JOURNAL OF ALGORITHM ASYNCHRONOUS (ALGRASY)
E-ISSN 3025-5015
Vol 2 issue 1 2024
page. 37-52

Mapping the Landscape: Bibliometric Analysis of Sustainable Applications in Artificial Intelligence and Machine Learning

Abdul Hannan[1], Rubel Amin[2*]

[1]*Principal officer, Bangladesh Commerce Bank LTD., Dhaka, Bangladesh*
[2]*School of Business, Woxsen University, Kamkole, Sadasivpet, Sangareddy District, Hyderabad, India*

*Correspondence author: *rubelamincu@gmail.com*

DOI: https://doi.org/10.61963/jaa.v2i1.119

INFO

Submitted: 12-12-2023,
Revised: 10-01-2024,
Accepted: 27-02-2024
Available Online: 05-03-2024

ABSTRACT

This study employs a comprehensive bibliometric approach to dissect the landscape of sustainable applications within the interdisciplinary realm of Artificial Intelligence and Machine Learning. Through systematic retrieval from major academic databases and rigorous analysis, we map out the current research landscape. Initial screening yielded 447 relevant articles, which underwent thorough bibliometric scrutiny, including citation, co-authorship, keyword, and co-citation analyses. Our screening criteria ensured the inclusion of 191 articles directly relevant to our study objectives. Notably, India and the United States emerged as leaders in research output, with India boasting the highest document count and citations, while the United States wielded significant citation impact despite fewer documents. Turkey stood out for its impactful research relative to document count, suggesting emerging influence. Furthermore, co-authorship and organization analyses unveiled intricate collaborative networks. Saudi Arabia exhibited strong collaborative ties, mirrored by Italy, while isolated entities like Uttaranchal Institute of Technology underscored limited collaboration despite research activity. A co-occurrence analysis of keywords highlighted central themes such as sustainability, AI/ML technologies, and their potential applications in addressing global challenges like climate change and smart city development. Finally, a detailed bibliographic coupling analysis illuminated the interconnectedness of seminal sources, emphasizing the varying degrees of citation frequency and collaborative influence within the research domain. Overall, our analysis provides a holistic view of the global research landscape in sustainable AI and ML applications, underscoring collaborative dynamics, key players, and avenues for future investigation.

Keywords**:** *Sustainable Applications, Artificial Intelligence, Machine Learning, Collaborative Patterns, Global Research Trends*

INTRODUCTION

The intersection of sustainability, artificial intelligence (AI), and machine learning (ML) stands at the forefront of contemporary research, reflecting a critical nexus between technological advancement and global environmental concerns (Sustainable Development Solutions Network, 2021). Statistics and reports underscore the urgency of addressing sustainability challenges through innovative approaches. According to the United Nations Environment Programme (UNEP), human activities continue to exert unprecedented pressure on the planet's ecosystems, driving biodiversity loss, climate change, and resource depletion (UNEP, 2019). In this context, harnessing the potential of AI and ML to foster sustainable practices has emerged as a pivotal strategy to mitigate environmental degradation and promote socio-economic development (Vinuesa et al., 2020).

A significant body of research has explored the application of AI and ML in various domains, ranging from healthcare and finance to transportation and agriculture (Glauner, Valtchev, & State, 2020). These technologies offer transformative capabilities, enabling data-driven decision-making, automation, and optimization of processes. Within the realm of sustainability, scholars and practitioners have investigated diverse avenues, including energy management, environmental monitoring, waste reduction, and conservation efforts (Rolnick et al., 2019). Existing studies have demonstrated the efficacy of AI and ML in addressing complex sustainability challenges, facilitating more efficient resource utilization, and enhancing resilience to environmental risks (Agrawal, Gans, & Goldfarb, 2018). However, despite notable progress, gaps persist in our understanding of the full potential and implications of integrating AI and ML into sustainable practices (Dwivedi et al., 2021).

This bibliometric analysis seeks to address these gaps and contribute to the burgeoning literature on sustainable applications of AI and ML. By systematically mapping the research landscape, identifying key trends, and evaluating knowledge gaps, this study aims to offer insights that can inform future research directions and policy interventions (Donthu et al., 2021). One of the primary motivations behind this research is to provide a comprehensive overview of existing scholarship, thereby facilitating a deeper understanding of the opportunities and challenges associated with harnessing AI and ML for sustainability (Müller, 2020). Furthermore, by highlighting areas where research efforts are lacking or insufficiently explored, this study aims to catalyze interdisciplinary collaboration and spur innovation in this burgeoning field (Gandomi & Haider, 2015). The overarching objective of this study is to conduct a bibliometric analysis of research publications related to sustainable applications of AI and ML. To achieve this goal, the following research questions will guide our inquiry:

What are the key thematic areas and trends in research on sustainable applications of AI and ML?

Which academic disciplines and geographic regions are most active in this field?

What are the main sources of scholarly publications, and how has the volume of research evolved over time?

What are the most cited papers and authors in this domain, and what insights can be gleaned from their contributions?

The remainder of this paper is structured as follows: Section 2 provides a review of the relevant literature, highlighting the theoretical foundations and conceptual frameworks that underpin research on sustainable AI and ML. Section 3 outlines the methodological approach adopted in this study, including data collection, processing, and analysis. Section 4 presents the findings of the bibliometric analysis, including key trends, thematic clusters, and citation patterns. Section 5 discusses the implications of these findings for theory, practice, and policy, while also identifying avenues for future research. Finally, Section 6 offers concluding remarks and outlines potential avenues for further inquiry.

LITERATURE REVIEW

AI and ML have garnered immense attention in recent years, revolutionizing various industries with their capabilities. AI refers to the development of computer systems capable of performing tasks that typically require human intelligence (Sarker, 2022). These tasks include understanding and responding to natural language, recognizing patterns and making decisions, learning and adapting from experience. AI aims to create machines that can mimic human cognitive abilities (Sajja et al., 2024). ML is a subset of AI that involves training algorithms on large datasets to make predictions or decisions without explicit programming (Rahmani et al., 2021). ML algorithms identify patterns in data and learn to make accurate predictions or take appropriate

actions. Common types of ML include, supervised learning (training on labeled data), unsupervised learning (training on unlabeled data), reinforcement learning (learning through trial and error). ML can be used in bibliometric analysis for topic modeling, citation network analysis, author profiling, trend prediction, automated literature review, and bias detection. Specific methods can be employed, depending on the research question and data (Taye, 2023). Sustainability is the practice of meeting present needs without compromising the ability of future generations to meet their own needs (Elsawy & Youssef, 2023). It encompasses three main pillars environmental sustainability (protecting the planet's resources), social sustainability (ensuring fairness and equity), economic sustainability (promoting long-term economic growth) (Hariram et al., 2023). Sustainability aims to create a balance between human activity and the natural environment for the benefit of all (Murzagalina et al., 2023). These technologies are foundational to the integration of intelligent systems into sustainable practices. AI enables machines to perceive, reason, learn, and act, while ML allows algorithms to learn from data and make predictions or decisions (Bibri et al., 2024). Amidst this technological advancement, the pursuit of sustainability has emerged as a critical global goal (Jiang et al., 2021). The intersection of AI/ML and sustainability presents a promising avenue for addressing environmental, social, and economic challenges. This literature review explores the evolving landscape of sustainable applications within AI and ML, as revealed by a bibliometric analysis (GeSI, 2020).

Sustainability, as a multidimensional concept, encompasses environmental conservation, social equity, and economic prosperity. Within the realm of AI and ML, researchers and practitioners are increasingly leveraging these technologies to develop innovative solutions that promote sustainability across various domains (van Wynsberghe, 2021). Our bibliometric analysis reveals a burgeoning research interest in this intersection, with a growing number of publications exploring the potential synergies between AI/ML and sustainability (Purvis et al., 2019).

One prominent area of research is sustainable energy management, where AI and ML techniques are employed to optimize energy consumption, enhance renewable energy integration, and mitigate environmental impacts (Aria & Cuccurullo, 2017). Studies have demonstrated the effectiveness of algorithms in optimizing energy distribution, predicting energy demand, and maximizing the efficiency of renewable energy systems. By harnessing AI/ML, stakeholders can achieve significant advancements in renewable energy adoption and contribute to the transition towards a low-carbon economy (Ahmad et al., 2020).

Additionally, AI and ML are playing a pivotal role in environmental monitoring and conservation efforts. Remote sensing technologies coupled with machine learning algorithms enable the analysis of vast amounts of geospatial data to track deforestation, monitor biodiversity, and assess ecosystem health (Benedetti et al., 2021). These insights empower policymakers and conservationists to make informed decisions and implement targeted interventions for preserving natural habitats and mitigating ecological degradation (Chen et al., 2021).

Moreover, AI-driven innovations are reshaping transportation systems to enhance sustainability and reduce carbon emissions. Intelligent transportation systems leverage ML algorithms to optimize traffic flow, predict congestion patterns, and facilitate the adoption of alternative transportation modes (Esteva et al., 2019). By optimizing routing algorithms and promoting shared mobility solutions, AI/ML contribute to reducing fuel consumption, alleviating traffic congestion, and improving air quality in urban areas (Mikalef et al., 2021).

In the realm of healthcare, AI and ML hold promise for advancing sustainable healthcare delivery systems. Predictive analytics and machine learning algorithms enable early disease detection, personalized treatment recommendations, and healthcare resource optimization (Nadella et al., 2023). By leveraging patient data and clinical insights, AI-driven healthcare solutions have the potential to improve patient outcomes, enhance healthcare accessibility, and optimize resource allocation, thereby contributing to the sustainability of healthcare systems (Ahmed et al., 2020).

The literature reviewed highlights the growing significance of sustainable applications within the domains of artificial intelligence and machine learning (Kar et al., 2022). By harnessing the power

of AI/ML, stakeholders across various sectors can address complex sustainability challenges and pave the way towards a more resilient and equitable future. As research in this area continues to evolve, interdisciplinary collaboration and innovation will be essential for realizing the full potential of AI/ML in advancing sustainability goals (Srivastava & Maity, 2023).

METHODS

This study employs a bibliometric approach to conduct a comprehensive analysis of the sustainable applications within the realm of AI and ML (Singh et al., 2024). The aim is to map out the current landscape of research in this interdisciplinary domain. The initial step involved the systematic retrieval of relevant scholarly articles from major academic databases (Bracarense et al., 2022). The search strategy was formulated to include articles that specifically addressed the intersection of sustainability, AI, and ML. The search terms used were “Sustainable,” “AI,” and “ML,” combined using Boolean operators. This resulted in an initial pool of 447 articles. The retained articles underwent rigorous bibliometric analysis, including citation analysis, co-authorship analysis, keyword analysis, and co-citation analysis. Various bibliometric indicators were employed to assess the impact, productivity, and collaboration patterns within the field of sustainable AI and ML applications.

Screening Criteria

To ensure the relevance and quality of the retrieved articles, a multi-step screening process was implemented. Articles were screened based on whether they contained all three search terms (Sustainable, AI, and ML), resulting in the acceptance of 447 articles. Articles were further filtered based on their subject areas to focus exclusively on disciplines pertinent to the study, such as "Business, Management and Accounting," "Psychology," "Arts and Humanities," "Economics," "Econometrics and Finance," "Social Sciences," and "Multidisciplinary." This step resulted in the retention of 447 articles. Articles with missing author information or affiliation were excluded, resulting in the removal of 7 articles. Only articles classified as “Article,” “Conference Paper,” “Book Chapter,” or “Review” were retained, leading to the exclusion of 18 articles. Articles without indexed keywords were excluded, resulting in the removal of 98 articles. Only articles in their final publication stage were considered, leading to the removal of 11 articles. Articles lacking author-provided keywords were excluded, leading to the removal of 53 articles. Only articles published in English were retained, leading to the exclusion of 2 articles. Articles without a Digital Object Identifier (DOI) were excluded, resulting in the removal of 12 articles. Articles were further screened to ensure they were directly related to the scope of the study, resulting in the acceptance of 191 articles.

Table 1. Search Criteria and Selection of Articles

Screening Criteria	Reject	Accept
Search Term (“Sustainable” AND “AI” AND “ML”)		447
Subject Area (“Business, Management and Accounting,” “Psychology,” Arts and Humanities,” “Economics,” “Econometrics and Finance,” “Social Sciences” and “Multidisciplinary”)	0	447
Missing authors	5	442
Missing Affiliation	2	440
Document Type (“Article,” “Conference Paper,” “Book Chapter, “And “Review”)	18	
Missing indexed keywords	98	
Publication Stage (Final)	11	
Missing authors keywords	53	
Language Screening (English)	2	

Missing doi	12	
Missing publisher	2	
Content Screening (Include articles related to the scope of the study)	53	191
Total Articles for the review		**191**

Source – Author's Calculations from Scopus Database.

RESULTS & DISCUSSION

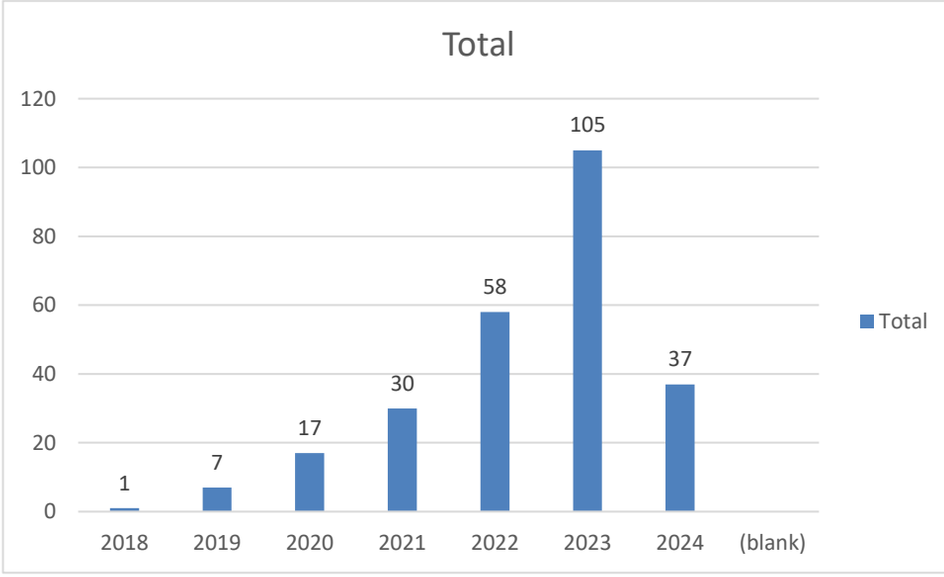
This section of the results delves into the research questions delineated within the document. It investigates trends in publication, recognizes primary authors boasting the most significant citation numbers, scrutinizes citation allocation across different countries, accentuates noteworthy journals within the Sustainable Applications in Artificial Intelligence and Machine Learning and assesses their influence on managerial methodologies (Szabó et al., 2024).

It delves into the publication landscape, pinpointing key figures in academic discourse and tracing the dissemination of scholarly contributions across global borders (Begum & Shaik, 2024). Spotlighting prevalent journals illuminates the platforms driving scholarly dialogue and knowledge dissemination within the Sustainable Applications in Artificial Intelligence and Machine Learning (Bahroun et al., 2023). Furthermore, it scrutinizes the impact of these scholarly works on practical management approaches, shedding light on integrating academic insights into real-world decision-making processes (Casazza & Gioppo, 2020). This segment encapsulates a comprehensive examination of research trends, authorship dynamics, citation distributions, and scholarly impacts, offering insights into the evolving landscape of Sustainable Applications in Artificial Intelligence and Machine Learning and their implications for managerial practices on a global scale (Sahran et al., 2022).

Sequential Publishing Trend

The bar graph showing the number of articles published on sustainable applications of AI and ML over a specific time period (likely years). The graph suggests a growing interest in research on sustainable applications of AI and ML. The number of published articles appears to be increasing over time. This indicates that researchers are recognizing the potential of these technologies to address sustainability challenges.

Figure 1. Publication Activity of Sustainable Applications in Artificial Intelligence and Machine Learning (Source: Author's Calculations from Scopus Database).



Co-authorship analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of authors

This data seems to represent a co-authorship analysis of research publications in the field of Sustainable Applications in AI and ML in table 2 (Maghsoudi et al., 2023). Each row represents a group of authors who have collaborated on a document related to this field, along with the number of documents they have co-authored and the total citations their work has received (Mitrović et al., 2023). The analysis reveals the collaborative networks within the research community focusing on sustainable applications of AI and ML. It's evident that there are various groups of authors with different levels of collaboration and impact. Authors like Xu Y., Liu X., Cao X., and others appear frequently in co-authorships, indicating a strong collaborative network among them. These groups have published multiple documents together and have received significant citations, suggesting the importance and impact of their work in the field. The analysis shows a diverse range of collaborative groups, with different sets of authors working together on various documents. This diversity reflects the interdisciplinary nature of research in sustainable AI and ML applications, involving experts from multiple domains. While some groups have a high number of citations, others have relatively fewer citations. This could be due to differences in the novelty, significance, or visibility of their research outputs. There are also authors who have authored documents individually or in smaller groups. These individual contributions are essential for bringing diverse perspectives and ideas to the field. Some groups have fewer documents and citations, indicating emerging collaborations or newer entrants into the field. These collaborations may evolve and grow in significance over time. Overall, the analysis provides insights into the collaborative dynamics and impact distribution within the research community focused on sustainable applications of AI and ML, highlighting key players, collaborative patterns, and potential areas for further investigation.

Table 2- Co-authorship analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of authors

Author	Documents	Citations
xu y.; liu x.; cao x.; huang c.; liu e.; qian s.; liu x.; wu y.; dong f.; qiu c.-w.; qiu j.; hua k.; su w.; wu j.; xu h.; han y.; fu c.; yin z.; liu m.; roepman r.; dietmann s.; virta m.; kengara f.; zhang z.; zhang l.; zhao t.; dai j.; yang j.; lan l.; luo m.; liu z.; an t.; zhang b.; he x.; cong s.; liu x.; zhang w.; lewis j.p.; tiedje j.m.; wang q.; an z.; wang f.; zhang l.; huang t.; lu c.; cai z.; wang f.; zhang j.	1	311
cioffi r.; travaglioni m.; piscitelli g.; petrillo a.; de felice f.	1	289
çinar z.m.; nuhu a.a.; zeeshan q.; korhan o.; asmael m.; safaei b.	1	278
javaid m.; haleem a.; singh r.p.; suman r.; gonzalez e.s.	1	174
said mohamed e.; belal a.a.; kotb abd-elmabod s.; el-shirbeny m.a.; gad a.; zahran m.b.	1	148
zahmatkesh h.; al-turjman f.	1	125
mehmood m.u.; chun d.; zeeshan; han h.; jeon g.; chen k.	1	121
waberski d.; riesenbeck a.; schulze m.; weitze k.f.; johnson l.	1	116
alanne k.; sierla s.	1	106
uusitalo m.a.; rugeland p.; boldi m.r.; strinati e.c.; demestichas p.; ericson m.; fettweis g.p.; filippou m.c.; gati a.; hamon m.-h.; hoffmann m.; latva-aho m.; parssinen a.; richerzhagen b.; schotten h.; svensson t.; wikstrom g.; wymeersch h.; ziegler v.; zou y.	1	90

heidari a.; navimipour n.j.; unal m.	1	87
solyali d.	1	71
tamburri d.a.	1	62
singh r.; akram s.v.; gehlot a.; buddhi d.; priyadarshi n.; twala b.	1	56
wongchai a.; shukla s.k.; ahmed m.a.; sakthi u.; jagdish m.; kumar r.	1	52
bijjahalli s.; sabatini r.; gardi a.	1	48

Co-authorship analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of organizations

This table seems to be presenting a co-authorship analysis of organizations involved in research related to Sustainable Applications in AI and ML in table3(Maghsoudi et al., 2023). Uttaranchal Institute of Technology, Uttaranchal University, Dehradun, India: This organization has produced 2 documents with a total of 61 citations, but there are no connections (total link strength of 0) with other organizations in this analysis. This could suggest that while they are active in research, they may not be collaborating extensively with other institutions in this specific field. Institute of Engineering, Hutech University, Ho Chi Minh City, Vietnam and Patet Research Group, Ho Chi Minh City University of Transport, Ho Chi Minh City, Vietnam: Both these organizations have produced 2 documents each with 32 citations, and they share a total link strength of 2, indicating some level of collaboration between them. Department of Mechanical Engineering, Jamia Millia Islamia, New Delhi, India: Similarly to the first entry, this organization has produced 2 documents with 28 citations but has no connections with other organizations in this analysis. AI and IoT, Hanumayamma Innovations and Technologies Pvt Limited, Hyderabad, India and Computer Engineering, San Jose State University, San Jose, United States: These two organizations also produced 2 documents each with 19 citations, and they share a total link strength of 2, suggesting some collaboration between them. Department of Civil Engineering, College of Engineering, Najran University, Najran, Saudi Arabia: This organization stands out with 3 documents, 14 citations, and a relatively high total link strength of 6, indicating strong collaboration with other institutions in this analysis. Department of Transport Systems, Traffic Engineering and Logistics, Faculty of Transport and Aviation Engineering, Silesian University of Technology, Katowice, Poland: This organization has 2 documents with 14 citations and a total link strength of 4, indicating significant collaboration with other institutions. Department of Civil and Environmental Engineering, College of Engineering, King Faisal University, Al-Ahsa, Saudi Arabia and School of Civil Engineering, Universiti Teknologi Malaysia, Johor, Johor Bahru, Malaysia: Both these organizations produced 2 documents each with 9 citations, and they share a total link strength of 5, suggesting a moderate level of collaboration between them. SLAC National Laboratory, Menlo Park, CA, United States and Stanford University, Materials Science and Engineering, CA, United States: These two organizations have produced 2 documents each with 5 citations, and they share a total link strength of 2, indicating some collaboration between them. Overall, this analysis provides insights into the collaborative networks between organizations conducting research in Sustainable Applications in AI and ML, highlighting clusters of strong collaboration as well as isolated entities.

Table 3- Co-authorship analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of organizations

Organization	Documents	Citations	Total Link Strength
uttaranchal institute of technology, uttaranchal university, dehradun, 248007, india	2	61	0
institute of engineering, hutech university, ho chi minh city, viet nam	2	32	2

patet research group, ho chi minh city university of transport, ho chi minh city, viet nam	2	32	2
department of mechanical engineering, jamia millia islamia, new delhi, india	2	28	0
ai and iot, hanumayamma innovations and technologies pvt limited, hyderabad, india	2	19	2
computer engineering, san jose state university, san jose, united states	2	19	2
department of civil engineering, college of engineering, najran university, najran, saudi arabia	3	14	6
department of transport systems, traffic engineering and logistics, faculty of transport and aviation engineering, silesian university of technology, krasińskiego 8 street, katowice, 40-019, poland	2	14	4
department of civil and environmental engineering, college of engineering, king faisal university, al-ahsa, 31982, saudi arabia	2	9	5
school of civil engineering, universiti teknologi malaysia, johor, johor bahru, 81310, malaysia	2	9	5
slac national laboratory, menlo park, ca, united states	2	5	2
stanford university, materials science and engineering, ca, united states	2	5	2

Co-authorship analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of countries

Based on the provided co-authorship analysis of sustainable applications in artificial intelligence and machine learning across different countries, several observations can be made in table 4 (Pandey et al., 2023). Leadership of India and the United States: India and the United States emerge as the leading contributors in terms of the number of documents produced. India has produced the highest number of documents (76), while the United States follows closely behind with 43 documents. This indicates a significant level of research activity and interest in sustainable applications of AI and ML within these countries. Citation Impact: Despite producing fewer documents, the United States has a notably higher citation count (789) compared to India (613), indicating the impact and influence of American research in this field. This suggests that research originating from the United States is highly regarded and influential in shaping the discourse on sustainable applications of AI and ML. Turkey's Impact Relative to Document Count: Turkey stands out with a relatively high citation count (569) compared to its number of documents (10). This suggests that despite producing fewer documents, Turkish research in this area is impactful and influential. Link Strength and Collaboration: Link strength represents the strength of collaboration between countries in producing research. Saudi Arabia stands out with the highest link strength (25), indicating strong collaborative ties with other countries in producing research on sustainable AI and ML applications. Italy also demonstrates high link strength (20), suggesting active collaboration with other countries in this field. Research Output versus Impact: While some countries like Germany and Australia have produced a moderate number of documents, their citation counts are relatively low. This may indicate that while they are active in research, their contributions may not be as impactful or influential in the field compared to countries with higher citation counts. Emerging Players: Countries like China and Pakistan are also actively contributing to research in sustainable AI and ML applications, with moderate numbers of documents and

citation counts. This suggests a growing interest and involvement from these regions in advancing research in this field.

Overall, the analysis highlights the global interest and collaboration in researching sustainable applications of artificial intelligence and machine learning, with certain countries emerging as leaders and others showing potential for further growth and impact.

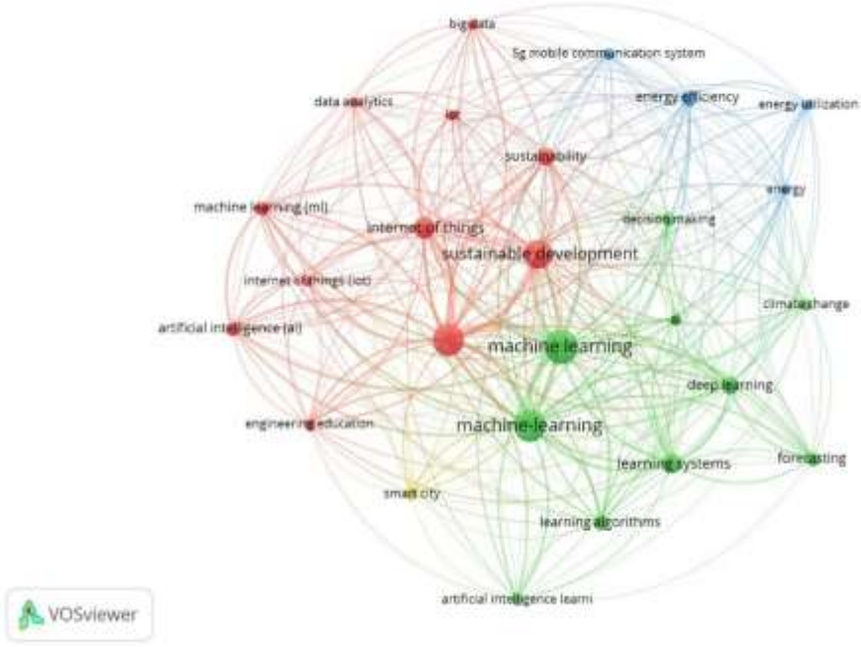
Table 4- Co-authorship analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of countries

Country	Documents	Citations	Total Link Strength
United States	43	789	18
India	76	613	29
Turkey	10	569	4
Italy	17	475	20
China	18	461	22
United Kingdom	14	373	17
Germany	20	257	20
Pakistan	14	106	15
Australia	10	92	11
Saudi Arabia	16	90	25
Spain	13	22	15

Co-occurrence analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of all keywords

Based on the figure, it appears to be a visualization of a co-occurrence analysis for keywords related to sustainable applications in AI and ML in figure 2 (Espina-Romero et al., 2023). Here's an interpretation of the connections. Central Keywords like Sustainable Development: This is the central concept around which other keywords co-occur. Sustainability-related keywords like Energy Efficiency/Utilization: These terms link AI/ML to potential solutions for reducing energy consumption and optimizing resource use. Climate Change: This suggests AI/ML could be used to mitigate climate change through solutions for renewable energy, carbon capture, or climate modeling. AI/ML Technology keywords like Machine Learning (ML): This is a core technology for developing AI applications for sustainability. Deep Learning: This is a specialized type of ML used in complex AI applications, potentially applied to tasks like environmental monitoring or climate data analysis. Learning Algorithms: These are the underlying mathematical models that enable AI/ML to learn from data. Other keywords like Big Data: Large datasets are crucial for training AI/ML models to tackle sustainability challenges. 5G Mobile Communication System: This high-speed mobile network might support the transfer of large datasets and facilitate real-time AI applications for sustainability. Internet of Things (IoT): This network of interconnected devices could generate data for AI/ML models to analyze and optimize various sustainability initiatives. Decision Making: AI/ML can potentially improve decision-making processes related to sustainability efforts. Smart City: This suggests AI/ML could be used to optimize resource management and infrastructure in urban environments. Interpretation: The co-occurrence analysis highlights the potential of AI and Machine Learning technologies to address sustainability challenges. Machine learning algorithms, especially deep learning, can analyze big data from various sources (IoT devices, sensor networks) to develop solutions for energy efficiency, climate change mitigation, and smart city development.

Figure-2. Co-occurrence analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of all keywords



Bibliographic coupling analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of sources

Bibliographic coupling analysis delves into the web of connections among documents through shared citations in table 5 (Nwagwu, 2024). In exploring Sustainable Applications in Artificial Intelligence and Machine Learning, we scrutinize the interrelations among pertinent sources. Sustainability (Switzerland) emerges as a pivotal hub, widely referenced across 12 documents with a staggering 709 citations. However, its total link strength, though significant in citation count, doesn't deeply tether it to other sources, hinting at a breadth over depth phenomenon. Sustainable Cities and Society, despite garnering 355 citations across 4 documents, lacks substantial interconnections, potentially indicating a peripheral influence within the discourse. IEEE Access occupies a notable position, balancing moderate citations with a robust link strength of 6, indicative of both frequent referencing and substantive ties with other sources, solidifying its centrality in the domain. Sensors, with 62 citations distributed across 4 documents, exhibits limited connections, suggesting a more isolated impact despite its mention. Energies, although with fewer citations, demonstrates moderate link strength, suggesting a meaningful level of interconnectedness with other sources. Journal of Cleaner Production mirrors Energies in its citation-to-link strength dynamic, presenting a modest but notable presence within the network. Communications in Computer and Information Science, while lacking in citation count, showcases a commendable link strength, potentially implying a concentrated influence despite fewer citations. Advances in Intelligent Systems and Computing, with a modest citation count, doesn't seem to forge strong interconnections with other sources, suggesting a standalone significance. Expert Systems with Applications, despite low citations, displays some degree of interconnectedness, hinting at a nuanced influence within the network. Lecture Notes in Computer Science, despite citations, appears disconnected from other sources, indicating a potential need for deeper integration into the discourse. Lecture Notes in Networks and Systems, with minimal citations and link strength, suggests a peripheral position within the landscape. This bibliographic coupling analysis unveils the complex tapestry of sources in Sustainable Applications in Artificial Intelligence and Machine Learning, shedding light on their varying degrees of citation frequency and interconnection.

Table 5. bibliographic coupling analysis of Sustainable Applications in Artificial Intelligence and Machine Learning of sources

Source	Documents	Citations	Total Link Strength
Sustainability (Switzerland)	12	709	3
Sustainable Cities And Society	4	355	0
Ieee Access	11	189	6
Sensors	4	62	1
Energies	5	31	2
Journal Of Cleaner Production	3	20	1
Communications In Computer And Information Science	6	14	2
Advances In Intelligent Systems And Computing	4	10	0
Expert Systems With Applications	3	8	1
Lecture Notes In Computer Science (Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	3	5	0
Lecture Notes In Networks And Systems	6	2	0

Bibliographic Coupling Analysis of Sustainable Applications in Artificial Intelligence and Machine Learning among the nations

Bibliographic coupling analysis offers a nuanced lens into the intricate web of connections within research domains, such as Sustainable Applications in AI/ML, across diverse geographical landscapes in table 6 (Bibri et al., 2024). India emerges as a frontrunner, boasting the highest document count (76) and citations (613), signifying its robust involvement and impact in this field. The substantial total link strength (3099) underscores a cohesive collaborative ethos within India's AI/ML research community. The United States, despite fewer documents, commands significant influence with a high citation count (789) and a strong total link strength (1629), underscoring its pivotal role in shaping global discourse in sustainable AI/ML applications. China parallels the US, showcasing a formidable presence with substantial citations (461) and a noteworthy total link strength (2502), echoing its ascent as a technological powerhouse. Italy, while trailing India in documents and citations, showcases commendable collaboration (total link strength: 1710) within its AI/ML research circles. Saudi Arabia stands out with a remarkable total link strength (2570), indicative of concerted collaborative endeavors despite moderate document and citation counts.

Other countries like Turkey, the United Kingdom, Germany, Pakistan, Australia, and Spain display diverse engagement levels, with varying document counts, citations, and total link strengths, echoing the global tapestry of sustainable AI/ML research. This analysis underscores the collaborative tapestry underpinning global research in sustainable AI/ML applications, showcasing the diverse contributions and interdependencies among nations in advancing scientific inquiry.

Table 6- Bibliographic Coupling Analysis of Sustainable Applications in Artificial Intelligence and Machine Learning among the nations

Country	Documents	Citations	Total Link Strength
United States	43	789	1629
India	76	613	3099
Turkey	10	569	418
Italy	17	475	1710
China	18	461	2502
United Kingdom	14	373	1789
Germany	20	257	1388
Pakistan	14	106	1709
Australia	10	92	1107

Saudi Arabia	16	90	2570
Spain	13	22	1263

Findings and Discussion

The provided co-authorship analysis of research publications in Sustainable Applications in AI and ML illuminates several critical findings and prompts discussions on collaborative networks, impact distribution, and emerging trends in the field. The analysis unveils a diverse array of collaborative networks among authors and organizations, showcasing varying levels of collaboration and impact. Notably, authors like Xu Y., Liu X., and Cao X. emerge as central figures in collaborative networks, spearheading impactful research endeavors. India and the United States emerge as frontrunners in research output, with India leading in document count and the United States in citation count. This highlights the significant research activity and influence within these countries, underscoring their leadership roles in the field. Despite variations in document count, citation counts offer insights into the impact and influence of research outputs. The United States' higher citation count compared to India suggests the influential nature of American research, shaping global discourse in sustainable AI/ML applications. Countries like Turkey demonstrate impactful research despite producing fewer documents, indicating potential for growth and influence in the field. Similarly, emerging players like China and Pakistan showcase increasing involvement, signifying a shifting landscape of research contributors. Strong collaborative ties, as observed in Saudi Arabia's high link strength, underscore the importance of collaborative endeavors in advancing research. Italy also demonstrates active collaboration, reflecting the interconnected nature of global research efforts in sustainable AI/ML applications. The analysis highlights the interdisciplinary nature of research in sustainable AI/ML applications, involving experts from diverse domains. This interdisciplinary approach fosters innovation and comprehensive solutions to complex challenges in the field. The findings prompt further investigation into emerging collaborative networks, impactful research outputs from diverse regions, and the integration of interdisciplinary perspectives. Future research endeavors can build upon these insights to foster global collaboration and drive advancements in sustainable AI/ML applications.

Limitations

Bibliometric analysis, while powerful, has limitations. Data quality, citation metrics, keyword selection, and country-level analysis can be biased. To mitigate these, researchers should use diverse databases, consider alternative metrics, employ text mining, combine with qualitative methods, and acknowledge limitations. The analysis is contingent upon the availability and accuracy of the data, which may not fully capture the entire landscape of research in sustainable AI/ML applications. Missing or incomplete data could skew the interpretation of collaborative networks and impact distributions. The analysis primarily focuses on co-authorship and citation metrics, neglecting other dimensions such as the quality of research, funding sources, and institutional affiliations, which could provide a more comprehensive understanding of research dynamics. The analysis might not capture the temporal evolution of collaborative networks and impact distributions over time. Trends in research collaboration and citation patterns could change, rendering the analysis outdated or incomplete. The analysis predominantly highlights contributions from certain countries, potentially overlooking valuable insights from underrepresented regions. This bias could distort perceptions of global research collaboration in sustainable AI/ML applications. While the analysis acknowledges the interdisciplinary nature of research in sustainable AI/ML applications, it may not fully capture the breadth of interdisciplinary collaborations and their impact on research outcomes.

Future Research Directions

Incorporating qualitative methodologies such as interviews or surveys could provide deeper insights into the motivations and challenges of research collaboration in sustainable AI/ML applications. Conducting longitudinal studies to track changes in collaborative networks and

impact distributions over time would offer a more dynamic perspective on research trends and emerging patterns. Integrating diverse data sources beyond co-authorship and citations, such as patents, grants, and social network analysis, could enrich our understanding of research dynamics in sustainable AI/ML applications. Exploring regional differences in research collaboration and impact distributions could uncover unique challenges and opportunities for fostering international collaboration and knowledge exchange. Employing advanced network analysis techniques, such as community detection and centrality measures, could reveal hidden structures and key players within collaborative networks in sustainable AI/ML applications.

CONCLUSION

In summary, the co-authorship and bibliographic coupling analyses provide valuable insights into the collaborative networks and research dynamics within the field of Sustainable Applications in AI/ML across different countries. India and the United States emerge as key contributors, with India leading in document count and the United States demonstrating significant citation impact. This reflects the substantial research activity and influence within these countries. China also plays a notable role, showcasing a strong presence and collaborative network, reflecting its growing significance in technological research. Countries like Turkey exhibit impactful research despite fewer documents, indicating the potential for further growth and influence in the field. Collaboration strength, as indicated by total link strength, highlights the interconnectedness and collaborative efforts among countries, with Saudi Arabia particularly standing out in this regard. Furthermore, the analyses reveal the interdisciplinary nature of research in sustainable AI/ML applications, involving experts from various domains. This diversity underscores the complexity of addressing sustainability challenges through AI and ML technologies. Overall, these insights provide a comprehensive understanding of the global landscape of research in sustainable AI/ML applications, emphasizing collaborative efforts, key players, and potential areas for future exploration and collaboration.

Acknowledgements

We would like to express our gratitude to friends, colleagues and professors. Special thanks to Woxsen University for its invaluable support and guidance throughout this study.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data Availability

The data used in this study are available upon reasonable request from the corresponding author.

REFERENCES

Agrawal, A., Gans, J., & Goldfarb, A. (2018). Prediction Machines: The Simple Economics of Artificial Intelligence. Harvard Business Review Press.

Ahmad, T., Zhang, D., Huang, C., Zhang, H., Dai, N., Song, Y., & Chen, H. (2020). Artificial intelligence in sustainable energy industry: Status quo, challenges, and opportunities. Journal of Cleaner Production, *289, 125834.* *https://doi.org/10.1016/j.jclepro.2020.125834*

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, *11(4), 959-975.* *https://doi.org/10.1016/j.joi.2017.08.007*

Ahmed, Zeeshan, et al. "Artificial intelligence with multi-functional machine learning platform development for better healthcare and precision medicine." *Database 2020 (2020):*

baaa010.

Alimi, A. E., Buraimoh, O. F., Aladesusi, G. A., & Babalola, E. O. (2021). University students' awareness of, access to, and use of artificial intelligence for learning in Kwara State. Indonesian Journal of Teaching in Science, 1(2), 91-104.

Benedetti, L., Giuliani, M., Mason, E., & Castelletti, A. (2021). A machine learning framework for assessing environmental monitoring networks: A case study for the Po River. Environmental Modelling & Software, *141, 105048.* *https://doi.org/10.1016/j.envsoft.2021.105048*

Bracarense, N., Bawack, R. E., Fosso Wamba, S., & Carillo, K. D. A. (2022). Artificial intelligence and sustainability: A bibliometric analysis and future research directions. Pacific Asia Journal of the Association for Information Systems, *14(2), 9.*

Begum N, A., & Shaik, S. (2024). Mapping the landscape: a bibliometric review of mergers and acquisitions through the lens of sustainability. Competitiveness Review: An International Business Journal.

Bahroun, Z., Anane, C., Ahmed, V., & Zacca, A. (2023). Transforming education: A comprehensive review of generative artificial intelligence in educational settings through bibliometric and content analysis. Sustainability, *15(17), 12983.*

Bibri, S. E., Huang, J., Jagatheesaperumal, S. K., & Krogstie, J. (2024). The synergistic interplay of artificial intelligence and digital twin in environmentally planning sustainable smart cities: a comprehensive systematic review. Environmental Science and Ecotechnology, *100433.*

Bibri, S. E., Krogstie, J., Kaboli, A., & Alahi, A. (2024). Smarter eco-cities and their leading-edge artificial intelligence of things solutions for environmental sustainability: A comprehensive systematic review. Environmental Science and Ecotechnology, 19, 100330. https://doi.org/10.1016/j.ese.2023.100330

Chen, Y., Zhang, X., Yang, W., Wu, W., & Shi, X. (2021). Applications of artificial intelligence in transportation and logistics. Journal of Traffic and Transportation Engineering (English Edition), *8(3), 393-408. https://doi.org/10.1016/j.jtte.2020.08.003*

Casazza, M., & Gioppo, L. (2020). A playwriting technique to engage on a shared reflective enquiry about the social sustainability of robotization and artificial intelligence. Journal of Cleaner Production, *248, 119201*.

Donthu, N., Kumar, S., Pattnaik, D., & Lim, W. M. (2021). A bibliometric retrospection of marketing from the lens of psychology: Insights from Psychology & Marketing. *Psychology & Marketing, 38(10), 1761-1787. https://doi.org/10.1002/mar.21543*

Dwivedi, Y. K., Hughes, D. L., Ismagilova, E., Aarts, G., Coombs, C., Crick, T., ... & Williams, M. D. (2021). Artificial Intelligence (AI): Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice, and policy. *International Journal of Information Management, 57, 101994. https://doi.org/10.1016/j.ijinfomgt.2019.08.002*

Elsawy, M., & Youssef, M. (2023). Economic sustainability: Meeting needs without compromising future generations. International Journal of Economics and Finance, 15(10), 1-23. https://doi.org/10.5539/ijef.v15n10p23

Esteva, A., Robicquet, A., Ramsundar, B., Kuleshov, V., DePristo, M., Chou, K., ... & Dean, J. (2019). A guide to deep learning in healthcare. Nature Medicine, *25(1), 24-29. https://doi.org/10.1038/s41591-018-0316-z*

Espina-Romero, L., Noroño Sánchez, J. G., Gutiérrez Hurtado, H., Dworaczek Conde, H., Solier Castro, Y., Cervera Cajo, L. E., & Rio Corredoira, J. (2023). Which industrial sectors are

affected by artificial intelligence? A bibliometric analysis of trends and Perspectives. Sustainability, *15(16), 12176.*

Ezinwa, C. A., Agbo, B. O., & Ozojukwu, C. G. (2024). Analysis of Knowledge and Use of Artificial Intelligence Among Bloggers in Enugu State. International Journal of Non-Governmental Organizations (NGOs) and Essays, 8(1), 1-26. doi: https://doi.org/10.37745/ijngoe.16/vol8n1126

Gandomi, A., & Haider, M. (2015). Beyond the hype: Big data concepts, methods, and analytics. *International Journal of Information Management, 35(2), 137-144. https://doi.org/10.1016/j.ijinfomgt.2014.10.007*

Global e-Sustainability Initiative (GeSI). (2020). Digital with Purpose: Delivering a SMARTer 2030. GeSI Report. *https://doi.org/10.13140/RG.2.2.24271.87205*

Glauner, P., Valtchev, P., & State, R. (2020). AI for the Common Good. *Springer*.

Hariram, N. P., Mekha, K. B., Suganthan, V., & Sudhakar, K. (2023). Sustainalism: An integrated socio-economic-environmental model to address sustainable development and sustainability. Sustainability, 15(13), 10682. https://doi.org/10.3390/su151310682

Jiang, F., Jiang, Y., Zhi, H., Dong, Y., Li, H., Ma, S., & Wang, Y. (2021). Artificial intelligence in healthcare: Past, present and future. Stroke and Vascular Neurology, *6(2), 145-153. https://doi.org/10.1136/svn-2020-000725*

Kar, A. K., Choudhary, S. K., & Singh, V. K. (2022). How can artificial intelligence impact sustainability: A systematic literature review. Journal of Cleaner Production, *376, 134120.*

Müller, V. C. (2020). Ethics of artificial intelligence and robotics. In *The Stanford Encyclopedia of Philosophy* (Fall 2020 Edition), Edward N. Zalta (ed.).

Mikalef, P., van de Wetering, R., & Krogstie, J. (2021). Building dynamic capabilities for digital transformation: An ongoing process of strategic renewal. Journal of Business Research, *128, 462-478. https://doi.org/10.1016/j.jbusres.2021.03.037*

Mitrović, I., Mišić, M., & Protić, J. (2023). Exploring high scientific productivity in international co-authorship of a small developing country based on collaboration patterns. Journal of big Data, *10(1), 64.*

Maghsoudi, M., Shokouhyar, S., Ataei, A., Ahmadi, S., & Shokoohyar, S. (2023). Co-authorship network analysis of AI applications in sustainable supply chains: Key players and themes. Journal of cleaner production, *422, 138472.*

Murzagalina, G. M., Surpkelova, A., Prodanova, N. A., Chernobrovkin, A. A., & Pizhurin, A. A. (2023). Balanced interaction of the environment and the economy: The role of sustainable development in ensuring environmental and economic benefits. Caspian Journal of Environmental Sciences, 1-6. https://doi.org/10.22124/CJES.2023.7201

Nadella, G. S., Satish, S., Meduri, K., & Meduri, S. S. (2023). A Systematic Literature Review of Advancements, Challenges and Future Directions of AI And ML in Healthcare. International Journal of Machine Learning for Sustainable Development, *5(3), 115-130.*

Nwagwu, W. E. (2024). Bibliographic coupling networks of global research on data literacy by documents, sources and authors. Journal of Librarianship and Information Science, *09610006241252655.*

Purvis, B., Mao, Y., & Robinson, D. (2019). Three pillars of sustainability: In search of conceptual origins. Sustainability Science, 14(3), 681-695. *https://doi.org/10.1007/s11625-018-0627-5*

Pandey, D. K., Hunjra, A. I., Bhaskar, R., & Al-Faryan, M. A. S. (2023). Artificial intelligence,

machine learning and big data in natural resources management: a comprehensive bibliometric review of literature spanning 1975–2022. Resources Policy, *86, 104250.*

Rahmani, A. M., Yousefpoor, E., Yousefpoor, M. S., Mehmood, Z., Haider, A., Hosseinzadeh, M., & Ali Naqvi, R. (2021). Machine learning (ML) in medicine: Review, applications, and challenges. Mathematics, 9(22), 2970. https://doi.org/10.3390/math9222970

Rolnick, D., Donti, P. L., Kaack, L. H., Kochanski, K., Lacoste, A., Sankaran, K., ... & Bengio, Y. (2019). Tackling climate change with machine learning. arXiv preprint arXiv:1906.05433.

Sustainable Development Solutions Network. (2021). *The Sustainable Development Goals Report 2021*. United Nations. *https://unstats.un.org/sdgs/report/2021/*

Srivastava, A., & Maity, R. (2023). Assessing the potential of AI–ML in urban climate change adaptation and sustainable development. Sustainability, 15(23), 16461.

Szabó, Z. A., Soós, S., & Schiller, E. (2024). Deductive content analysis as a research method in the field of education sciences–A systematic literature review of journal articles in Web of Science (2019–2023). Journal of Adult Learning, Knowledge and Innovation.

Singh, A., Kanaujia, A., Singh, V. K., & Vinuesa, R. (2024). Artificial intelligence for Sustainable Development Goals: Bibliometric patterns and concept evolution trajectories. Sustainable Development, *32(1), 724-754*.

Sahran, F., Altarturi, H. H., & Anuar, N. B. (2023). Exploring the landscape of AI-SDN: A comprehensive bibliometric analysis and future perspectives. Electronics, *13(1), 26.*

Sarker, I. H. (2022). AI-based modeling: techniques, applications and research issues towards automation, intelligent and smart systems. SN Computer Science, 3(2), 158. https://doi.org/10.1007/s42979-022-01043-x

Sajja, R., Sermet, Y., Cikmaz, M., Cwiertny, D., & Demir, I. (2024). Artificial intelligence-enabled intelligent assistant for personalized and adaptive learning in higher education. Information, 15(10), 596. https://doi.org/10.3390/info15100596

Taye, M. M. (2023). Understanding of machine learning with deep learning: architectures, workflow, applications and future directions. Computers, 12(5), 91. https://doi.org/10.3390/computers12050091

United Nations Environment Programme (UNEP). (2019). *Global Environment Outlook – GEO-6: Healthy Planet, Healthy People*. Cambridge University Press.

van Wynsberghe, A. (2021). Sustainable AI: AI for sustainability and the sustainability of AI. AI and Ethics, *1(3), 213-218. https://doi.org/10.1007/s43681-021-00043-6*

Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S., ... & Nerini, F. F. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. *Nature Communications*, 11(1), 233. *https://doi.org/10.1038/s41467-019-14108-y*