score

The table reports total citation to the 116-article analyzed in journal indexed in the Web of Science. PageRank analysis serves as an alternative approach in gauging the prestige of a publication. It is an extension of the original algorithm developed by Brin and Page (1999), which was designed to prioritize web pages based on Google search (Tandon et al., 2021). This metric increases as the publication in question gets cited by other highly cited publications. It's important to note that an increase in citations does not always signify high prestige, as the correlation between citations and prestige can vary (Baker et al., 2020). Table 5 also displays the findings from the PageRank analysis. It seems there is a discrepancy where articles with fewer global and local citations tend to have a higher PageRank. Notably, this discrepancy is also noticeable between the outcomes of

PageRank and ranking based on number of citations. This result indicates that the prestige of a publication may not always rely on the quantity of citations it receives; rather, it might be influenced by how often it contributes to another high-quality research. Reichenberger (2018) is found to be the most influential publication in both methods. However, Dal Fiore (2014) and Cook (2020) seem to be in the lower ranks while Mancinelli (2020), Nash (2018), Cook (2020) and Orel (2019) find better place in PageRank Scores

Leading and Influential Publishers in Digital Nomadism (RQ24)

The 116 articles appeared in 86 journal. Table 6 presents 10 journals with the greatest number of publications on digital nomadism. The top journal among others is the World Leisure Journal with eight publications and 99 total citations. On the other side the journal Information Technology & Tourism collecting total of 206 citations with five publications seems to be the most influential with an average citation of 12.4 while the journal of Worldwide Hospitality and Tourism Themes collecting no citation as of May 2023 with seven publication looks the least influential journal. However, it should be kept in mind that the total citation numbers are sensitive to the publication dates of the papers as well. All top journals are indexed in WoS and the most frequent publisher among the top ten journals is SAGE publications followed by Springer Nature. The academic impact of leading journals publishing on digital nomadism based on several indicators can be seen in Table 7. Based on all parameters taken into account, including the year the first article was published, the journal of Information Technology & Tourism is deemed to be the most influential, as predicted by Table 6. In contrast, the journal of Worldwide Hospitality and Tourism Themes is not included in this ranking.

Table 6. Top 10 publishing journals in digital nomadism (2005-2024) ranked based on the number of total publications.

Rank	Name of Journal	TP	TC	TC/TP	Publisher	Index
1	World Leisure Journal	8	99	12.4	Taylor & Francis	ESCI
2	Worldwide Hospitality and Tourism Themes	7	0	0.0	Emerald	ESCI
3	Information Technology & Tourism	5	206	41.2	Springer Nature	SSCI
4	Computer Supported Cooperative Work-The J. of Collaborative	4	46	11.5	Springer Nature	SCI-E/SSCI
5	Sustainability	4	4	1.0	MDPI	SSCI
6	Tomsk State University Journal	3	6	2.0	Tomsk State Uni.	SSCI
7	Journal of Destination Marketing & Management	2	32	16.0	ScienceDirect	SSCI
8	Journal of Information Technology	2	6	3.0	SAGE Publications	SCI-E/SSCI
9	Social media & Society	2	33	16.5	SAGE Publications	SSCI
10	Journal of Travel Research	2	6	3.0	SAGE Publications	ESCI

TP: Total Publications; **TGC:** Total Global Citations; **TC/TP:** Average citation per publication

Table 7. Contributing journal indexes in field of usability testing research

Rank	Journal	h index	g index	m index	TC	TP	PY start
1	Information Technology & Tourism	5	5	1	206	5	2020
2	World Leisure Journal	5	8	0.833	99	8	2019
3	Computer Supported Cooperative Work-The Journal of Collaborative Computing and Work Practices	3	4	0.273	46	4	2014
4	Journal of Destination Marketing & Management	2	2	0.5	32	2	2021
5	Journal of Information Technology	2	2	0.667	6	2	2022
6	Social Media & Society	2	2	0.4	33	2	2020
7	Transfers-Interdisciplinary Journal of Mobility Studies	2	2	0.5	6	2	2021
8	Advances in Tourism, Technology and Systems, Vol 2	1	1	0.333	3	1	2022
9	Annals of Leisure Research	1	1	0.143	97	1	2018
10	Annals of Tourism Research	1	1	1	3	1	2024

h index: h number of publications cited at least h times; **g index:** g number of publications receiving at least g citations; **m index:** is defined ash/n, where is the h-index and n is the number of years since the first published paper of the scientist; **TC:** total citations; **TP:** number of publications; **PY start:** publication year start

Conceptual Structure of the Related Topics (RQ3)

The selected keywords have been determined to best reflect the content of the publications and provide information about the topics covered. Additionally, through the use of network and text analysis, the keywords and patterns embedded in these words reveal the composition of the publications (Damar & Ozdagoglu, 2022). ***Factor analysis*** is conducted on the author keywords using the Multiple Correspondence Analysis (MCA) method. Factor analysis reduces the dimensionality of the data, allowing for the representation of data in lower dimensions (Bibliometrix, 2020). In the study, a ***conceptual structure map*** is created by clustering the proximity and distance of keywords used together or separately in the articles through factor analysis. Thus, the ***thematic structures***, developed applying Conceptual Structure Factorial Analysis based on Multiple Correspondence Analysis through the Bibliometrix package in R integrated into the Biblioshiny user interfaces, is shown in Figure 4.

The conceptual structures of studies in the digital nomad field are clustered into three groups. The first group (blue cluster) clusters around topics such as digital nomadism, migration, digital nomad, mobility, identity, pastoral digital nomadism, nomadic computing, movement. The second group (red cluster) is clustered around topics such as climate.change, adaptation, ethnicity, technology. The last group (green cluster) consists of the topics such as remote.work, neoliberalism, citizenship and work.

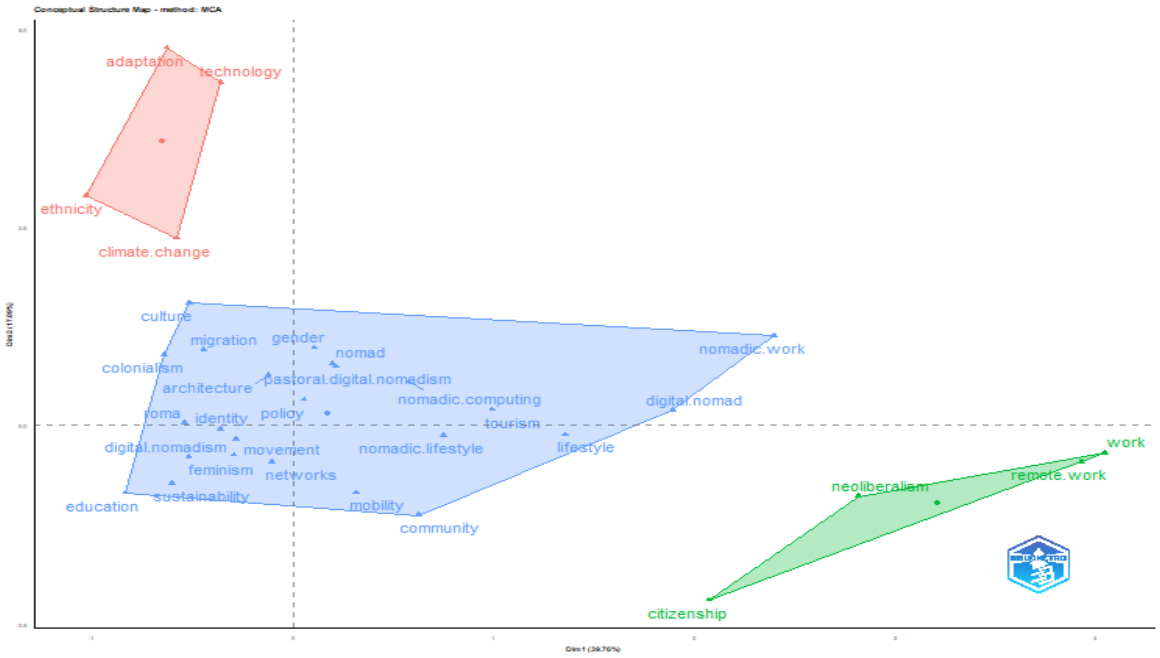

Figure 4. Conceptual structure map

Thematic Map and Evolution (RQ3)

Thematic analysis is an analytical approach that involves systematically extracting qualitative data (such as text) from a set of documents (such as articles, interviews) in order to identify, analyze, and report on recurring themes (Lim et al., 2022). The bubble size is determined by the word occurrences in the cluster. The X-axis indicates the ***importance*** of a research issue and shows ***network cluster centrality***, or the ***degree of interaction*** with other graph clusters. ***Density***, a measure of a cluster network's internal strength and theme expansion, is represented by the Y-axis (Alkhammash, 2023). The thematic map analysis comprises the identification of four distinct themes: the "***motor theme***," the "***niche theme***," the "***emerging or declining theme***," and the "***basic theme***." *The* ***motor theme***, also known as the dominant or primary theme, embodies the primary focus of the map by capturing significant patterns and trends in the data. Conversely, the ***niche theme*** serves as a supplementary secondary theme, representing specific aspects or subtopics related to the overarching theme of

the map, providing additional context and insights. The terms "**emerging or declining theme**" are utilized to characterize spatial patterns on the map, with the former indicating a decrease in size or intensity of a feature across different areas, and the latter signifying an increase. The ***basic theme*** encompasses the integration of other significant themes on the map, including the ***motor theme***, presenting a comprehensive understanding of the mapped data and the interrelations among various themes (Aras, 2023).

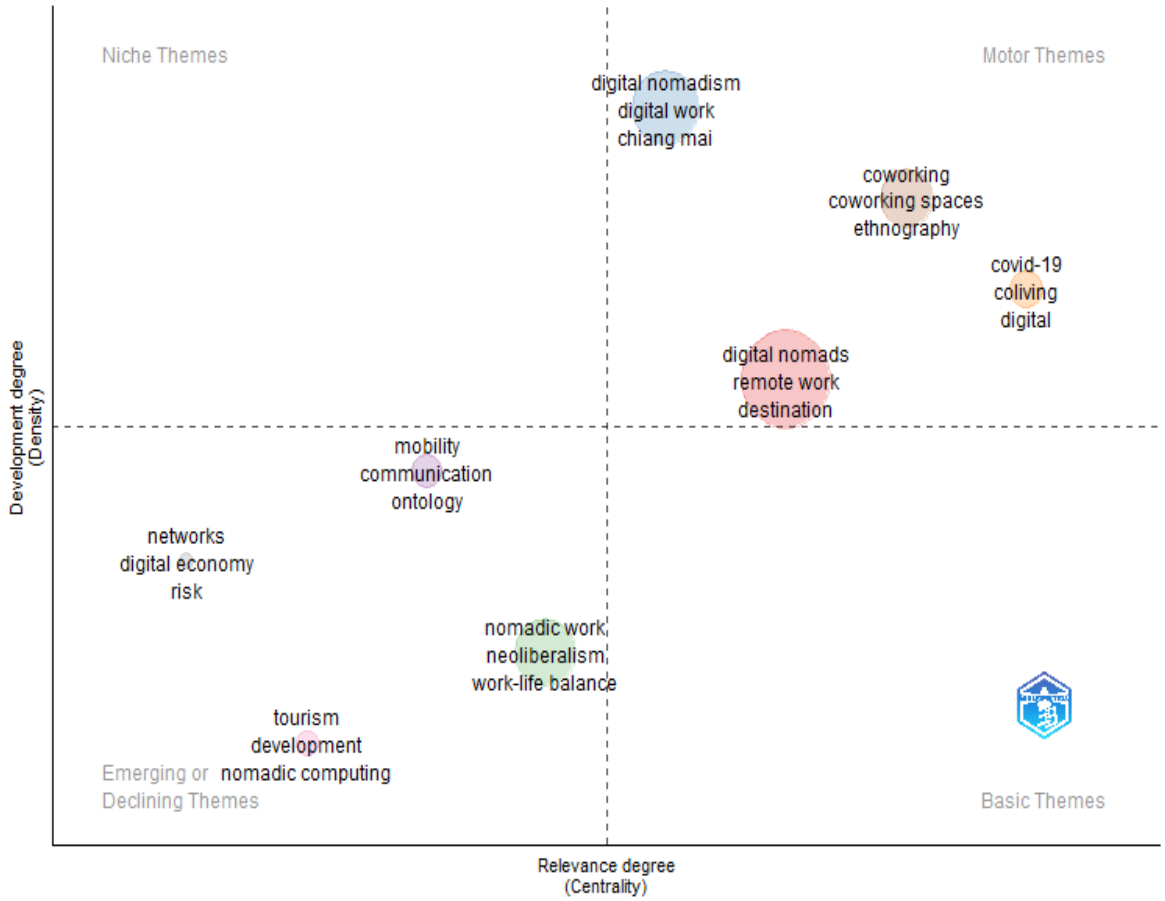

Figure 5. Thematic map

Graphing themes revealed the following: (a) ***motor themes*** (first quadrant, top right): high centrality and density in the cluster network indicate that themes are well-developed and important for organizing a research topic; (b) ***niche themes*** (second quadrant, top left): high density and low centrality indicate that themes are of limited relevance; (c) ***emerging or declining themes*** (third quadrant, left bottom): low centrality and low density indicate that themes are *marginal* and *minimally* developed; (d) ***basic themes*** (fourth quadrant, right bottom): *high centrality* and *low density* hint at their minimal development. In this context, the thematic map analysis of studies on digital nomads is presented in Figure 5. Accordingly, in the first cluster of "***motor themes"***, the keywords "*digital nomadism*" and "*digital work*". In the second cluster keywords such as "*digital nomads*," "*remote work*" and "*destination*" are gathered. In the "***emerging themes"*** quarter, the first cluster include keywords like "*tourism*" "*development*" and "*nomadic computing*" whereas the second cluster encompasses "*network*", "*digital economy*" and "*risk*". Keywords; "*mobility*", "*communication*" and "*ontology*" show a mutual approximation as third cluster while "*nomadic work*", "*neoliberalism*" and "*work life balance*" forms a group as fourth cluster. The **niche themes** and **basic themes** quarter are not occupied by any keyword.

Trendiest Topics in Digital Nomadism (RQ4)

Keyword Analysis is conducted to envisage the trendiest topics in the field of digital nomadism. Table 8 and Figure 6 show the most frequently used keywords in digital nomad field namely "digital nomad" (46), "digital nomadism" (24), "remote work" (16).

Table 9 and Figure 6 shows the top keywords based on the frequency of their occurrence

Table 8a. Top keywords by the frequency (Author Keywords)

Author Keywords	**F**
Digital Nomads	46
Digital Nomadism	24
Remote Work	16
Nomadic Work	13
Mobility	8
Covid-19	5
Digital Work	5
Coworking	4
Neoliberalism	4
Tourism	4
Coworking Spaces	3
Destination	3
Development	3
Ethnography	3
Lifestyle	3
Lifestyle Mobility	3
Mobile Work	3
Networks	3
Work-Life Balance	3
Total	156

F: Frequency

Table 8b. Top keywords by the frequency (Abstract Keywords)

Author Keywords	**F**
Digital	438
Nomads	192
Nomadism	140
Research	105
Study	84
Social	78
Nomadic	75
Paper	73
Workers	58
Nomad	56
Tourism	56
Mobility	54
Lifestyle	53
Mobile	50
Article	49
Travel	43
Analysis	42
Spaces	42
Development	39
Total	1727

F: Frequency

Trend Topics and Its Evolution by Time (RQ4)

RQ4. What is the trend topic of research in digital nomad?" aims to identify the trend topics in digital nomad. To answer RQ4, we analyzed the trend topic of 116 documents. Trend topic analysis is performed to comprehend the initial trends in the field. This type of analysis presents a distribution graph illustrating time on the horizontal axis and the most commonly utilized terms (topics) on the vertical axis. It serves as a graphical depiction in which each topic is linked with a year indicating when that topic was observed. Such analysis is employed to gain insights into the progression of research within a particular domain (Kaur, 2024).

Figure 6. WordCloud (Abstract keywords)

Figure 7 depict the trending topics over the period. Topics such as "*digital nomad*", "*remote work*" (Al-Hadi and Al-Aufi, 2019; Bonneau et al., 2023; Atanasova, 2022; Cook, 2023; Eager et al., 2022; Kabachnik & Ryder, 2013; Levinson & Hooley, 2014; James & Southern, 2019; Marushiakova & Popov, 2020; Suliman and Açıkgöz, 2022), "*tourism*" (Arisoy, 2024; Bassyiouny & Wilkesmann, 2023; Borges, 2022), "*nomadic work*" (Al-Masslawi, et al., 2017; Bean & Eisenberg, 2006), "*mobility*" (Aroles et al, 2023; Cigdemli et al., 2024) and "*identity*" (Levinson & Hooley, 2014;; Marx et al., 2023; Michaud et al., 2022; Prester et al., 2023; Jarrahi et al., 2019; Sánchez-Vergara et al., 2023; Marx et al., 2023; Michaud et al., 2022) gained momentum. Determining the latest trend topics is a critical strategic step in conducting innovative research and maintaining a leadership role in the field. Additionally, it facilitates reaching a broad audience and contributes to the advancement of the field by filling knowledge gaps.

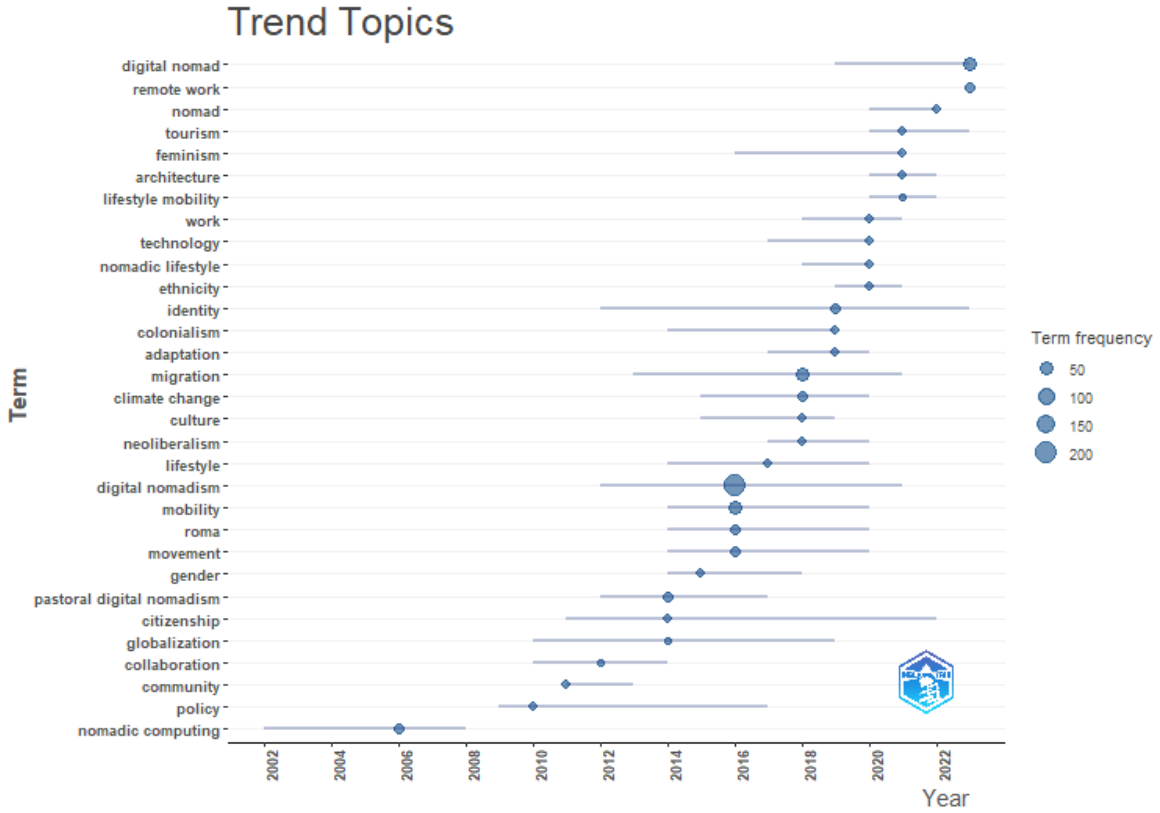

Figure 7. Trend topics

Factors Influencing Destination Choice of Digital Nomads (RQ5)

"RQ5. What are the factors influencing destination choice?" To answer RQ5, we have identified the factors influencing destination choice through the use of content analysis (Table 9). The results obtained through content analysis exhibit similarities with some studies found in the literature: The work identities of nomadic workers generally focus on "*connectivity*", "*access*", and "*coordination*" (Mark & Su, 2010). Among the factors that influence the next location preference of digital nomads, "*connectivity*" is particularly effective (Lacárcel et al., 2024). Digital nomads have the freedom to explore the world by conducting their work through computers and internet connections. Individuals who adopt this work model often work by traveling to various geographical regions without being tied to a fixed office.

Among the factors influencing digital nomads' choice of their next location are "*employment*", "*retirement*", "*gastronomy*", "*coworking*", "*job motivation*", "*culture*", "*customer service*", "*connectivity*", "*working hours*", "*visa issues*", and "*loneliness*" (Lacárcel et al., 2024).

Table 9. Factors influencing destination choice of digital nomads

Rank	Factors	F
1	Coworking	15
2	Cultural and social diversity	12
3	Employment	11
4	Mobility challenges	11
5	Climate and weather conditions	9
6	Job motivation	8
7	Visa issues	8
8	Connectivity	7
9	Infrastructure difficulties	6
10	Health services and safety	5
11	Social networks and community connections	5
12	Natural beauty and activities	4
13	Accessibility and transportation convenience	3
14	Gastronomy	2
15	Customer service	2
16	Loneliness	2
17	Legal and regulatory conditions	2
18	Retirement	1
19	Working hours	1
20	Cost and economic situation	1
21	Career opportunities	1
Total		116

F: Frequency

Mobility challenges and infrastructure difficulties (Cotroneo et al., 2007) also impact destination selection. Nomadic workers develop various strategies to conduct their work with mobile technologies. Ethnographic research reveals how nomadic workers seek resources to create their mobile offices, synchronize with others across different time zones, and navigate strategies when lacking local infrastructure knowledge (Mark & Su, 2010).

Sustainable Destination Strategies to Attract Digital Nomads (RQ6)

What are the sustainable destination strategies to attract digital nomads? To answer RQ6, we have identified the sustainable destination strategies through the use of content analysis (Table 10). Through our content analysis, it has become apparent that the rising popularity of digital nomadism as a work model necessitates the need for various regulations to accommodate this emerging form of work. Digital nomadism is becoming an increasingly preferred work model, necessitating various regulations for this new way of working.

The results obtained using content analysis exhibit similarities with some studies found in the literature. For instance, Zhou at al. (2024) posit that digital nomadism is seen as a new tourist movement creating an important area for management and marketing with smart destination strategies as a new form of tourist mobility, bringing opportunities and challenges for destination management. Their model is considered offering professionals the

freedom to carry out their work flexibly while creating new tourism and business opportunities. Besides, Putra and Agirachman (2016) advocate that with the rise of digital nomadism, smart destinations necessitate much more competitiveness by considering the needs of nomadic workers, travel arrangements, and social requirements with new understanding tourism focusing the concept of digital nomadism has created a creative transformation in the tourism industry to attract the global consumers of this new market.

Table 10. Sustainable destination strategies

Rank	Strategy	F
1	To create communities to strengthen the social connections of digital nomad	12
2	Regulations regarding work and travel flexibility	9
3	Providing flexibility in visa and accommodation	7
4	Provision of safe and suitable working environments	5
5	Establishment of appropriate legal framework for job security and social rights	4
6	Development of smart destination strategies and support for digital nomads' destinations	4
7	Development of secure technological solutions for data privacy and security	4
8	Regulations regarding job opportunities and social security	3
9	Technological infrastructure for digital nomads	2
Total		**50**

F: Frequency

Furthermore, Reichenberger (2018) suggests the need for flexibility in visa and accommodation arrangements for digital nomads, as they frequently travel and live in different geographical regions for short periods. This is directly related to the fact that digital nomads often travel between countries and work in various geographic regions. On the other hand, Aroles et al. (2023) emphasize the uncertainties digital nomads may face regarding job security and social benefits. Therefore, it is necessary to establish an appropriate legal framework for digital nomadism. The regulation of issues such as the protection of workers' rights, insurance, and social security is important for the sustainability of digital nomadism and the well-being of nomadic workers. Zhou et al. (2024) highlight the necessity of developing smart destination strategies that attract and support digital nomads. These strategies should provide solutions for the work, travel, social life, financial situation, and basic needs of digital nomads. Matsushita (2023) and Michaud et al. (2022) theorize that developing suitable coworking spaces and technological infrastructure for digital nomads is important. Digital nomads often balance work and travel, and they express the need for specific spaces for both activities. These spaces should have the infrastructure to allow digital nomads to work efficiently and conduct their business.

Digital nomads work by using different workspaces and technologies, benefiting from the advantages of the flexible work model. However, to ensure the successful sustainability of this work model, it is necessary to provide suitable working environments and strengthen technological infrastructure (Nash et al., 2021). Digital nomads prioritize data privacy and security; therefore, secure technological solutions need to be developed for them (Calzada, 2023; Bonneau et al., 2023). Especially after the COVID-19 pandemic, providing safe and suitable working environments that digital nomads can prefer has become crucial. Regulations for digital nomadism should focus on areas such as visa and accommodation flexibility, job security and social rights, smart destination strategies, coworking spaces, and technological infrastructure. These regulations can be important steps in improving the working and living conditions to attract digital nomads and ensuring the sustainability of this new work model for local people, companies local and central governments of the destinations. In this regard, the characteristics and needs of digital nomads reflect the changes and opportunities in the modern working world. Digital nomads can sustain their work in different geographical regions due to flexible working hours and spaces. However, these flexibilities require the establishment of certain regulations and infrastructure (Zhou et al., 2024).

The Theories Explaining the Phenomenon of Digital Nomadism (RQ7)

RQ7. Which theories have been used to explain the phenomenon of digital nomadism? Content analysis has been used to answer the question (Table 11). In the literature, the phenomenon of digital nomadism has been explained with the following theories in terms of causal relationships, emphasized factors, and situations: Social Theories of Risk, (Atanasova et al, 2024; Ehn et al., 2022; Klyagin et al., 2018), Lifestyle Mobilities Framework, (Mancinelli, 2020), Crime Pattern Theory (Miocevic, 2024), Realistic Group Conflict Theory (Miocevic, 2024), Marketing Theory (Schwarz, 2023), Modernity Theory, (Xiao and Lutz, 2024), Miller's Theory of Materiality (Schwarz et al., 2023), Neo-tribe theory (Zumbusch & Lalicic, 2020), Identity Theory (Marx et al., 2023), Stakeholder Theory (Hannonen et al., 2023), Individualization Theory (Kannisto, 2016),

Lifestyle Mobilities Framework (Cohen et al., 2015), Maslow's Hierarchy of Needs (Kaufman, 2023), Urban Theory (Jung & Buhr, 2022). The theories which were employed to explain the concept of digital nomadism and its interaction with other variables in previous publications are gathered and considered useful for the future researchers in grasping the basics of the mechanisms in the relevant theories.

Table 11. The theories explaining the phenomenon of digital nomadism

Rank	Theories	F
1	Identity Theory	4
2	Social Theories of Risk	3
3	Miller's Theory of Materiality	1
4	Urban Theory	1
5	Maslow's Hierarchy of Needs Theory	1
6	Lifestyle Mobilities Framework	1
7	Stakeholder Theory	1
8	Individualization Theories	1
9	Crime Pattern Theory	1
10	Realistic Group Conflict Theory	1
11	Marketing Theory	1
12	Neo-tribe Theory	1
13	Modernity Theory	1
Total		**18**

Literature Based Recommendations for Future Research (RQ8)

The Web of Science database was selected for this study due to several reasons: it stands out as the most updated, accurate, efficient, and reliable database for bibliometric analyses; it covers a wide variety of publication formats, including full-text articles, reviews, editorials, conference proceedings (both journal and book-based), abstracts, technical papers, and chronologies; it encompasses more than 90 million records, surpassing the 69 million records of Scopus; it offers a broader temporal coverage compared to Scopus; and it consistently yields results for the same query used with similar search parameters across time (Kaur, 2024; Yan & Zhiping, 2023; Wang et al., 2023; Tsai et al., 2023; Tan et al., 2024). Reviewing the findings from content analyses, the study proposes the following five research agendas to advance the literature on digital nomadism.

Table 12. Future research recommendations

Main theme	Sub-theme	F
Digital nomad lifestyle and sustainable tourism	Travel habits	5
	Environmental impacts	6
	Contributions to sustainable Tourism	7
Carbon footprint and digital nomadism	Carbon footprint	3
	Sustainable travel practices	5
Community dynamics and digital nomads	Social	8
	Economic impacts	4
The impact of digital nomadism	Local communities	3
	Economy	2
	Tourism	8
	Society	3
Total		**54**

This study combines the future recommendations taken mostly recommended from the previous studies as shown in below. Despite much research on board digital nomad, several areas merit additional work. Here are some research gaps that future researchers could address.

1. To comprehend the relationship between digital nomadism and sustainability, there is a need for a more comprehensive study on the travel habits of digital nomads, their environmental impacts, and their contributions to sustainable tourism.

2. Investigating the relationship between carbon footprint and digital nomadism, and exploring ways to mitigate the environmental impact of digital nomads through sustainable travel practices and remote work arrangements.
3. Research could be conducted on the dynamics of communities formed by digital nomads and their social and economic impacts.
4. Understanding the role of collaborative work at the local community level is of critical importance to better grasp the impact of digital nomads on the communities they inhabit. For instance, the utilization of shared workspaces, meetings, and café areas can have a significant influence on the contributions of digital nomads to the local economy and their integration into community life. However, issues such as socio-spatial segregation effects and the expansion of spaces related to these areas are still not fully understood. Therefore, future research should delve into how digital nomads play a role in local communities in more detail and provide further insights on this matter.
5. Future research focusing on the geo-economic characteristics of digital nomadism and its impact on destination choice is crucial for filling the knowledge gaps in this field. Specifically, understanding the factors that influence digital nomads' choice of destinations is vital for providing better service to the tourism industry and developing sustainable tourism policies. Such research can help us better understand the impact of digital nomadism on regional economies, the tourism industry, and societal structures.
6. Through the comprehensive review of literature, no singular theory was found that could adequately explain the phenomenon of digital nomadism on its own. Simultaneously, it became evident that the multifaceted phenomenon of digital nomadism eludes a singular theoretical explanation. We contend that there exists a notable gap resulting from the absence of a comprehensive perspective and the adoption of a narrow focus in these theories as they explore specific contexts of the digital nomad phenomenon.

Conclusion

This study contributes significantly to the field in several aspects. Initially, it scrutinizes the publication trends within this domain by analyzing annual publications, alongside contributions from publications, publishers, universities/ institutions, and countries. Secondly, it identifies pivotal studies and authors through the examination of citation and co-authorship networks. Thirdly, it delineates the intellectual landscape of this field by uncovering prevalent themes and intellectual structures via co-occurrence and co-citation analyses, aiding scholars in steering clear of stagnation and propelling the field forward. Fourthly, through the amalgamation of bibliometric analysis and systematic literature review, this study offers a comprehensive and impartial exploration of the literature under review. Finally, it outlines four prospective avenues for future research to steer scholarly inquiry in this realm. Consequently, our study provides a comprehensive overview of the research landscape concerning digital nomadism utilizing a bibliometric analysis and structured literature review.

Nevertheless, this study might be constrained by a certain methodological limitation, which could be addressed by future research. Future bibliometric studies may consider the inclusion of other databases, such as Scopus, EBSCO, or Google Scholar could provide more information for future analyses.

Recommendations

Authors of this study recommend future business researchers in digital nomad to examine the analyses and acquire guidance and insight into the topics they may focus on in their own studies and also find journals, countries and other authors that may be interested in their work.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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