Artificial Intelligence an Enabler for Sustainable Engineering Decision Making in Uncertain Environment: A Review and Future Propositions

Abstract

Sustainable development goals (SDGs) are gaining significant importance in the current environment. Many businesses are keen to adopt SDGs to get a competitive edge. There are certain challenges in realigning the present working scenario for sustainable development, which is a primary concern for society. Various firms are adopting sustainable Engineering (SE) practices to tackle such issues. Artificial intelligence (AI) is an emerging technology that can help the ineffective adoption of sustainable practices in an uncertain environment. This work presents a review of AI applications in SE for decision-making in an uncertain environment. SCOPUS database was considered for shortlisting the articles. Specific keywords on AI, SE, and decision-making were given, and a total of 127 articles were shortlisted after implying inclusion and exclusion criteria. Bibliometric study and network analyses were performed to analyse the current research trends and to see the research collaboration between researchers and countries. Emerging research themes were identified using structural topic modeling and discussed further. Research propositions corresponding to each research theme were presented for future research directions. Finally, the implications of the study were discussed.

Keywords: Artificial intelligence; Sustainable engineering; decision making; uncertain environment; Sustainable development goals

1. Introduction

As the global population is increasing rapidly and has crossed seven billion people, the major concern for the current scenario is to minimise resource consumption and save resources for future generations (Urbaniec et al., 2018; Khan et al., 2021). Engineers are getting pressurised to utilise resources optimally to fulfill existing peoples' demands (Davidson et al., 2010). Practitioners and engineers are adopting sustainable engineering (SE) practices to minimise resource consumption. SE practices emerged from the earlier 1990s when resource scarcity was realised (Adams and Karney, 1991). The SE practices are not being fully explored because of the non-availability of compatible technologies. In earlier 2014s, Industry 4.0 technologies came into the picture, which has vast potential for sustainable

benefits. One such technology of Industry 4.0 is artificial intelligence (AI). Adoption of AI technologies and SE practices provides significant benefits in terms of optimising resource consumption, minimising emissions, and enabling efficient decision-making in an uncertain environment. In this regard, this study aims to present the review of published articles in the field of AI and SE for smooth decision-making in an uncertain environment. The following research questions are aimed to address in this study:

RQ1. *What is the research trend in terms of sustainable development using AI techniques with SE practices?*

RQ2. *What are the research propositions for future work no AI and SE practices for smooth decision making?*

To address these research questions, this article presents a systematic literature review (SLR) in the field of AI and SE in decision making. Articles in the investigating field were collected and shortlisted from the SCOPUS database by giving proper keywords. Bibliometric and network analyses were conducted for the shortlisted articles using the R package and VOSviewer, respectively. Further, emerging research themes were identified using structural topic modeling (STM). Research propositions corresponding to each emerging research theme were highlighted for future research directions. Then finally, the implications of the study were discussed, which enables the industry practitioners, researchers, and policymakers to effectively utilise AI techniques for effective adoption of SE practices to enable smooth decision making in an uncertain environment.

2. Systematic literature review

An SLR methodology is the core part of the research field. It helps in identifying the current research practices happenings in the investigating field. It also helps analyse the research gaps in the investigating area and provides future research work that can be done in the investigating field. In this article, we followed an SLR methodology as adopted by Naz et al. (2021). The flow of the study is presented in Figure 1. In this study, we choose the SCOPUS database as the reference to collect and shortlist articles in the field of AI in SE under uncertain environments. Keywords were selected based on the research study and are fed to the SCOPUS database, and a total of 325 articles were found.

Further, by giving inclusion and exclusion criteria, we shortlisted 127 articles for the study. Then further bibliometric study and network analysis were then performed to analyse the current research trends and understand the research collaboration between authors and countries. Further, emerging research themes were identified using STM. Finally, research propositions were made for each identified research theme for future research work.

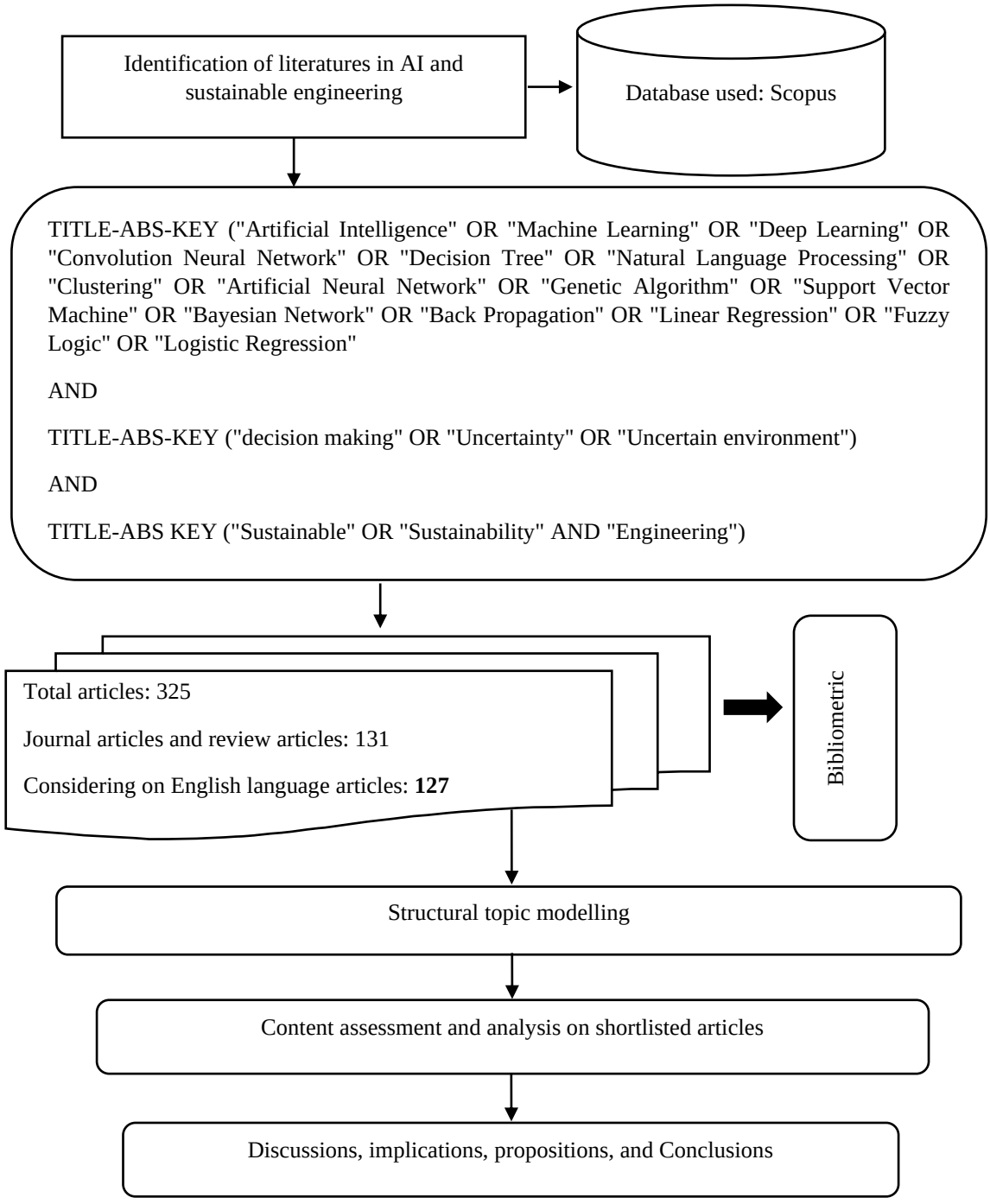

Figure 1. Flowchart of SLR

3. Bibliometric study

A bibliometric study was done to analyse the research trends in year-wise publications, most contributing authors and countries, and highly cited documents. This article used the R package to present a bibliometric study on AI in SE for the uncertain environment. Table 1 presents the basic information about the shortlisted article from the SCOPUS database in the investigating field.

Table 1. Main information about shortlisted articles

Description	**Results**
Timespan	1996:2021
Documents	127
Average years from publication	4.39
Average citations per document	20.93
Average citations per year per doc	3.952
References	8130
Document types	
Article	114
Review	13
Document contents	
Keywords plus (id)	1434
Author's keywords (de)	558
Authors	
Authors	542
Author appearances	559
Authors of single-authored documents	3
Authors of multi-authored documents	539
Authors collaboration	
Single-authored documents	3
Documents per Author	0.234
Authors per Document	4.27
Co-Authors per Documents	4.4
Collaboration index	4.35

The year-wise article statistics were analysed and are presented in Figure 2. From the figure, it can be seen that there is a huge growth in the article trend, i.e., from 8 articles in 2019 to 25 articles in 2020.

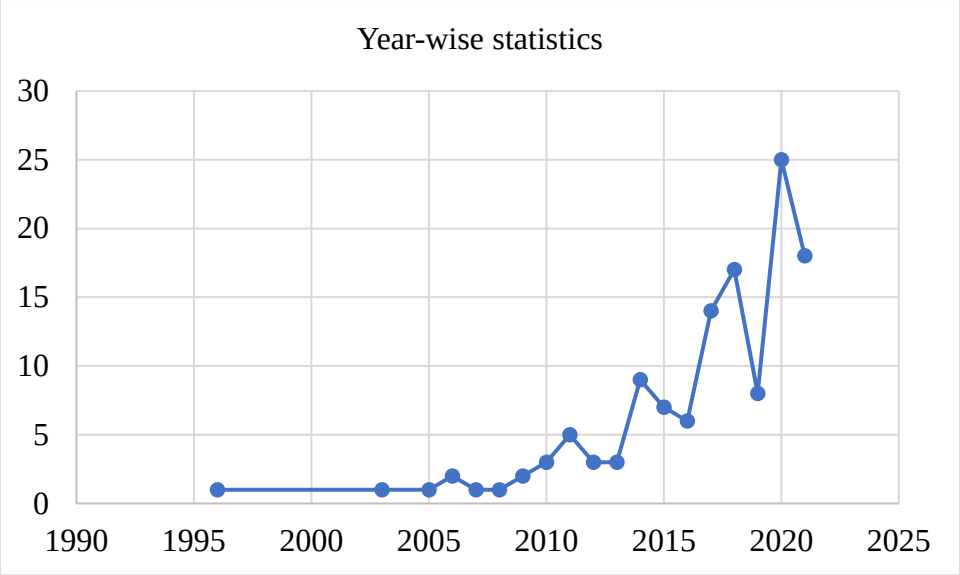

Figure 2. Year-wise statistics

The top contributing countries in the research field of AI in SE for the uncertain environment are presented in Table 2. It can be seen from the table that, USA, China, and the UK were the top three countries publishing a good number of articles in the investigating field.

Table 2. Country-wise article statistics

Country	Article count
USA	77
China	46
UK	24
Iran	18
Spain	16
Germany	15
Italy	13
India	12
Australia	11
Canada	11

The countries receiving a good number of citations for the research work on AI in SE for the uncertain environment are presented in Table 3. The table shows that though the USA has the highest number of publications in the investigating field, the highest citation count is received by China. It is also found that though France has only one article, it has the highest average article citations of 106.

Table 3. Country-wise articles citations

Country	Total citations	Average article citations
China	481	37.00
Australia	321	53.50
USA	316	28.73
Canada	246	41.00
UK	182	30.33
France	106	106.00
Spain	85	14.17
Iran	80	13.33
Lithuania	80	40.00
Portugal	71	17.75

The top ten affiliations performing high-volume research in AI in SE are presented in Table 4. The table shows that Islamic Azad university published the highest number of articles in the investigating field.

Table 4. Top ten affiliations in AI in SE

Affiliations	Articles
Islamic Azad university	4
Blekinge Institute of technology	3
Cornell university	3
Kainan university	3
Pakistan institute of engineering and technology	3
Ton Duc Thang university	3
Universitas Riau	3
University of Bayreuth	3
University of California	3
Alexandria university	2

The top ten publishing source in the field of AI in SE is presented in Table 5. From the table, it is found that the Journal of Cleaner Production is the highly publishing journal for AI in SE with a total of 8 articles, around 6.3% of articles considered, followed by Sustainability (Switzerland), and IEEE Access with 7 4 articles respectively.

Table 5. Top ten publishing source for AI in SE

Sources	Articles
Journal of Cleaner Production	8
Sustainability (Switzerland)	7
IEEE Access	4
Annual Reviews in Control	3
Journal of Environmental Management	3
Science of The Total Environment	3

International Journal of Production Research	2
International Journal of Advanced Manufacturing Technology	2
Ecological Indicators	2
Applied Sciences (Switzerland)	2

Table 6 presents the most cited documents in the field of AI in SE under uncertain environments. From the table, it is found that Lu et al. (2007) received the highest citation of 269, followed by McIntosh et al. (2011) and Eckart et al. (2017) with 204 and 203 citations, respectively.

Table 6. Top highly cited articles in the field of AI in SE under uncertain environment

Article	Total Citations	TC per Year	Normalised TC
Lu et al. (2007)	269	17.93	1
McIntosh et al. (2011)	204	18.54	2.67
Eckart et al. (2017)	203	40.6	6.45
Addo et al. (2008)	131	9.35	1
Chen et al. (2011)	110	10	1.43
Panetto et al. (2019)	106	35.33	5.17
Deo and Şahin (2017)	94	18.8	2.99
Tung and Yaseen (2020)	91	45.5	9.47
Antucheviciene et al. (2015)	77	11	2.54
Hu and Bidanda (2009)	66	5.07	1.57

The essential keywords used by authors for the research publications in the investigating field are presented in Table 7. From the table, it is found that decision making is the most used keyword in the field of AI in SE under the uncertain environment with the frequency of occurrence of 89 followed by sustainable development and artificial intelligence with the frequency of 53 and 43, respectively. The keyword cloud has also been prepared and is presented in Figure 3.

Table 7. Top twenty keywords in the field of AI in SE under uncertain environment

Words	Occurrences	Words	Occurrences
decision making	89	fuzzy logic	11
sustainable development	53	learning systems	11
artificial intelligence	43	life cycle	11
decision support systems	30	neural networks	11
sustainability	19	water supply	11
risk assessment	15	environmental impact	9
decision support system	14	genetic algorithms	9
forecasting	14	optimization	9
water management	14	waste management	9
uncertainty analysis	13	article	8

Figure 3. Word cloud

4. Network analysis

Network analysis was performed to analyse the collaboration network between authors and countries and the co-occurrence between keywords. Network analysis was performed using VOSviewer. The keyword co-occurrence network was developed in the field of AI in SE under an uncertain environment and is presented in Figure 4. A total of 1769 keywords were used in the considered articles. We selected only those keywords whose occurrence is more than 5, so the count was reduced to 54. The keyword co-occurrence network diagram consisting of 54 keywords is presented in Figure 4.

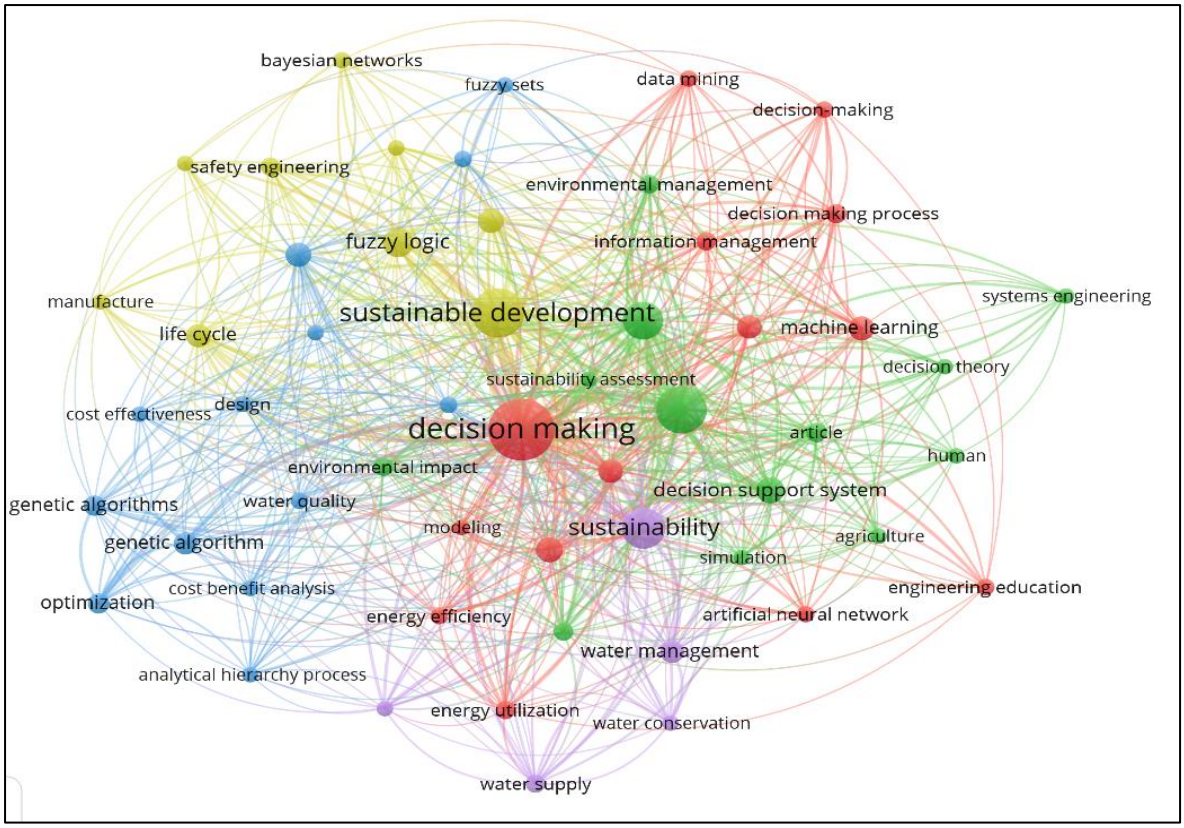

Figure 4. keyword co-occurrence network

The author collaboration network was formed by considering all the authors of the considered articles. Only three clusters were formed in the author collaboration network consisting of 17 authors, while other authors were excluded because of no connectivity with others. The developed author collaboration network is presented in Figure 5.

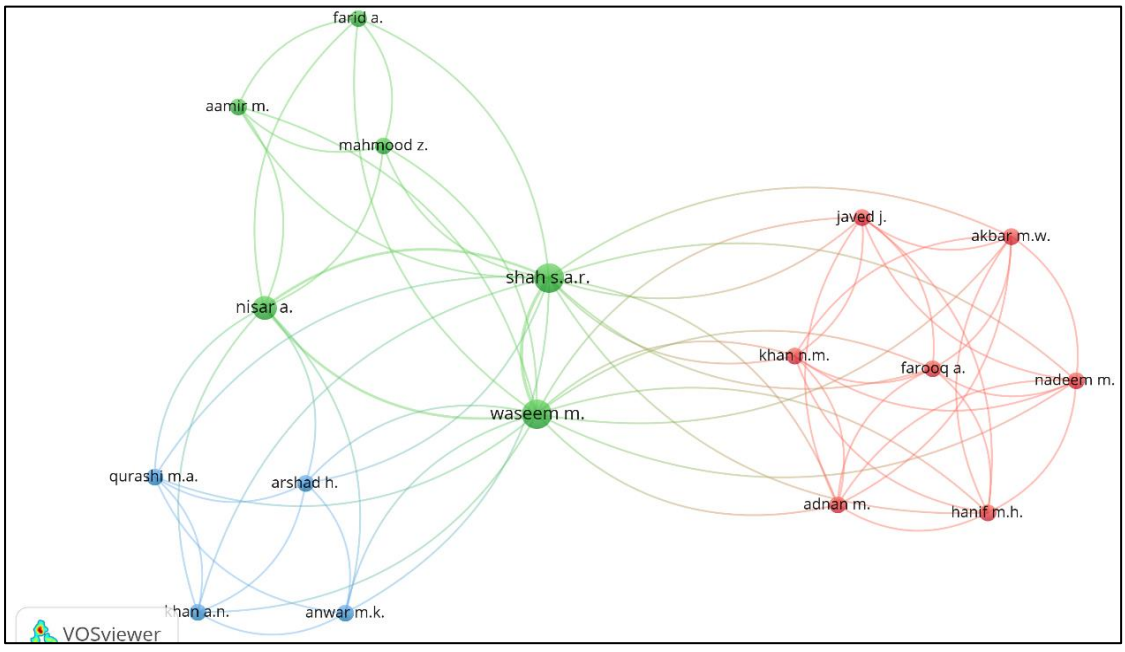

Figure 5. Author collaboration network

The country collaboration network was also developed using VOSviewer. In this study, we considered only countries with at least 2 articles in the field of AI in SE under uncertain environments, so the number of countries was reduced to 37 from 54. Further, 8 clusters were formed comprising 36 countries, while one country was excluded because of low connectivity with others. The developed country collaboration network is presented in Figure 6.

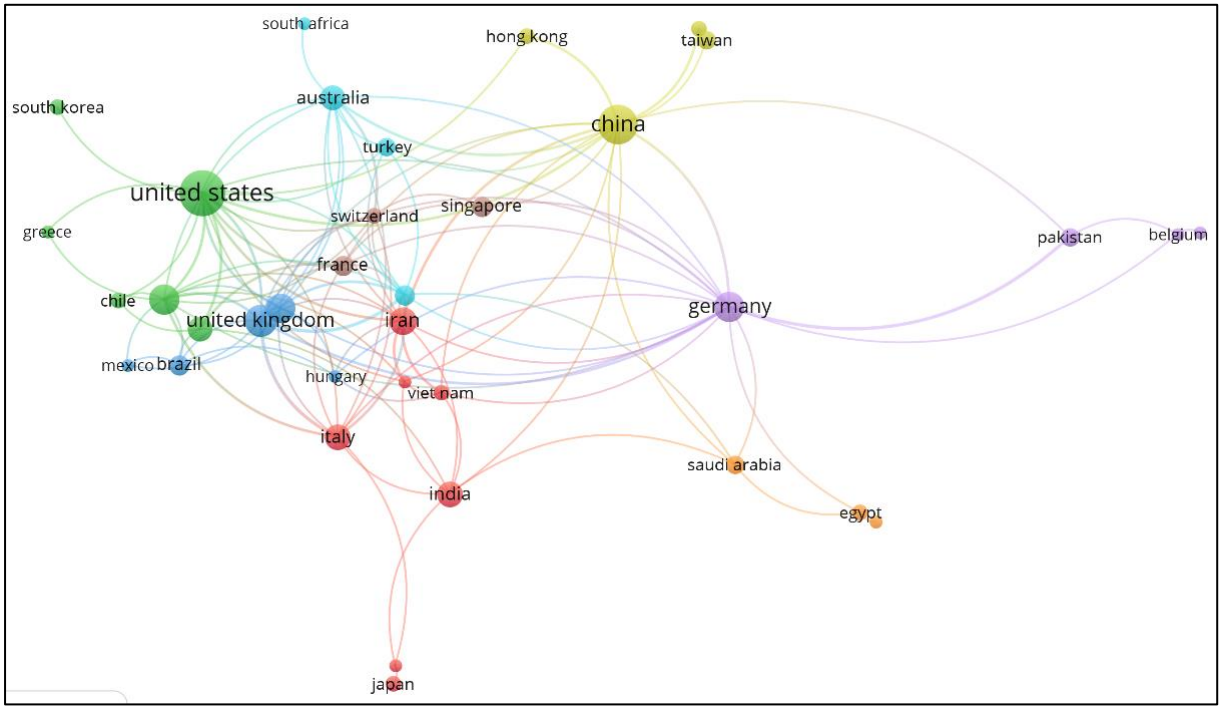

Figure 6. Country collaboration network

5. Emerging research themes

In this section, structural topic modeling (STM) was used to identify the emerging research themes in the field of AI in SE under uncertain environments. The steps followed for STM could be referred from Naz et al. (2021). The top identified word for each topic is presented in Table 8.

Table 8. Top identified words under each topic

S. No.	Topic label	Words with the highest probability	Frex	Lift
1.	Sustainable product design	product, sustain, design, system, process, proposed,	manufacture, product, pavement, life, material,	AHP, commercial, eco-design, London, bridge,

S. No.	Topic label	Words with the highest probability	Frex	Lift
		develop	cycle, design	cope, electron
2.	Technology development in SE	model, research, develop, use, data, technology, network	vision, digit, river, discovering, future, human, problem-solve	composite, food, realise, creative, curious, ecosystem
3.	Decision making in sustainable supply chain	model, use, decision, sustain, risk, propose, studies	risk, land, supplier, health, select, agriculture, benefit	accidental, determinist, firm, fleet, link, reaction, return
4.	Machine learning in sustainable engineering	model, evaluate, use, algorithm, result, ANN, optimum	ANN, slope, maximum, algorithm, evaluate, suitable, test	ameliorate, hydraulic, infeasible, minimum, neuron, recovery, specialist
5.	Resource utilization for sustainability	water, manage, system, energies, model, use, decision	water, urban, energies, topic, stakeholder, municipal, data-driven	character, single, tropic, wastewater, bay, discharge, elevate
6.	Decision making in sustainability research	sustain, model, engine, use, process, approach, method	usable, secure, business, MCDM, methodology, probabilistic, characteristic	metaheuristic, unbalance, unequal-area, constraint-chromosome, imbalance

5.1 Sustainable product design

Sustainable developments are gaining significant importance in different aspects of engineering research. The manufactured product may have a significant impact on a different aspect of sustainability throughout its life cycle. Kulatunga et al. (2015) have found that approximately 80% of impacts of the product are derived in the product design stage. So, to enhance the sustainability of products, it is necessary to emphasise sustainable product design. Boyko (2009) integrated the sustainability tasks such as determining sustainability agenda, analysing the trade-offs between sustainability issues, and generating sustainability practices for the product in the design phase. Sustainable product design enables effective product development planning considering all stages of its life cycle, starting from material extraction to the end of life phase (Gagnon et al., 2012). The aim of sustainable product design is to reduce resource consumption and minimise the emissions generated out of it (Ahmad et al., 2018). Further, Umeda et al. (2012) proposed a framework to integrate life cycle perspectives in the product design phase to make an eco-product design. Various eco-

design tools are available such as design for environment (DFE), quality function deployment (QFD), and life cycle assessment (LCA) to enable sustainable product design (Hosseinpour et al., 2015; Agrawal and Vinodh, 2019).

The following propositions are to be investigated in further research:

Proposition 1: Life cycle assessment of the manufactured product to understand the environmental impacts ensuring sustainability.

Proposition 2: Development of a framework for integrating SE with supply chain management to enhance sustainable supply chain performance.

Proposition 3: Establishment of novel product design tools to support industrial sustainability.

5.2 Technology development in SE

Technology development plays an essential role in the growth of the economy. In the current scenario, technology development is emerging as the fourth industrial revolution, also known as Industry 4.0. Industry 4.0 has created huge potential for sustainable development (Nara et al., 2021). Industry 4.0 technologies integrate advanced manufacturing technologies with information technologies to ensure sustainability in the engineering field (Wei et al., 2017). The benefits achieved from adopting such technologies include efficient energy consumption, waste minimization, optimum resource consumption, and minimum emissions (Dalenogare et al., 2018). The results of such benefits may provide significant sustainable benefits (Ghobakhloo, 2018). Many studies show the importance of technological advancements for sustainable development (Beier et al., 2020). Kiel et al. (2020) highlight the socio-technical aspects of technology advancements to ensure sustainable development. Further, Kamble et al. (2020) highlighted the positive impact of technology advancement on sustainability's triple bottom-line benefits.

The following propositions are to be investigated in further research:

Proposition 4: Analyzing the socio-technical aspects of SE in the Industry 4.0 environment.

Proposition 5: Performing empirical studies to assess the performance of manufacturing systems deploying Industry 4.0.

Proposition 6: Understanding the role of Industry 4.0 in the sustainable development of technological systems.

5.3 Decision making in sustainable Supply chain

Supply chain (SC) includes various business activities such as procurement, manufacturing, distributions, supplies, and selling, including various stakeholders such as suppliers, business partners, logistics providers, and customers. The various activities involved in SC may directly or indirectly impact sustainable development (Paul et al., 2017). These impacts are also known as triple bottom line impacts on SC. Environmental impacts include global warming, carbon emissions, and air pollutants (de Vries and Ferrarini, 2017). Social impacts include low wages, child labor, health, and social wellbeing (Munny et al., 2019). Economy impacts include a firm's profit, productivity, and return on investments (Mota et al., 2015). As the SC has a significant impact on all three aspects of sustainability, every firm includes sustainable practices in their SC. Various decision-making techniques have been applied to analyse the sustainability of SC, such as analysis of success factors for sustainable SC (Luthra et al., 2018), performance assessment of sustainable SC (Kazancoglu et al., 2018), barriers and drivers analysis in sustainable production (Luthra et al., 2016; Shankar et al., 2016), and green supplier selection (Li et al., 2019).

The following propositions are to be investigated in further research:

Proposition 7: Exploring the role of decision-making techniques in examining the sustainability aspects of SC.

Proposition 8: Utilization of multi-criteria decision-making techniques integrated with fuzzy approaches to analyse the sustainable supplier selection model.

Proposition 9: Role of several stakeholders in SC in improving the supply chain performance, ensuring sustainability.

5.4 Machine learning in sustainable engineering

SE is an approach to running systems or modeling that efficiently utilizes resources and products (Bhatnagar et al., 2021). Machine learning plays a significant role in sustainable computing and has greater implications on sustainable innovation targets. Specific machine learning algorithms are necessary to address the SE problems (Bhatnagar et al., 2021). Moreover, artificial intelligence is the most rapidly growing field of technology facilitating sustainable development goals (Khamis et al., 2019). With regards to SE of civil structures, buildings are considered the world's most significant contributor to greenhouse gas emissions, energy demand, waste generation, and resource consumption (D'Amico et al., 2019). Thus, machine learning applications were significant in the quicker shift to a sustainable built environment (D'Amico et al., 2019).

Further, machine learning applications have been seen in river engineering sustainability, flood risk mitigation, and water resource management (Cui et al., 2020). The study conducted by Cui et al. (2020) developed a novel time-series machine learning model named emotional neural network to predict hourly river flow based in Australia. The emotional neural network method showed significant results in simulating the hourly river flow contributing to the water resource monitoring and river engineering sustainability. The role of machine learning is found to be crucial in structural health monitoring systems. Sevieri and De Falco (2020) presented a machine learning-based framework for Italian concrete gravity dam to monitor structural health. The developed framework facilitated the detection of damages and reduction in uncertainties associated with the structural behavior of dams. Similarly, machine learning applications have been observed in developing sustainable dams (Yahya et al., 2020). Machine learning techniques showed meaningful understandings for water assets management, fulfilling the research in SE with respect to water dam research (Yahya et al., 2020). Considering meteorological data required to operate environmental learning, machine learning techniques significantly predict energy flux and significant wave height (Gómez-Orellana et al., 2021). Gómez-Orellana et al. (2021) discussed the importance of software tools based on machine learning to address the problems related to ocean and coastal engineering, sustainable energy manufacturing, and environmental modeling, which helps enhance SE.

The following propositions are to be investigated in further research:

Proposition 10: Assessing the role of machine learning in addressing coastal and ocean engineering issues from the perspective of sustainable development.
Proposition 11: Applying machine learning algorithms to mitigate the risk related to natural disasters.
Proposition 12: Exploring the application of machine learning in structural health monitoring for ensuring sustainable structures.

5.5 Resource utilization for sustainability

Resource utilization in SE provides new avenues and opportunities for establishing natural environments to attain minimum energy use and new resources with reduced pollution and waste (Yu et al., 2016). The use of renewable resources is essential to achieve sustainability, and more consumption of non-renewable resources increases the environmental burden on surrounding ecosystems (Yu et al., 2016). Thus, by encouraging technological innovation and

reducing total resource utilization, sustainable development can be achieved. Sueyoshi and Goto (2018) discussed the corporate sustainability of Japanese organizations concerning the assessment of their economic activities. The authors recommended focusing more on environmental aspects of manufacturing activities than operational ones to achieve sustainability with reduced resource consumption. Amândio et al. (2021) focussed on establishing an evolutionary multi-objective approach to facilitate the planning of road pavement rehabilitation. The authors' study contributed to support the decision-making on resource engineering. The optimization system was a vital contribution to creating more sustainable and intelligent pavement engineering with minimum resource utilization. Further, with the introduction of new technologies, there is an increase in demand for sustainable products, which demands minimum resource utilization (Oliveira et al., 2021).

The following propositions are to be investigated in further research:

***Proposition 13*:** Discovering the sustainable technology innovations through AI to facilitate reduced emissions and waste minimization, enhancing resource efficiency.
***Proposition 14*:** Operationalizing the Industry 4.0 technologies in developing sustainable products with minimum resource utilization.
***Proposition 15*:** Developing the structural model of factors integrating resource utilization strategies and SE.

5.6 Decision making in sustainability research

Several organisations are attempting to deploy strategies ensuring sustainability into their day-to-day operations decisions. Decision-making in sustainability is a growing area and is considered a vital element in the success of businesses. Thus, with respect to SE, decision-making towards sustainable research need to be explored. The best environmental watershed plan was selected using a fuzzy multi-criteria decision-making approach named fuzzy analytic hierarchy process (Chen et al., 2011). The findings of the study helped in achieving sustainability in watershed tourism resources and destination planning. Similarly, the significant applications of decision-making were seen in the mining industry for identifying the most feasible solution for the technological mining process from the viewpoint of environment and safety (Sirb and Popa, 2014).

The fuzzy analytic hierarchy process was used to examine the uncertainty in the design of concrete structures, ensuring sustainability (del Caño et al., 2016). The fuzzy method was

found to be significant in decision-making to achieve sustainability goals (del Caño et al., 2016). The developed decision support system for planning of water distribution system ensuring sustainability was found to be efficient, satisfactory, and practical (Freund et al., 2017). Further, the adoption of complex theory addressed the engineering management issues that provided a smooth way to sustainability (Abatecola and Surace, 2020). Tian et al. (2021) constructed a sustainability assessment framework using the fuzzy VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) approach. The sustainability index was obtained for water environment treatment public-private partnership projects. The proposed framework is shown support to effective decision making and handling sustainability assessment problems.

The following propositions are to be investigated in further research:

Proposition 16: Application of fuzzy multi-criteria decision-making techniques to assess the barriers with respect to organisation's sustainable performance.

Proposition 17: Development of sustainable support system enabling decision making in the improvement of systems.

Proposition 18: Establishment of a framework for effective decision-making in an uncertain environment in assessing sustainability-related problems for water treatment systems.

6. Discussion

A systematic literature review was performed using structural topic modeling and bibliometric analysis to understand the role of AI in SE decision-making in an uncertain environment. The structural topic modeling aids in obtaining the thematic topics from recognised literature. The thematic topics generated from structural topic modeling include Sustainable product design, Technology development in SE, Decision making in sustainable SC, Machine learning in SE, Resource utilization for sustainability, and decision making in sustainability research. The developments in SE are gaining significant attention from researchers in the domain of sustainable product design. As discussed in the study conducted by Kulatunga et al. (2015), the product design stage contributes to 80% of the environmental impacts. This enabled researchers to focus on sustainable product design-related aspects to ensure sustainability.

Further, sustainability activities and practices for the product allow effective design planning during the product development stage comprising of life cycle assessment phases. The product design stage needs to be integrated with its life cycle assessment phase to create a

green product design. Also, Agrawal and Vinodh (2019) suggested various green product design tools, namely quality function deployment, life cycle assessment, etc. For technology development in SE, Industry 4.0 technologies are observed as the significant enabler for sustainable development. The adoption of technologies presents several advantages, such as waste minimization, minimum resource consumption, and minimum emissions. There exists a positive impact on sustainable manufacturing with the advancements of technology (Kamble et al., 2020). The next thematic topic illustrated the discussion on decisions making aspects in SC ensuring sustainability. Several activities related to SC directly impact sustainable development (Paul et al., 2017). The decision-making techniques helped analyse the barriers, drivers, and critical success factors of SC ensuring sustainability.

Artificial intelligence is the most rapidly developing field of Industry 4.0, helping to achieve sustainable goals. Machine learning plays a significant role in sustainability assessment. Moreover, machine learning algorithms helped in addressing SE problems. Machine learning applications were seen in developing SE of civil structures, i.e., buildings that contributed to greenhouse gas emissions, etc. Thus, machine learning helps obtain a quicker change to a sustainable built environment (D'Amico et al., 2019). The time series machine learning model named emotional neural network showed promising results for predicting hourly river flow based in Australia. The emotional neural network helped in modeling the hourly river flow contributing to the water resource monitoring and river engineering sustainability. Furthermore, machine learning algorithms helped in developing sustainable dams and addressing other problems related to coastal and ocean engineering (Gómez-Orellana et al., 2021). Another interesting topic reviewed with respect to SE is resource utilization for sustainability. Resource utilization in SE delivered new opportunities for creating natural environments with minimum use of new resources facilitating reduced pollution and waste. Sustainable development can be accomplished by promoting technological innovation and reducing total resource utilization (Yu et al., 2016). Further, the previous studies suggested concentrating more on the ecological aspects of manufacturing activities than operating one to attain sustainability. Several organizations are trying to implement sustainable strategies into their operations decisions. Decision-making in sustainability is a growing area and is considered a vital element in the success of businesses. The decision-making approach was seen in the selection of the best environmental watershed plan (Chen et al., 2011) that helped in realising sustainability in watershed tourism resources and destination planning.

6.1 Implications

A systematic literature review was carried out using structural topic modeling and bibliometric analysis to understand the role of AI in SE dealing with decision-making in an uncertain environment. The structural topic modeling facilitates recognizing the key topics from recognised literature, which would help the readers understand the role of AI in SE. The key topics generated from structural topic modeling include Sustainable product design, Technology development in SE, Decision making in sustainable SC, Machine learning in SE, Resource utilization for sustainability, and decision-making in sustainability research. The present study discussed the importance of sustainable product design to help researchers and industry practitioners develop eco-friendly designs. Moreover, the present work provides the opportunity for industry practitioners to explore the capability of Industry 4.0 technologies in delivering sustainable solutions in uncertain environments through sharing knowledge and ideas. One key consideration focussed was pertaining to applications of machine learning in developing SE designs. This would help industries explore the role of AI in developing sustainable products and novel business models. The present study also encourages the researchers to understand the review process and investigate the other promising areas in SE.

7. Conclusions

Sustainable developments and engineering are fundamentally linked to create sustainable solutions through sharing of new knowledge and ideas. With the advent of Industry 4.0 technologies, significant changes have been observed in modifying the existing system to a sustainable one. One of such technology's roles, i.e., AI in SE, is being understood in this study with the help of a systematic literature review. These days the concept of sustainability has been extensively utilised in several disciplines. In this regard, the present study explored the significance of AI in engineering decision-making in an uncertain environment. The bibliometric analysis and structural topic modeling were used to extract the promising topics from the previous studies. This study helped deliver deeper insights on the role of AI in SE facilitating decision-making in an uncertain environment. The existing studies discussed the role of AI in sustainable product design, decision making, sustainable SC, and resource utilization.

Although the present study covers the significant aspect of AI in enabling SE, it possesses few limitations. The study is restricted to journals papers and review articles, whereas conference proceedings, company reports, field reports, book chapters, etc., have been

excluded from the analysis. The bibliometric analysis facilitated categorising the growth pattern and quantity of the previous work on AI in SE. Future research directions have been introduced in the form of propositions for each thematic topic.

References

Abatecola, G., & Surace, A. (2020). Discussing the Use of Complexity Theory in Engineering Management: Implications for Sustainability. *Sustainability*, *12*(24), 10629.

Adams, B. J., & Karney, B. W. (1991, June). Sustainable Engineering Practice: Aspects Of Environmental Engineering Education. In *Proceedings of the 1991 International Symposium on Technology and Society-ISTAS91* (pp. 302-310). IEEE.

Addo, K. A., Walkden, M., & Mills, J. T. (2008). Detection, measurement and prediction of shoreline recession in Accra, Ghana. *ISPRS Journal of Photogrammetry and Remote Sensing*, *63*(5), 543-558.

Agrawal, R., & Vinodh, S. (2019). State of art review on sustainable additive manufacturing. *Rapid Prototyping Journal*.

Ahmad, S., Wong, K. Y., Tseng, M. L., & Wong, W. P. (2018). Sustainable product design and development: A review of tools, applications and research prospects. *Resources, Conservation and Recycling*, *132*, 49-61.

Amândio, A. M., das Neves, J. M. C., & Parente, M. (2021). Intelligent planning of road pavement rehabilitation processes through optimization systems. *Transportation Engineering*, *5*, 100081.

Antucheviciene, J., Kala, Z., Marzouk, M., & Vaidogas, E. R. (2015). Solving civil engineering problems by means of fuzzy and stochastic MCDM methods: current state and future research. *Mathematical Problems in Engineering*, *2015*.

Beier, G., Ullrich, A., Niehoff, S., Reißig, M., & Habich, M. (2020). Industry 4.0: How it is defined from a socio-technical perspective and how much sustainability it includes–A literature review. *Journal of cleaner production*, *259*, 120856.

Bhatnagar, V., Sharma, S., Bhatnagar, A., & Kumar, L. (2021, March). Role of Machine Learning in Sustainable Engineering: A Review. In *IOP Conference Series: Materials Science and Engineering* (Vol. 1099, No. 1, p. 012036). IOP Publishing.

Chen, V. Y., Lien, H. P., Liu, C. H., Liou, J. J., Tzeng, G. H., & Yang, L. S. (2011). Fuzzy MCDM approach for selecting the best environment-watershed plan. *Applied soft computing*, *11*(1), 265-275.

Chen, V. Y., Lien, H. P., Liu, C. H., Liou, J. J., Tzeng, G. H., & Yang, L. S. (2011). Fuzzy MCDM approach for selecting the best environment-watershed plan. *Applied soft computing*, *11*(1), 265-275.

Cui, F., Salih, S. Q., Choubin, B., Bhagat, S. K., Samui, P., & Yaseen, Z. M. (2020). Newly explored machine learning model for river flow time series forecasting at Mary River, Australia. *Environmental Monitoring and Assessment*, *192*(12), 1-15.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*, 383-394.

D'Amico, B., Myers, R. J., Sykes, J., Voss, E., Cousins-Jenvey, B., Fawcett, W., ... & Pomponi, F. (2019, June). Machine learning for sustainable structures: a call for data. In *Structures* (Vol. 19, pp. 1-4). Elsevier.

Davidson, C. I., Hendrickson, C. T., Matthews, H. S., Bridges, M. W., Allen, D. T., Murphy, C. F., ... & Austin, S. (2010). Preparing future engineers for challenges of the 21st century: Sustainable engineering. *Journal of cleaner production*, *18*(7), 698-701.

de Vries, G. J., & Ferrarini, B. (2017). What accounts for the growth of carbon dioxide emissions in advanced and emerging economies? The role of consumption, technology and global supply chain participation. *Ecological Economics*, *132*, 213-223.

del Caño, A., Pilar de la Cruz, M., Gómez, D., & Pérez, M. (2016). Fuzzy method for analysing uncertainty in the sustainable design of concrete structures. *Journal of Civil Engineering and Management*, *22*(7), 924-935.

Deo, R. C., & Şahin, M. (2017). Forecasting long-term global solar radiation with an ANN algorithm coupled with satellite-derived (MODIS) land surface temperature (LST) for regional locations in Queensland. *Renewable and Sustainable Energy Reviews*, *72*, 828-848.

Eckart, K., McPhee, Z., & Bolisetti, T. (2017). Performance and implementation of low impact development–A review. *Science of the Total Environment*, *607*, 413-432.

Farashazillah Yahya and Bashirah Mohd Fazli and Hasimi Sallehudin and Izham Jaya (2020) *Machine learning in dam water research: an overview of applications and approaches*. International Journal of Advanced Trends in Computer Science and Engineering, 9 (2).

Freund, A., Aydin, N. Y., Zeckzer, D., & Hagen, H. (2015). A decision-support system for sustainable water distribution system planning. *IEEE computer graphics and applications*, *37*(1), 44-55.

Gagnon, B., Leduc, R., & Savard, L. (2012). From a conventional to a sustainable engineering design process: different shades of sustainability. *Journal of Engineering Design*, *23*(1), 49-74.

Ghobakhloo, M. (2018). The future of manufacturing industry: a strategic roadmap toward Industry 4.0. *Journal of Manufacturing Technology Management*.

Gómez-Orellana, A. M., Fernández, J. C., Dorado-Moreno, M., Gutiérrez, P. A., & Hervás-Martínez, C. (2021). Building suitable datasets for soft computing and machine learning techniques from meteorological data integration: A case study for predicting significant wave height and energy flux. *Energies*, *14*(2), 468.

Hosseinpour, A., Peng, Q., & Gu, P. (2015). A benchmark-based method for sustainable product design. *Benchmarking: An International Journal*.

Hu, G., & Bidanda, B. (2009). Modeling sustainable product lifecycle decision support systems. *International Journal of Production Economics*, *122*(1), 366-375.

Kamble, S., Gunasekaran, A., & Dhone, N. C. (2020). Industry 4.0 and lean manufacturing practices for sustainable organisational performance in Indian manufacturing companies. *International Journal of Production Research*, *58*(5), 1319-1337.

Kazancoglu, Y., Kazancoglu, I., & Sagnak, M. (2018). Fuzzy DEMATEL-based green supply chain management performance: application in cement industry. *Industrial Management & Data Systems*.

Khamis, A., Li, H., Prestes, E., & Haidegger, T. (2019). AI: a key enabler of sustainable development goals, Part 1 [industry activities]. *IEEE Robotics & Automation Magazine*, *26*(3), 95-102.

Khan, I., Hou, F., & Le, H. P. (2021). The impact of natural resources, energy consumption, and population growth on environmental quality: Fresh evidence from the United States of America. *Science of the Total Environment*, *754*, 142222.

Kiel, D., Müller, J. M., Arnold, C., & Voigt, K. I. (2020). Sustainable industrial value creation: Benefits and challenges of industry 4.0. In *Digital Disruptive Innovation* (pp. 231-270).

Kulatunga, A. K., Karunatilake, N., Weerasinghe, N., & Ihalawatta, R. K. (2015). Sustainable manufacturing based decision support model for product design and development process. *Procedia CIRP*, *26*, 87-92.

Li, J., Fang, H., & Song, W. (2019). Sustainable supplier selection based on SSCM practices: A rough cloud TOPSIS approach. *Journal of cleaner production*, *222*, 606-621.

Lu, L. Y., Wu, C. H., & Kuo, T. C. (2007). Environmental principles applicable to green supplier evaluation by using multi-objective decision analysis. *International journal of production research*, *45*(18-19), 4317-4331.

Luthra, S., Mangla, S. K., Shankar, R., Prakash Garg, C., & Jakhar, S. (2018). Modelling critical success factors for sustainability initiatives in supply chains in Indian context using Grey-DEMATEL. *Production Planning & Control*, *29*(9), 705-728.

Luthra, S., Mangla, S. K., Xu, L., & Diabat, A. (2016). Using AHP to evaluate barriers in adopting sustainable consumption and production initiatives in a supply chain. *International Journal of Production Economics*, *181*, 342-349.

McIntosh, B. S., Ascough II, J. C., Twery, M., Chew, J., Elmahdi, A., Haase, D., ... & Voinov, A. (2011). Environmental decision support systems (EDSS) development–Challenges and best practices. *Environmental Modelling & Software*, *26*(12), 1389-1402.

Mota, B., Gomes, M. I., Carvalho, A., & Barbosa-Povoa, A. P. (2015). Towards supply chain sustainability: economic, environmental and social design and planning. *Journal of cleaner production*, *105*, 14-27.

Munny, A. A., Ali, S. M., Kabir, G., Moktadir, M. A., Rahman, T., & Mahtab, Z. (2019). Enablers of social sustainability in the supply chain: An example of footwear industry from an emerging economy. *Sustainable Production and Consumption*, *20*, 230-242.

Nara, E. O. B., da Costa, M. B., Baierle, I. C., Schaefer, J. L., Benitez, G. B., do Santos, L. M. A. L., & Benitez, L. B. (2021). Expected impact of industry 4.0 technologies on sustainable development: A study in the context of Brazil's plastic industry. *Sustainable Production and Consumption*, *25*, 102-122.

Naz, F., Kumar, A., Majumdar, A., & Agrawal, R. (2021). Is artificial intelligence an enabler of supply chain resiliency post COVID-19? An exploratory state-of-the-art review for future research. *Operations Management Research*, 1-21.

Panetto, H., Iung, B., Ivanov, D., Weichhart, G., & Wang, X. (2019). Challenges for the cyber-physical manufacturing enterprises of the future. *Annual Reviews in Control*, *47*, 200-213.

Paul, S. K., Sarker, R., & Essam, D. (2017). A quantitative model for disruption mitigation in a supply chain. *European Journal of Operational Research*, *257*(3), 881-895.

Sevieri, G., & De Falco, A. (2020). Dynamic structural health monitoring for concrete gravity dams based on the Bayesian inference. *Journal of Civil Structural Health Monitoring*, *10*(2), 235-250.

Shankar, K. M., Kumar, P. U., & Kannan, D. (2016). Analyzing the drivers of advanced sustainable manufacturing system using AHP approach. *Sustainability*, *8*(8), 824.

Sirb, L., & Popa, D. (2014). An approach in terms of fuzzy logic within 'Rosia Montana mining project 'regarding the ensurance of business and community sustainability by using cyanide. *Journal of environmental protection and ecology*, *15*(1), 223-233.

Souza Oliveira, A., Caetano dos Santos Silva, B., Vasconcellos Ferreira, C., Ribeiro Sampaio, R., Aparecida Souza Machado, B., & Coelho, R. S. (2021). Adding Technology Sustainability Evaluation to Product Development: A Proposed Methodology and an Assessment Model. *Sustainability*, *13*(4), 2097.

Souza Oliveira, A., Caetano dos Santos Silva, B., Vasconcellos Ferreira, C., Ribeiro Sampaio, R., Aparecida Souza Machado, B., & Coelho, R. S. (2021). Adding Technology Sustainability Evaluation to Product Development: A Proposed Methodology and an Assessment Model. *Sustainability*, *13*(4), 2097.

Sueyoshi, T., & Goto, M. (2018). Resource utilization for sustainability enhancement in Japanese industries. *Applied Energy*, *228*, 2308-2320.

Tian, C., Peng, J. J., Zhang, S., Wang, J. Q., & Goh, M. (2021). A sustainability evaluation framework for WET-PPP projects based on a picture fuzzy similarity-based VIKOR method. *Journal of Cleaner Production*, *289*, 125130.

Tung, T. M., & Yaseen, Z. M. (2020). A survey on river water quality modelling using artificial intelligence models: 2000–2020. *Journal of Hydrology*, *585*, 124670.

Umeda, Y., Takata, S., Kimura, F., Tomiyama, T., Sutherland, J. W., Kara, S., ... & Duflou, J. R. (2012). Toward integrated product and process life cycle planning—An environmental perspective. *CIRP annals*, *61*(2), 681-702.

Urbaniec, K., Mikulčić, H., Wang, Y., & Duić, N. (2018). System integration is a necessity for sustainable development. *Journal of Cleaner Production*, *195*, 122-132.

Wei, Z., Song, X., & Wang, D. (2017). Manufacturing flexibility, business model design, and firm performance. *International Journal of Production Economics*, *193*, 87-97.

Yu, X., Geng, Y., Dong, H., Fujita, T., & Liu, Z. (2016). Emergy-based sustainability assessment on natural resource utilization in 30 Chinese provinces. *Journal of Cleaner Production*, *133*, 18-27.