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An Exploratory State-of-the-Art Review of Artificial Intelligence Applications in Circular Economy using Structural Topic Modeling

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Abstract
The world is moving into a situation where resource scarcity leads to an increase in material cost. A possible way to deal with the above challenge is to adopt Circular Economy (CE) concepts to make a close loop of material by eliminating industrial or post-consumer wastes. Integration of emerging technologies such as Artificial Intelligence (AI), machine learning, and big data analytics provides significant support in successfully adopting and implementing CE practices. This study aims to explore the applications of AI techniques in enhancing the adoption and implementation of CE practices. A systematic literature review was performed to analyze the existing scenario and the potential research directions of AI in CE. A collection of 220 articles was shortlisted from the SCOPUS database in the field of AI in CE. A text mining approach, known as Structural Topic Modeling (STM), was used to generate different thematic topics of AI applications in CE. Each generated topic was then discussed with shortlisted articles. Further, a bibliometric study was performed to analyze the research trends in the field of AI applications in CE. A research framework was proposed for AI in CE based on the review conducted, which could help industrial practitioners, and researchers working in this domain. Further, future research propositions on AI in CE were proposed.

Keywords Artificial intelligence · Circular economy · Emerging technologies · Structural topic modeling · Text mining · Big data analytics

1 Introduction

Recent advancements in the manufacturing sector and globalization are approaching planetary limits where a slight increase in carbon emission may lead to an exponential increase in global warming (Zwier et al. 2018; Khayyam et al. 2021). The various environmental impacts associated with global warming are land degradation, freshwater degradation, and biodiversity loss (Choi and Hwang 2015). Even the resource consumption is increasing drastically. According to a survey conducted in the European zone, 60% of End of Life (EoL) materials are still not recycled and reused for future use (Preston and Herron 2011). Circular Economy (CE) is one important solution to deal with the above problems. CE is an initiative of cleaner production as it supports the recycling and reuse of materials to optimize resource consumption and minimize environmental impacts (Husain et al. 2021). The definition of CE states as "a strategy which aims at reducing both inputs of virgin materials and output of wastes by closing economic and ecological loops of resource flows" (Haas et al. 2015; Husain et al. 2021). CE ensures benefits in Triple Bottom Line (TBL) aspects of sustainability, i.e., benefits in terms of economy, environment, and society (Ma et al. 2020; Husain et al. 2021). There are many issues associated with the traditional business model, such as heavy wastage, improper disposal, and high

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emissions (Riesener et al. 2019). Therefore, it is important to transform the linear economy model into the CE model.

According to a recent study (Kortelainen et al. 2019), applications of Artificial Intelligence (AI) has gained the interest of academics, practitioners, policymakers, and corporations across the world. AI integration in CE improves autonomous and remote monitoring efficiency during the production process and product lifespan. According to (Ramadoss et al. 2018), significant data is generated during manufacturing processes and during the use or disposal of materials, components, and products, and AI can assist in the analysis of this data. AI can aid processes by offering technical means for the quick response and feedback learning. Both are done efficiently, coping with high complexity and large volumes of data while increasing awareness (Ghoreishi and Happonen 2020). AI can be a crucial enabler of a systematic change, such as from data to decision-making processes. Many studies (Stock and Seliger 2016; Rajput and Singh 2019a, b) are available towards transforming the linear economy model into a CE model by adopting recycling, reusing, and remanufacturing strategies. However, there are several challenges to the practical implementation of the CE model. This can be addressed by deploying emerging technologies such as AI, machine learning, and big data analytics.

Recently, many researchers have shown the applications of AI in CE practices (Alonso et al. 2021; Pieroni et al. 2021). AI is one of the critical technologies of Industry 4.0. The use of AI algorithms has numerous advantages in the CE domain, such as real-time data analysis to decrease traffic congestion, the energy usage of cooling services optimization, etc. AI development has produced powerful algorithms for analysis which helped in prediction, optimization, pattern recognition, etc. (Lv et al. 2020). In this regard, this article aims at analyzing the importance of AI in CE practices to enable the digital CE model. A systematic review was presented by collecting articles in the field of AI and CE. The SCOPUS database was used to gather papers in AI in CE by using appropriate keywords. 220 articles were shortlisted to perform the systematic review. To start with the review, Structural Topic Modeling (STM) based text mining approach was used to generate thematic topics (Sharma et al. 2021). Then shortlisted articles were reviewed based on these generated thematic topics from STM. Further, the bibliometric study was also performed to analyze the trends of research articles published in the field of AI in CE. Then finally, a conceptual framework was proposed which integrates AI with CE practices which could enable successful adoption of AI approaches in CE practices. This study was carried out to answer the following research questions:

RQ1. What are the AI techniques which could be helpful in the adoption of CE practices?
RQ2. What are the current research trends associated with AI in CE?
RQ3. What are the potential future research directions in the area of AI in CE?

Based on the above research questions, the following objectives are specified for this article:

- To identify important AI techniques which enable smooth adoption and implementation of CE practices.
- To explore and visualize recent research trends in AI adoption in CE.
- To propose research propositions for future research directions of AI in CE.

To achieve these objectives, this study starts with a systematic literature review of AI articles in CE. STM-based text mining technique was utilized to generate topics in the field of AI in CE from shortlisted articles. Different aspects of AI in CE were explored, and various AI techniques have been explored for their adoption in the CE model to enhance its acceptability. Bibliometric studies were also carried out to analyze the research trends of AI in CE. Further, a conceptual framework was proposed which could enhance the utilization of AI techniques in the adoption of CE practices.

The remaining section of this article is as follows: Sect. 2 shows systematic literature review methodology, Sect. 3 shows bibliometric analysis, Sect. 4 shows structural topic modeling approach, review of articles based on generated topics were presented in Sect. 5. Discussion and implications were presented in Sect. 6, and Sect. 7 shows conclusions of the study.

2 Systematic Literature Review

A systematic literature review (SLR) methodology has been followed to review the published articles in the field of AI in CE. The SLR methodology helps in exploring the uncovered area in the investigating field. In this work, we followed the SLR methodology as presented by Agrawal et al. (2021a, b). To follow the SLR methodology in AI in CE, we collected published articles from the SCOPUS database. Scopus database was chosen for article collection as it is one of the largest databases consisting of peer review articles. The SLR methodology followed in this study is presented in Fig. 1.

In this article, we followed a four-stage review methodology. The first stage includes the retrieval of articles in the investigating area. Here we collected articles from the

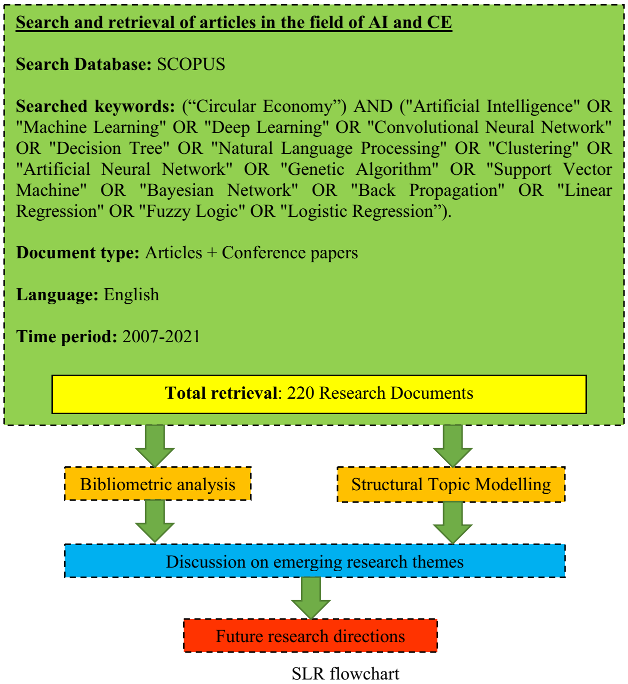


Fig. 1 SLR flowchart

SCOPUS database by giving shortlisted keywords. A total of 220 articles were shortlisted for analysis.

After shortlisting articles, we moved to the second phase, where we presented the bibliometric study of the shortlisted articles. Here, we used the R package and VOS viewer for bibliometric study and network analysis. We analyzed year-wise, country-wise, and journal-wise trends of articles. We also analyzed the authors' collaboration and country collaboration followed by research fields in the area of investigation using STM. We used the R package and performed the STM to generate ten emerging research fields in the area of AI in CE.

Further in stage 3, we identified ten emerging research themes. Each theme was discussed, and a future direction preposition was presented for each research theme. Then finally, in stage 4, we proposed a future research framework, implications of the study, and conclusion based on the study. The recently published studies on applications of AI techniques in CE are given in Table 1.

3 Bibliometric Study

Bibliometric analysis is being used by many researchers in different fields to analyze the research trends in the investigating field. Various packages available to perform bibliometric analysis are Histcite, Gephi, Bibexcel, R package, and Pajek

Table 1 Applications of AI techniques in CE

Article	AI techniques	Research Focus
Nañez Alonso et al. (2021)	Convolutional neural network (CNN)	A methodology was developed for automatic recycling of materials, namely paper, glass, plastic, etc., using image identification and CNN. The study helped to distinguish the glass and plastic materials
Salvador et al. (2021)	Fuzzy logic	The authors aimed to analyze the strategies of CE through a survey. The authors used fuzzy logic approach to analyze the data. The study helped in identifying focus areas where industries need to focus more for successful implementation of CE practices
Yin et al. (2021)	Genetic algorithm	Genetic algorithm was used in optimizing the makespan in flow shop scheduling for sustainable rubber manufacturing. The findings show the reduction of makespan by 11.2%
Lieder et al. (2020)	Support vector machine	The authors developed an algorithm for the circular business model using support vector machine that trained the survey data and analyzed the consumer choice behavior
Schmidt et al. (2020)	Linear regression	The study identified and analyzed material efficiency indicators that reflect the environmental impact of the waste management system. The authors used linear regression to analyze the relationship between different indicators with environmental impact
Susanty et al. (2020)	Clustering	The authors examined the relationship of environmental-oriented supply chain cooperation practices on CE practices in wooden furniture industry using a clustering approach
Li et al. (2019)	Artificial neural network (ANN)	The study aimed to establish a model related to multi-objective disassembly sequence optimization and evaluate the remaining useful life of end-of-life products using ANN
Anttonen et al. (2018)	Natural language processing	The authors showed the application of natural language processing in analyzing the relationship between industry, university, and government facilitating CE
Zamfir et al. (2017)	Decision tree	Decision tree models were used to identify the most significant factor influencing the decisions on CE adoption in European SMEs
Wang (2016)	Bayesian network	The author aimed to analyze and predict the stability of CE practices in the industrial chain with the help of the Bayesian network. The author analysesd the relationship between factors that affects the stability of CE

Table 2 Main information collected about AI and CE articles

Important information collected from bibliometric analysis	
Time period: 2007–2021	
Description	**Results**
Shortlisted documents	220
Article	124
Conference paper	57
Conference review	17
Review articles	22
Average citations per document	6.06
References	11,867
Author Information	
Authors	675
Authors with single-authored documents	21
Authors of multi-authored documents	654
Author's Keywords	703
Single-authored documents	37

(Agrawal et al. 2021a, b). In this study, we used the R package to perform bibliometric analysis. R package also has a web interface which is called biblioshiny. In this study, we used the web interface of the R package called biblioshiny. The main information about shortlisted articles is presented in Table 2.

The year-wise publications of the articles in the field of AI and CE are presented in Fig. 2.

From Fig. 2, an increasing trend can be seen in the research which started in 2007. It is found that from 2018 the trend in the publication has increased rapidly, i.e., 115% increase in trend in 2018 as compared to 2017. Figure 3 presents a world map showing the number of articles published by different countries.

From Fig. 3, it is found that China is the leading country in terms of publication in the field of AI and CE with 113 articles, followed by the UK and Germany with 37 and 26 articles, respectively. Figure 4 presents a world map showing the citations received by different countries in AI and CE fields.

From Fig. 4, it is found that Finland, China, and Italy are the leading countries with 249, 163, and 162 received citations, respectively. Table 3 shows the top leading journals in the AI and CE field.

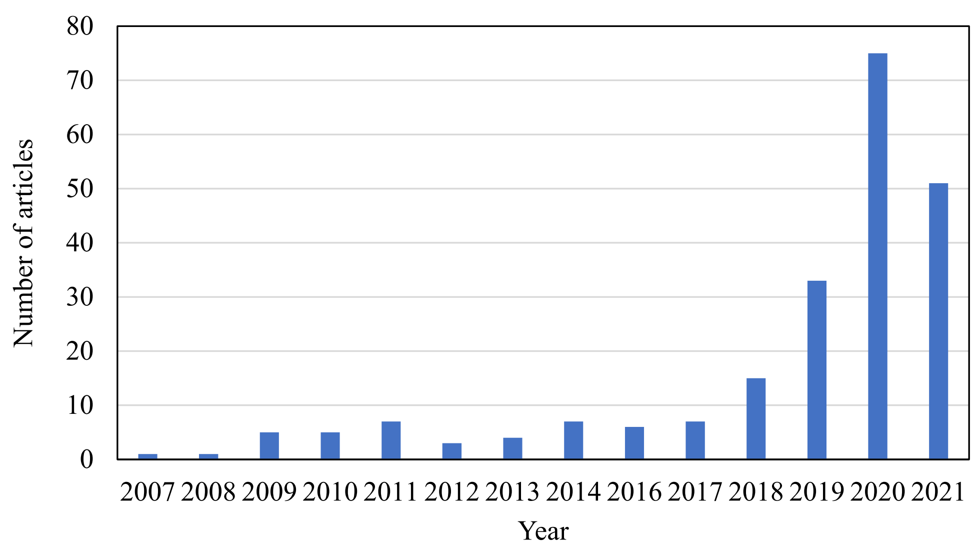
From Table 3, it is found that the Journal of Cleaner Production and Sustainability are the leading journals publishing article in the field of AI in CE with 24, 17 and 7 articles respectively.

Network analysis was carried out using the VOS viewer package to analyze the collaboration network among researchers and countries. Figure 5 shows the author's collaboration network for AI and CE research field.

Among 220 articles considered in this study, there are 673 authors. For network analysis, we considered all authors, and the number of clusters formed is 9 with 73 authors in it, while other authors are not included because of low connectivity with other authors. The top three clusters are shown in red, green, and blue colours, with 11 authors in each. The smallest cluster is the one shown in pink colour with only five authors in it. From the author's collaboration network, it is found that Wang J. is the author having the maximum connection with other authors with 16 links and 21 total link strengths.

Figure 6 shows the country's collaboration network for AI and CE research field. Among 220 articles considered in this study, there are 48 countries. For country network analysis, we considered all countries, and the number of clusters formed is 9 with 36 countries in it while other countries are not included because of low connectivity with other countries. The biggest two clusters are shown in red and green colour, with 6 countries each. The smallest cluster shown in pink has with only 3 countries in it. From the country's collaboration network, it is found that China is having a maximum connection with

Fig. 2 Year-wise publication of articles in the field of AI in CE



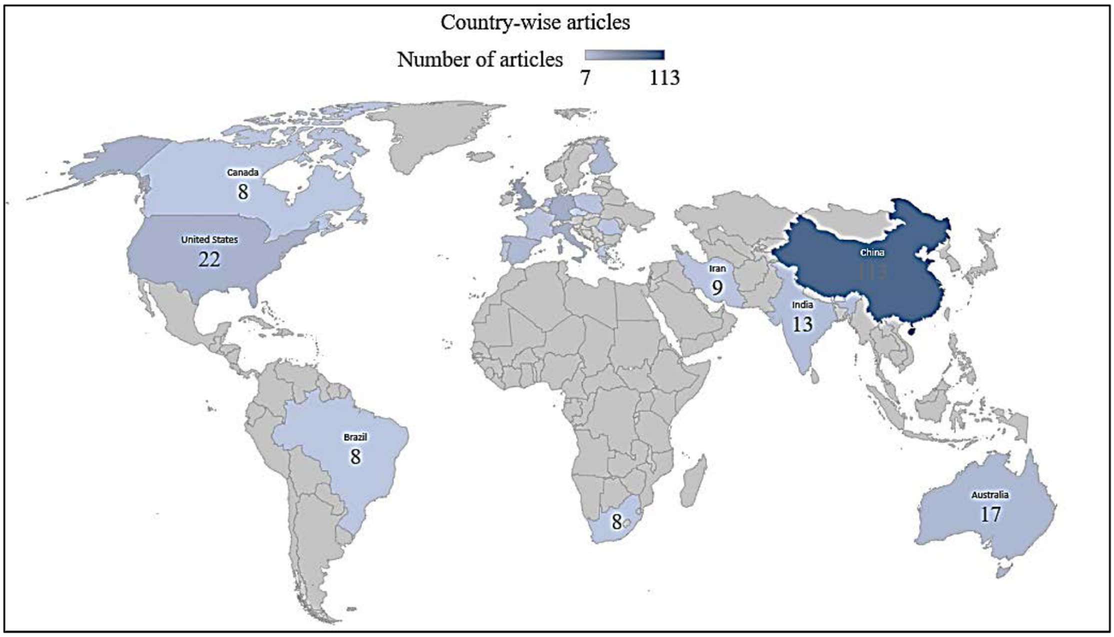


Fig. 3 Country-wise number of articles published in AI and CE

other countries with 18 links and 23 total link strength. UK, Germany, Italy and USA are the other countries which have good collaborations with other countries.

4 Text Analytics using Structural Topic Modeling

Topic modeling is an essential technique of text analytics that is used to analyze text from documents. It is an unsupervised machine learning technique that learns itself and explored different themes in collecting documents (Sharma et al. 2021). The generated themes from topic modeling techniques are

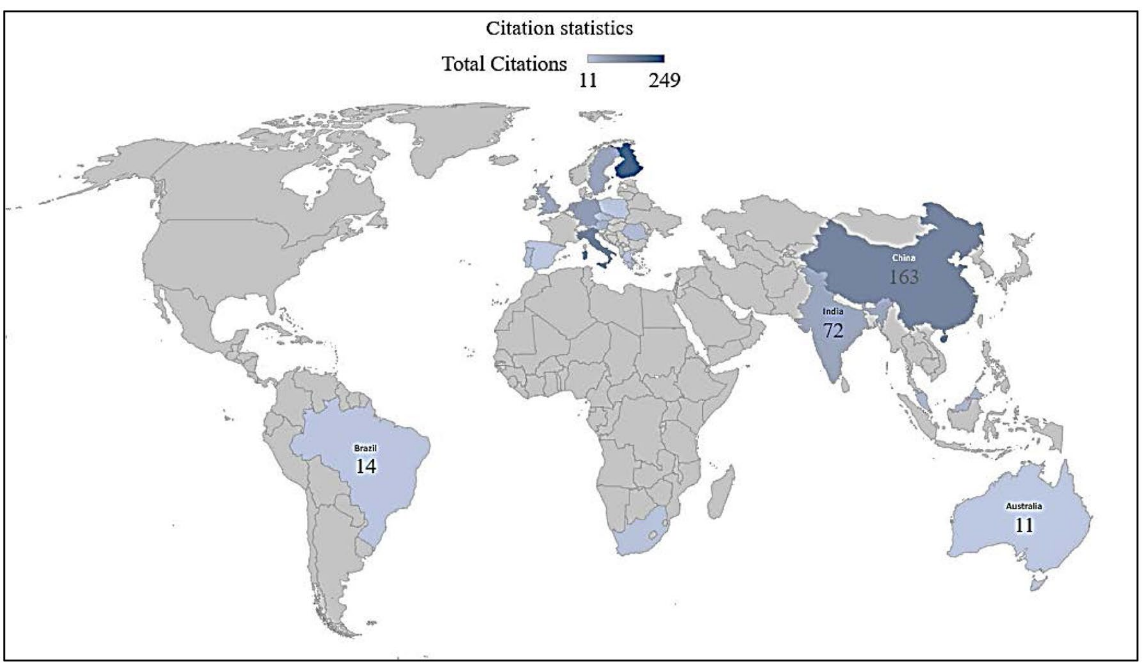


Fig. 4 Country-wise citations in the field of AI and CE

Table 3 Important journal publishing articles in the field of AI in CE

Journals	Articles
Journal of Cleaner Production	24
Sustainability (Switzerland)	17
Resources Conservation and Recycling	7
Procedia CIRP	4
Science of The Total Environment	4
Sustainable Production and Consumption	4
Technological Forecasting and Social Change	4
Waste Management	4
Energies	3
Clean Technologies and Environmental Policy	2

based on the similarity of words in documents. So, a structure of topics can be generated from topic modeling by extracting similar keywords from the collection of documents. The generation of the structure of topics from topic modeling is called Structural Topic Modeling (STM).

STM is a topic modeling technique that helps in analyzing the text from the documents and generates thematic topics based on similarity and frequency of words. STM is a generative type of model, and the generative process for the STM technique is as follows (Roberts et al. 2019):

Step 1: Analyze the topic parameter θ_d for each word in document d by using the log-normal linear model from the vector of document covariates X_d.

$$\overrightarrow{\theta_d}|X_d\Upsilon,\Sigma \sim LogisticNormal(\mu = X_d\Upsilon,\Sigma) \quad (1)$$

where, X_d Represents 1-by-P vector, Υ represents P-by-(k-1) matrix of coefficients, and Σ represents a covariance matrix of (K-1)- by- (K-1).

Step 2: Generate the topic model β, which represents words of each topic (k), by utilizing baseline distribution (m) of length V, the topic-specific deviation $K_{k,v}^{(t)}$ of topic k, the covariate group deviation $K_{yd,v}^{(c)}$ of topic k, and the interaction between each topic and group deviation $K_{yd,k,v}^{(i)}$

$$\beta_{d,k,v} = \frac{exp(m_v + K_{k,v}^{(t)} + K_{yd,v}^{(c)} + K_{yd,k,v}^{(i)})}{\sum_v exp(m_v + K_{k,v}^{(t)} + K_{yd,v}^{(c)} + K_{yd,k,v}^{(i)})} \quad (2)$$

Step 3: for every word in collected documents, ($n \in \{1,2,3,\ldots\ldots..N_d\}$):
Draw word topic assignment based on an unsupervised model that can be generated from multinomial distribution:

$$Z_{d,n}|\overrightarrow{\theta_d} \sim Multinomial(\overrightarrow{\theta_d}) \quad (3)$$

$$W_{d,n}|Z_{d,n},\beta_{d,k=Z_{d,n}}\overrightarrow{\theta_d} \sim Multinomial(\beta_{d,k=Z_{d,n}}) \quad (4)$$

To generate thematic topics from collected documents, the text from the article abstract, title, and keywords were combined from the text corpus, which is used as input to the STM approach. Initially, text cleaning was done by removing commonly used words, also called stop words. Further, non-English words, special characters, equations, and numbers were also removed to make it feasible for the STM approach. A total of 220 documents were considered, as shown in Table 2. R-package is an open-source package

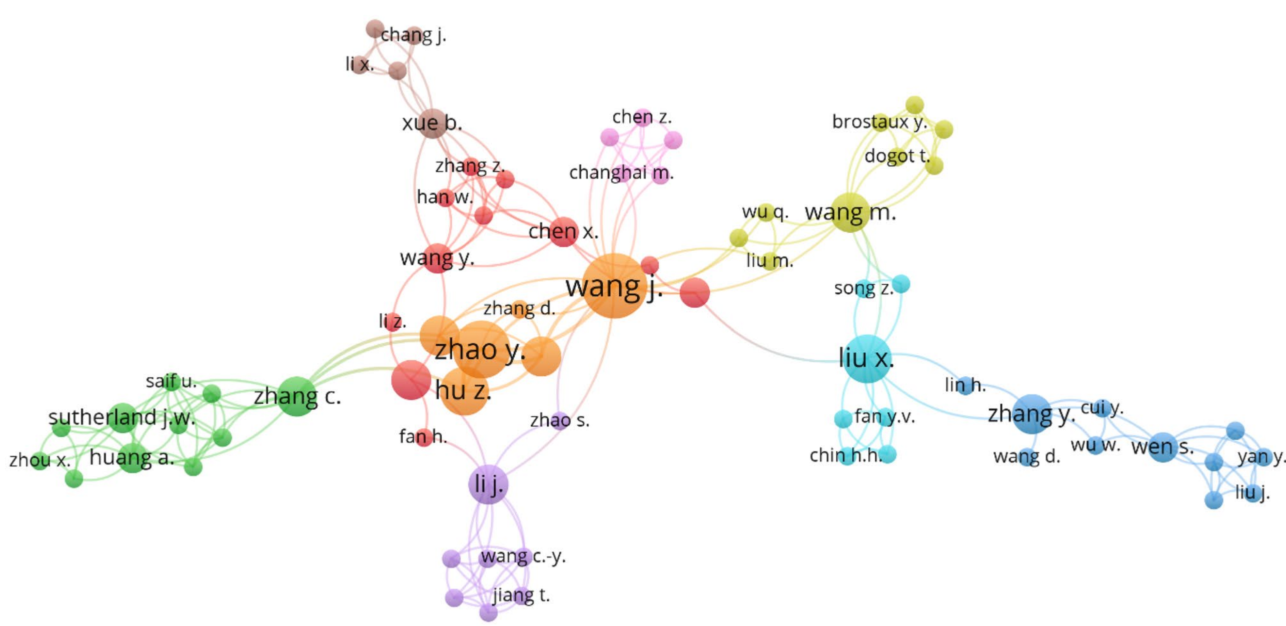


Fig. 5 Author collaboration for AI and CE research work

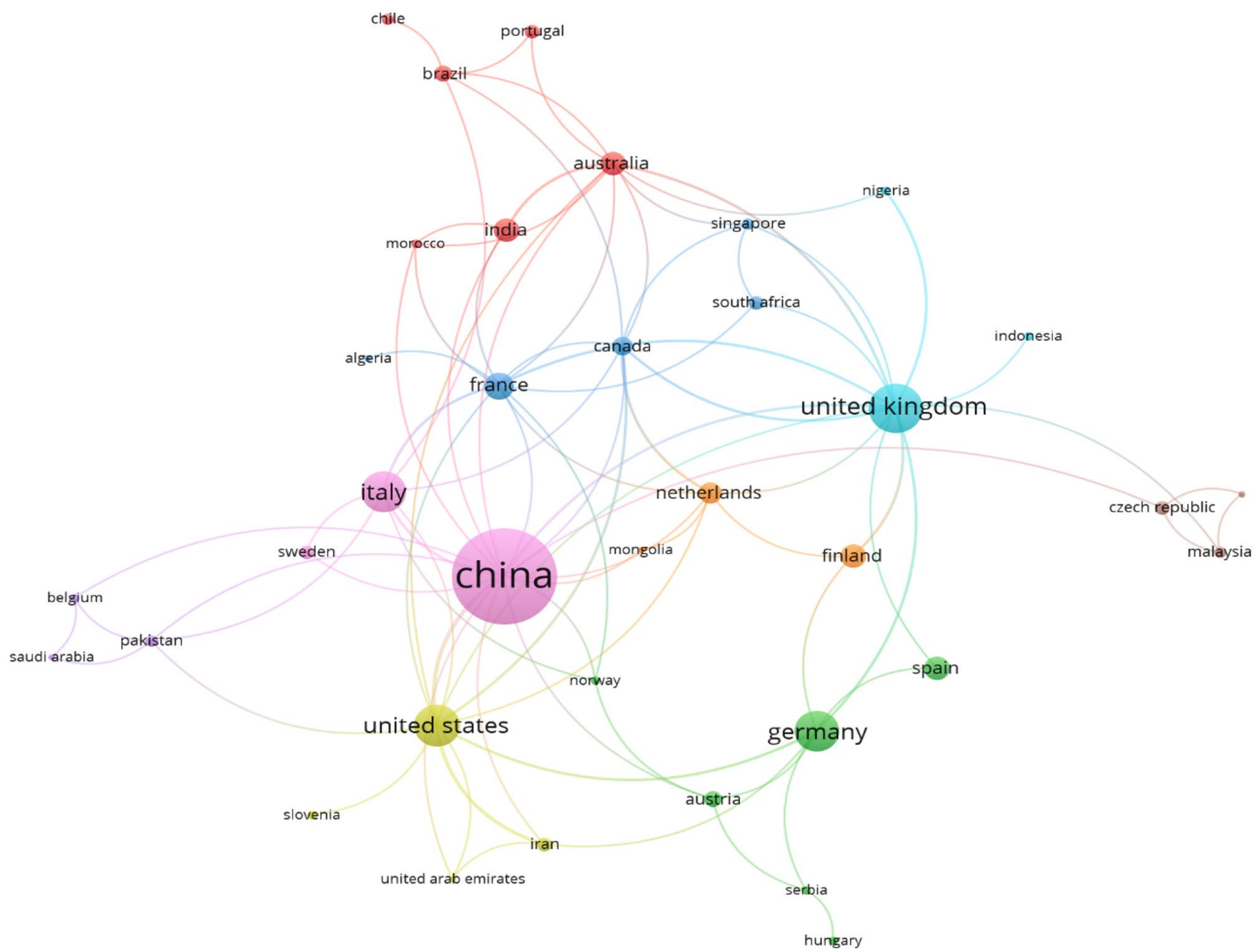


Fig. 6 Country collaboration for AI and CE research work

used for statistical analysis, so we used the R-package to perform the STM approach using the inbuilt STM library in R-package. The generated topics from the STM approach are presented in Fig. 7.

From Fig. 7, the topic labels are generated. Topic 1 label "Industrial strategy towards CE" generated from the probabilistic distribution of most frequent words such as 'circular', 'economic', 'industrial', 'sustain', 'research', 'innovation', and 'strategy'. Topic 2 label "Sustainable development" generated from words 'environment', 'development', 'studies', 'energies', 'china', 'research', and 'analysis'. Similarly, other topics are generated from respective most frequent words and are presented as below.

Topic 1: Industrial strategy towards CE; **Topic 2:** Sustainable development; **Topic 3:** AI algorithms in CE models; **Topic 4:** Economy development with CE; **Topic 5:** Waste management; **Topic 6:** System management with AI; **Topic 7:** CE logistics and network design; **Topic 8:** Product service system (PSS); **Topic 9:** Design strategies in CE; **Topic 10:** Research models on CE.

Further, in each topic, the important words are identified using the inbuilt command in R-package. The top identified words under each topic are presented in Table 4.

Table 4 shows high frequent words under each generated topic. Two other metrics were also presented in Table 4, namely Frex and Lift. Lift shows frequent words which are only important to the specific topic, usually lift words are rare words in a particular topic. Frex stands for frequency-exclusivity words, which means frequent and exclusive words to a particular topic. After generating topics from the STM approach, we have reviewed articles based on each topic, and discussion has been provided for each topic in the next section. The world map of emerging research topics is presented in Fig. 8.

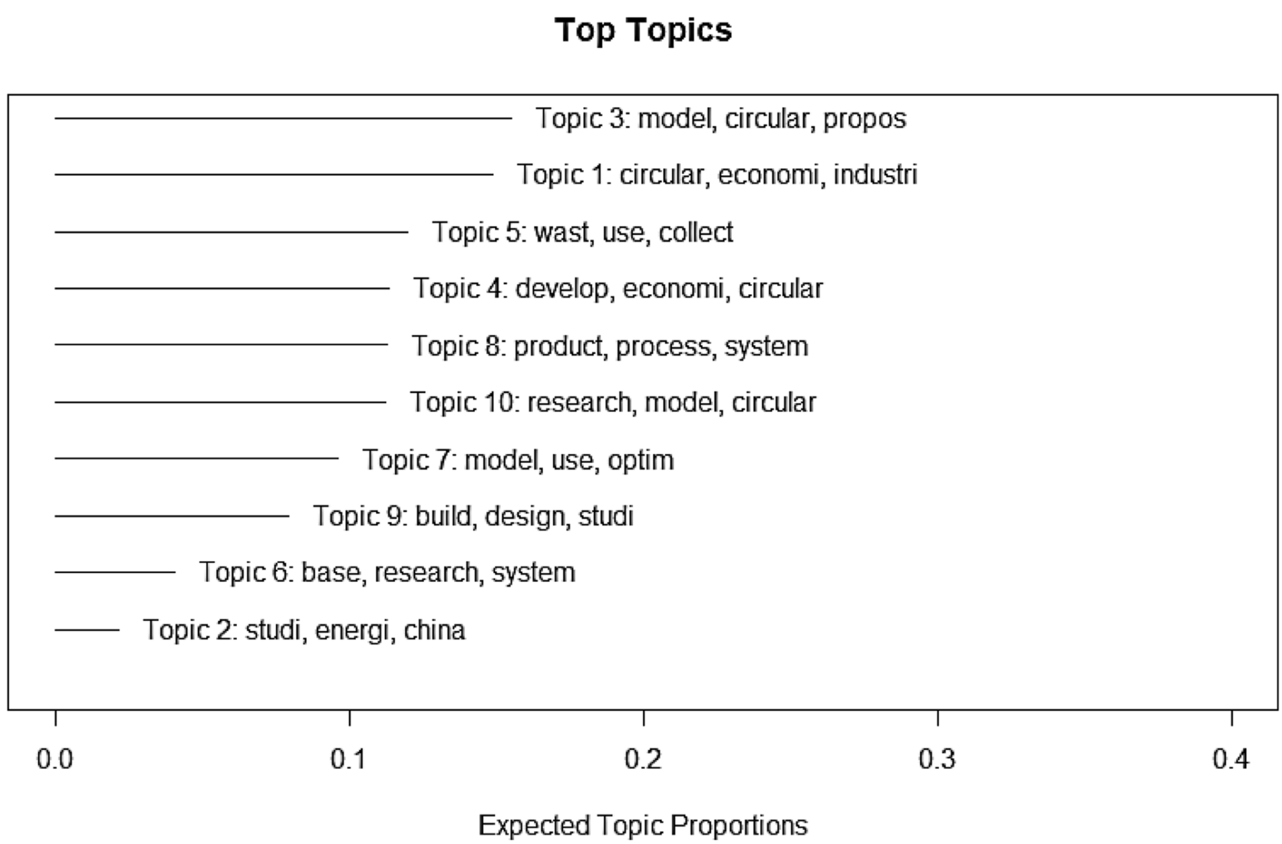


Fig. 7 Generated topic labels from the STM approach

5 Emerging Research Themes of AI and CE

5.1 Industrial Strategy towards CE

The transformation from linear to a CE within business brings various practical challenges for organizations. To overcome these challenges, the organization needs to develop strategies that guide industrial business strategists and designers in transitioning from linear to CE. A CE model brings various benefits, such as minimized input waste resources and emissions. The systematic implementation of the CE in the European Union considered recycling the most common industrial strategy (Mhatre et al. 2021). The industrial sectors, namely, health equipment, recreation, mining, and quarrying, showed a slow approach towards CE implementation in European Union (Mhatre et al. 2021). The CE implementation in Indian automobile industries adopted an industrial strategy of identifying and prioritizing the roadblocks to focus on specific potential roadblocks hindering CE implementation (Agrawal et al. 2021a, b). Various roadblocks existed in the adoption of CE in Indian automobile industries, namely, 'lacking the ability to deliver high quality remanufactured products', 'lack of awareness in society', 'maintaining the design of reuse product', and 'lack of consumer knowledge about refurbished product' (Agrawal et al. 2021a, b). The CE has been developed as a promising avenue for an organization to realize sustainability.

The integrated resource flow approach for a CE consisting of a production-consumption system was advantageous for implementing sustainable CE (Velenturf et al. 2019). The industrial strategy of creating sustainable wealth from holistic management of natural resources for establishing sustainable development had been used in developing countries (Scheel et al. 2020; Zhu and Gao 2021). Moreover, the low carbon industrial strategy for reducing climate change was used for accelerating the transformation towards low carbon CE (Busch et al. 2018; Huo et al. 2021a, b). The most common circular business models were recycling procedures and results-oriented product-service systems that uncovered the CE's strategic capabilities (Rosa et al. 2019). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Table 4 Top identified words under each topic

S. No	Topic label	Words with the highest probability	Frex	Lift
1	Industrial strategy towards CE	circular, economic, industrial, sustain, research, innovation, strategy	barrier, innovation, firm, practical, companies, strategy, concept	avenue, federal, managerial, triple, call, research
2	Sustainable development	environment, development, studies, energies, china, research, analysis	river, vanadium, low-carbon, china, energies, ecology, protect	inner, tradable, vanadium, aircraft, automatic
3	AI algorithms in CE models	model, circular, proposal, use, economical, product, algorithm	disassemble, proposal, genet, multi-object, algorithm, remanufacturer, grey	constitute, cylinder, decide, fungus, padding, shorten, arrange
4	Economy development with CE	develop, economic, circular, enterprise, evaluate, network, industries	enterprise, IEEE, region, coal, evaluation, index, form	complicate, core-peripheral, animal, bi-level, brand, citizenship, decentralization
5	Waste management	waste, use, collect, recycle, management, result, economic	collect, waste, food, aware, restaurant, vehicle, regression	baseline, continue, express, fleet, incineration, Italian, possess
6	System management with AI	base, research, system, manage, model, technology, application	sport, code, heritage, image, culture, computer, web	annotation, circuit, e-commerce, ahp-fuzzy, antiseismic, apollo, arm
7	CE logistics and network design	model, use, optimal, studies, develop, logistics, network	bioenergies, reaction, temperature, optimal, cell, locate, logistics	bioenergies, enough, fix, spss, square, strict
8	Product service system (PSS)	product, process, system, use, cost, manufacture, remanufacture	remanufacture, manufacture, will, cost, asset, repair, robot	American, award, computer-aid, monte carlo, reactor, spare
9	Design strategies in CE	build, design, studies, material, construct, process, waste	build, concrete, membrane, residential, eco-innovation, component, deep	matter, mortar, multi-material, pavement, percentage, polymer, reusable
10	Research models on CE	research, model, circular, sustain, business, data, new	fashion, topic, business, review, custom, literature, consumer	curriculum, home, society, attain, co-create, crisp-dm, embed

Proposition 1: The development of a framework depicting strategies that guide industrial policymakers during the transition from linear to the CE.

Proposition 2: The identification of best industrial strategies for the CE to be adopted by industries using fuzzy-based theory.

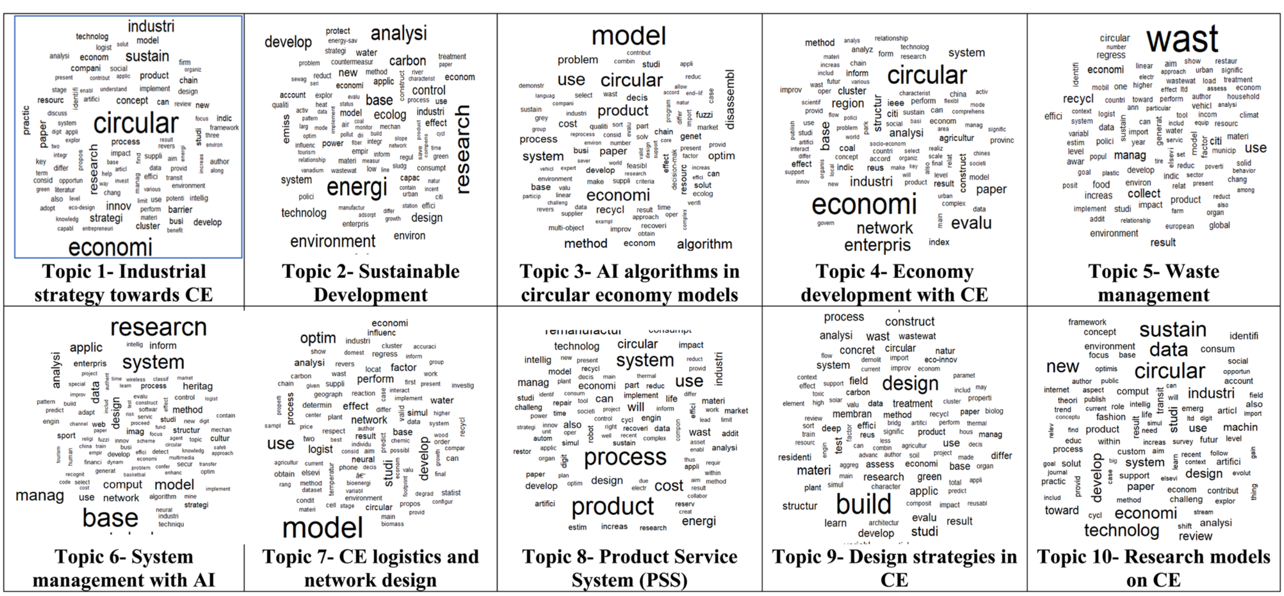


Fig. 8 Word map of ten emerging research topics of AI

Proposition 3: The development of an AI-based model of CE indicators and performance assessment of an organization for its smooth transition.

5.2 Sustainable Development

The major concern for developed and developing economies is sustainable development, as economic development has headed to more expensive and scarcer resources. The CE is considered to be the sustainable economic system where the economic development is dissociated from the recourse use by recirculation and reduction of the natural resources. The circular supply chain and circular business help understand sustainability ambitions (Geissdoerfer et al. 2018). Sustainable development is a significant difference between linear and circular economies, emphasizing recycling, waste reduction, and pollution reduction (Sauvé et al. 2016; Khurshid et al. 2021). The sustainable development framework resulted in seven operating principles, namely, adjusting inputs to the system to regeneration rates, closing the system, maintaining the value of resources within the system, adjusting outputs from the system to absorption rates, educating for CE, reducing the system's size and designing for CE necessary for the implementation of the CE had been proposed (Suárez-Eiroa et al. 2019). Sustainability is considered to be the condition of a CE where a strong beneficial relationship existed between them (Geissdoerfer et al. 2017). The strongest relationship had been observed between CE practices and sustainable development goals targets, namely, Affordable and Clean Energy, Clean Water and Sanitation, Responsible Consumption and Production, Decent Work and Economic Growth, and Life on Land (Schroeder et al. 2019; Bie et al. 2021). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 4: Analysing the relationship between recycling, waste reduction, and pollution reduction to achieve sustainable development.
Proposition 5: The development of a sustainable framework depicting CE operating principles for a smooth transition from linear to CE.
Proposition 6: Investigating the linkage between CE practices and sustainable development goals target using survey-based techniques.

5.3 AI Algorithms in Circular Economy Models

AI is one important technologies of Industry 4.0. The use of AI algorithms has numerous advantages in the CE domain, such as real-time data analysis to decrease traffic congestion, the energy usage of cooling services optimization, etc. AI development has produced powerful algorithms for analysis which helped in prediction, optimization, pattern recognition, etc. The contribution of AI had been observed in the transformation of linear economy models to CE models. The CE and AI had been identified as common driving enablers of Industry 4.0 (Rajput and Singh 2019a, b). AI provided a significant advantage across all the tasks and functions in the reverse logistics process with a CE (Wilson et al. 2021). AI supports the CE strategies in the operational process by analyzing the operational data paired with failure data and maintenance logs for decision support and improved fault diagnosis (Kristoffersen et al. 2020). The use of AI was seen in segregating plastics and improving recycled plastics information using blockchain smart contracts driven by multi-sensor data fusion AI-based algorithms to transform the CE of plastic waste (Chidepatil et al. 2020).

Moreover, AI algorithms applications were observed in achieving a sustainable CE where customer involvement was significant (Agrawal et al. 2021a, b). The AI algorithms are supported correctly by distinguishing between plastic and glass with the help of image recognition techniques within a CE (Alonso et al. 2021). The AI algorithms also helped introduce the sectorial business models' patterns to aid manufacturing organizations in decreasing complexity and uncertainty within CE business models (Pieroni et al. 2021). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 7: Utilizing AI techniques to perform real-time data analysis for energy usage of cooling services optimization.
Proposition 8: Exploring the indispensable enablers of Industry 4.0 for smooth adoption of CE in organizations.
Proposition 9: The AI algorithms applications for distinguishing between plastic and glass with the help of image recognition technology within the CE.

5.4 Economy Development with CE

The economic development with the CE has gained significant importance due to its ability to stress recycling resources to protect the environment and save resources. CE has been adopted as a development strategy by various countries. It played a significant role in managing the industrial structure, building an ecological civilization, changing the way of economic growth, and finally supporting sustainable development. China's basic national policy promoted CE as a model of economic development based on the ecological movement of natural materials, proper utilization of natural resources, and compliance with ecological laws to attain economic development (Zhijun and Nailing 2007). The CE development model formed the principles of reduce, reuse, and recycle to achieve sustainable development that had been perceived as 'from cradle to cradle' approach (Qiao and Qiao 2013). The Chinese government considered the construction of CE as an essential aspect of city growth. A certain relationship had been observed between the urban circular development index and economic development in China (Wang et al. 2018).

The economic development measured by European Union countries gross domestic product influenced the CE variables, namely, the recycling rate of municipal waste, the recycling rate of packaging waste by type of packaging, recycling of bio-waste (kg per capita), the recycling rate of e-waste, etc. (Grdic et al. 2020). The economic development with CE improved on reducing the pollution emissions in high polluting and energy-intensive industries and supervising the energy consumption (Fan and Fang 2020). Furthermore, backstop technological development, pollution abatement, technological development, and autogenous structural ecologicalization were found to be the potential drivers of sustainable economic growth (Zhou et al. 2020). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 10: The influence of CE as a development strategy in managing the industrial structure, building an ecological civilization, changing the way of economic growth and sustainable development.
Proposition 11: The role of economic development within the CE on reducing the pollution emissions in high polluting and energy-intensive industries.
Proposition 12: The development of AI-based for supervising the energy consumption within the CE.

5.5 Waste Management

Waste management is an important consideration to achieve a CE. Moreover, it is the foundation for the CE to achieve better resource management and more waste prevention. In European Union, a strategic waste management policy was adopted to reach the CE targets by substantially modifying its course of adoption (Luttenberger 2020). A multi-waste management concept had been proposed as a foundation for the CE model. The multi-waste management includes complete recovery of waste as energy and slow release of fertilizers, mass, and energy integration of individual waste treatment processes to achieve more economical single integrated process and treatment in the facilities such as municipal, biomass, and industrial (Hidalgo et al. 2019; Zhao et al. 2020). The socio-economic effect of changes in the waste management system had been observed on waste management in a CE (Tomić and Schneider 2020). Within the CE, the role of waste management was to promote the preservation of material value by recycling (Salmenperä et al. 2021). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 13: Identifying the strategic waste management policies using user-based prediction with the help of AI techniques.
Proposition 14: The development of a multi-objective waste management model for optimizing energy consumption using AI-based optimization algorithms.
Proposition 15: The role socio-economic effect changes in waste management concerning waste management within the CE.

5.6 System Management with AI

The integration of industries, government, and institutions is necessary to enhance the system and achieve sustainable benefits (Anttonen et al. 2018). This is also called as triple helix concept on integration. The adoption of big data technologies, IoT devices, and AI systems has increased the adoption of data analytics techniques for effective system management (Lv et al. 2021a). The usage of the data-driven model was seen in literature to analyze the challenges faced by the manufacturer in the different manufacturing processes (Fisher et al. 2020). A genetic algorithm was used to develop an environment cost control system (Chen et al. 2020). A Decision Support System (DSS) was proposed by Alavi et al. (2021) for sustainable supplier selection by utilizing best–worst method and a fuzzy inference system. A decision-making approach was used by Vlachokostas et al. (2020) to analyze different alternatives of bio-waste treatment to generate bioenergy and other bio-products from the bio-waste. A design for remanufacturing based closed-loop supply chain framework was shown in the literature (Niu et al. 2019) for effective decision making in design for remanufacturing investments. An IoT-based DSS was proposed for the CE business model to effectively monitoring and tracking of products in real-time (Mboli et al. 2020). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 16: The use of an AI-based data-driven model to explore the challenges faced by the manufacturer in the different manufacturing processes.
Proposition 17: To examine various alternatives of bio-waste treatment to generate bioenergy and other bio-products from the bio-waste using AI techniques.
Proposition 18: The development of an IoT-driven decision support system for the CE business model to supervise and track products in real-time effectively.

5.7 CE Logistics and Network Design

A shift from a linear economy to a CE is one of the prime goals of government organizations to tackle environmental, economic, and social challenges. A nonlinear optimization model was presented by Lechner and Reimann (2020) for decision-making related to reprocessing disposition. A vehicle routing problem was proposed for a two-echelon reverse logistics network design to minimize carbon emissions (Cao et al. 2021). The reverse logistics practices are being considered to promote cleaner production and a CE. In this regard, the barriers to the adoption of reverse logistics practices were analyzed (Dutta et al. 2021). The emerging technologies of AI were explored for their application in reverse logistics and CE (Wilson et al. 2021). As reverse logistics concepts are gaining importance, it is essential to analyze supplier selection from the viewpoint of reverse logistics (Zhang et al. 2020). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 19: Use of AI techniques to minimize the carbon emissions for two-echelon reverse logistics network design.
Proposition 20: To explore the role of AI in reverse logistics and CE.
Proposition 21: The prediction of supplier behavior in the reverse logistic application within a CE using AI techniques.

5.8 Product Service System (PSS)

PSS is a tool which is growing recently as a practical application for sustainability concepts (Pecorari and Lima 2021). Integration of CE, along with the product development and service stage, is a complex and challenging task (Halstenberg and Stark 2019). A product designer should consider both product development and service stage along with CE practices to satisfy customer demand. A PSS will be considered as a suitable model for product designers to satisfy all needs (Halstenberg and Stark 2019). A framework was proposed in the literature that is based on declining the resource uses to support PSS (Kjaer et al. 2019). The decline in resource uses will enable the successful adoption of CE strategies. Sustainable PSS can be considered as an ideal business model for economic, environmental, and social development (Hernandez 2019). The factors of PSS were analysed for its acceptance and enhancing customer experience (Pecorari and Lima 2021). PSS business model can be an effective way to adopt CE practices (Pieroni et al. 2019). The adoption of a closed-loop supply chain and PSS will enhance operational efficiency by increasing throughput in the production process (Camilleri 2019; Huo et al. 2021a, b). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 22: The development of a sustainable product-service system framework to adopt CE practices in the organization.
Proposition 23: The development of an AI-based closed-loop supply chain and product-service system to improve the operational efficiency in the production process.
Proposition 24: Exploring several design alternatives of product-service systems with regards to smart manufacturing for enhancing CE adoption in industries.

5.9 Design Strategies in CE

The two important aspects of sustainable production and CE are process optimization and improved design. The consideration of economic and social aspects in cleaner production is considered as sustainable production design (Van Fan et al. 2020). A closed-loop supply chain model was presented by (Liao et al. 2020) for the agriculture sector. Different algorithms were used, such as genetic algorithm, Simulated Annealing, and Keshtel Algorithm to optimize the proposed model. Sustainable design theories such as Eco-design, PSS design, collaborative ecosystem design, and sustainable business model design were effective design theories that can be adopted in industries to enable socio-economic systems (Baldassarre et al. 2020). The usage of additive manufacturing technologies was seen in literature to automate repair and restoration activities. AI-based techniques can be used for design optimization in additive manufacturing-based repair activities (Abd Aziz et al. 2021). Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 25: Prioritizing the design strategies in the CE using an AI-based decision support system that guides industrial practitioners during the transition to the CE.
Proposition 26: Examining the role of additive manufacturing technologies to automate and predict repair and restoration activities using AI algorithms.
Proposition 27: Exploring the significance of sustainable design theories such as Eco-design, collaborative ecosystem design, and sustainable business model design in industries to enable socio-economic systems.

5.10 Research Models on CE

A circular business model was proposed by Bianchini et al. (2019), which will enhance the adoption of CE practices in the industry. The proposed circular business model was a visualization tool helps in identification of opportunities or unexplored area for implementation of CE practices. A decision support system was proposed for the CE business model, which uses IoT sensors for tracking, monitoring, and analyzing products in real-time (Mboli et al. 2020). Deep learning models can be used to analyze and predict the amount of waste construction material that can be reused (Akanbi et al. 2020). Machine learning algorithms were also used in literature to analyze the population behavior towards the CE model (Lieder et al. 2020). A hierarchical structure of the CE model was proposed by Planing (2018) to transform the linear model into the circular model. A data-driven model was proposed in literature based on data mining technologies (Fisher et al. 2020). Researchers used a machine learning model to optimize power consumption (Wang and Zhang 2020). A closed-loop supply chain model was developed for plastic recycling (Ren et al. 2020), in which a stochastic programming model was proposed for analyzing carbon emissions. Thus, after reviewing the above-mentioned topic, we can propose the followings propositions under this topic for future research:

Proposition 28: Development of AI-based decision support system for a CE business model that uses IoT sensors to analyze products in real-time.

Proposition 29: From the sustainable development point of view, practical strategies of CE enabling sustainable development could be prioritized using fuzzy-based theories.

Proposition 30: The influential barriers and enablers of the CE could be identified and used for mathematical and optimization models to optimize the industrial practices to achieve more profit and reduced cost.

6 Discussion and Proposed Research Model

The present study utilizes structural topic modeling and a systematic literature review to explore the research on AI in CE. The structural topic modeling helped in extracting the thematic topics from identified papers. The generated thematic topics, namely Industrial strategy towards CE, Sustainable development, AI algorithms in CE models, Economy development with CE, Waste management, System management with AI, CE logistics and network design, Product-Service System (PSS), Design strategies in CE and Research models on CE have been identified. With respect to industrial strategy towards CE, significant contributions had been observed. Recycling was the most common industrial policy in the European Union's systemic implementation of the CE. The industrial sectors of health equipment, recreation, mining, and quarrying have been reluctant to adopt CE in the European Union (Mhatre et al., 2021). To focus on real possible roadblocks hindering CE implementation, Indian automotive industries used an industrial policy of finding and prioritizing roadblocks (Agrawal et al. 2021a, b). The adoption of CE in the Indian automotive industry was hampered by several issues, including a lack of ability to produce high-quality remanufactured goods, a lack of societal awareness, retaining the design of reuse products, and a lack of customer information about refurbished products (Agrawal et al. 2021a, b).

Recycling procedures and results-oriented commodity service processes were the most popular circular business models, revealing strategic capabilities for CE (Rosa et al. 2019). The CE, which emphasizes recycling, waste reduction, and emission reduction, differs significantly from the linear economy (Sauvé et al. 2016). The sustainable development framework proposed by Suárez-Eiroa et al. (2019) provided seven operating principles: adjusting system inputs to regeneration rates, closing the system, preserving the importance of capital within the system, adjusting system outputs to absorption rates, educating for CE, decreasing system scale, and planning for CE, all of which are needed for the adoption of CE. The role of AI in the transition of linear economy models to CE models has been observed. Industry 4.0's common moving enablers have been described as the CE and AI (Rajput and Singh 2019a, b). In the reverse logistics phase of the CE, AI offered a major advantage across all activities and functions. Furthermore, a CE was encouraged by China's basic national policy as a mode of economic development focused on the sustainable movement of natural materials, proper use of natural resources, and adherence to environmental laws to achieve economic progress (Zhijun and Nailing 2007; Ahmed et al. 2020).

The CE development model established the concepts of reduce, reuse, and recycle in order to accomplish sustainable development, previously referred to as a "cradle to grave" solution (Qiao and Qiao 2013). The CE variables, such as the recycling rate of urban waste, the recycling rate of packaging waste by the form of packaging, the recycling of bio-waste (kg per capita), and the recycling rate of e-waste, were all affected by economic growth as determined by the gross domestic product of European Union countries (Grdic et al. 2020). As a basis for the CE paradigm, a multi-waste management framework was suggested by Hidalgo et al. (2019). The application of AI in CE had also been observed in Multi-waste management. Multi-waste management requires full waste energy recovery and slow fertilizer release, mass, and energy convergence of individual waste treatment systems to achieve a more cost-effective unified, optimized solution and treatment of urban, biomass, and industrial facilities. The adoption of data analytics techniques for efficient system management has increased as big data technology, IoT computers, and AI systems have become more popular (Lv et al. 2021b). The

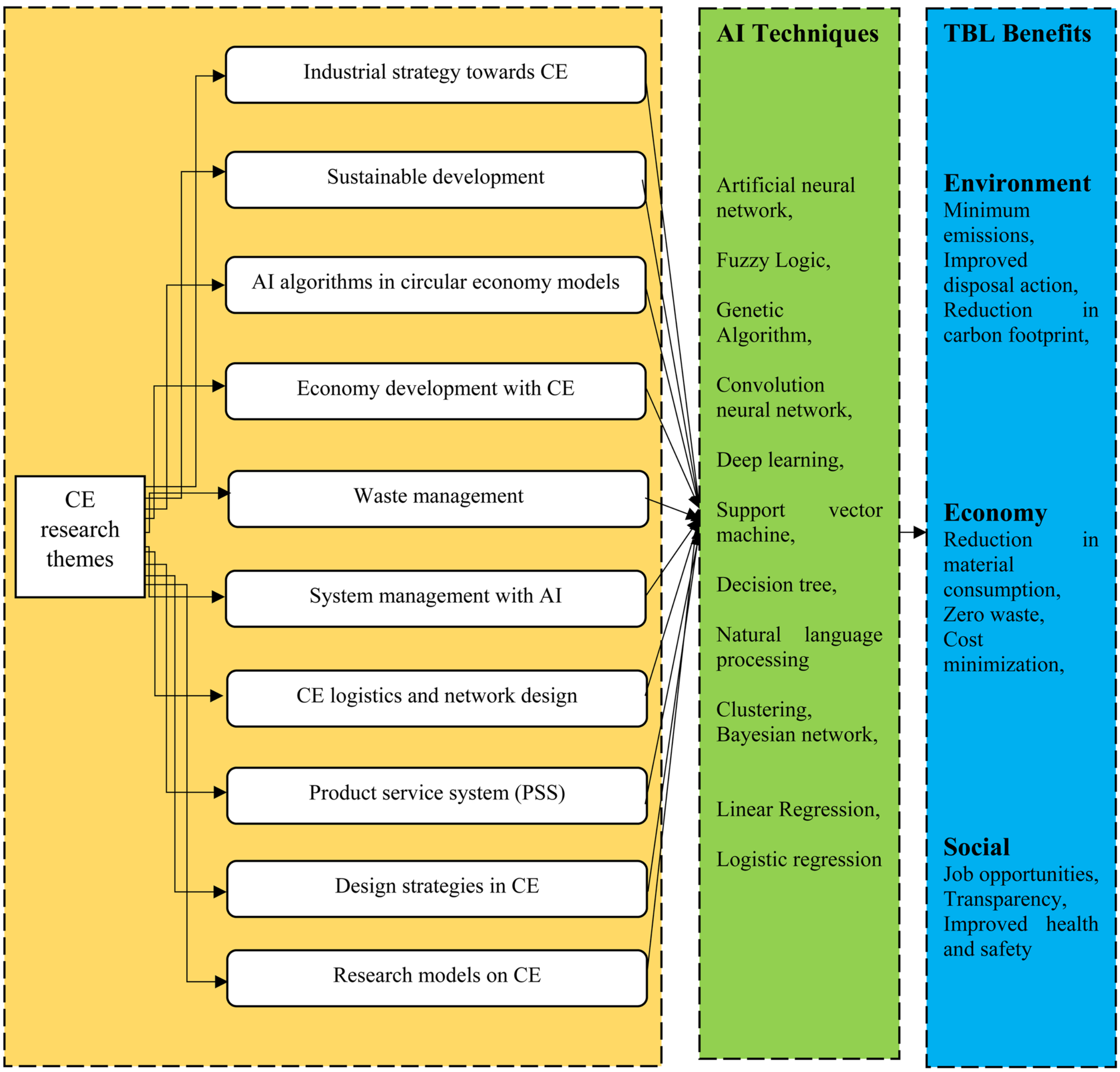


Fig. 9 A proposed research framework for AI in CE

use of a data-driven model to analyze the problems faced by manufacturers in various manufacturing processes has been documented in the literature (Fisher et al. 2020). In order to encourage cleaner manufacturing and a CE, reverse logistics activities are being discussed. The obstacles to reverse logistics adoption were investigated (Dutta et al. 2021).

AI's new innovations were investigated for their potential use in reverse logistics and the CE (Wilson et al. 2021). A data-driven paradigm focused on data mining technology had been presented (Fisher et al. 2020). A future research framework is proposed in Fig. 9.

Sustainable PSS can be seen as an optimal business model for the advancement of the economy, the environment, and culture (Hernandez 2019). The variables of PSS were investigated for their recognition and ability to improve customer service (Pecorari and Lima 2021). The PSS business model can be a useful tool for implementing CE activities (Pieroni et al. 2019). Eco-design, PSS design, shared environment design, and sustainable business model design are examples of successful sustainable design theories that can be implemented in industries to allow socioeconomic structures (Baldassarre et al. 2020). In the literature, machine learning algorithms were also used to analyze population behavior against a CE paradigm (Lieder et al. 2020). Planing (2018) suggested a hierarchical CE model framework for converting a linear model to a circular model.

The proposed framework includes the ten emerging research themes of CE in the first stage. In the second stage, the proposed framework includes various AI techniques which can be included in CE practices to achieve enhanced results. Then finally, the third stage includes the triple bottom line benefits achieved by integrating AI in CE in terms of environment, economy, and social benefits.

6.1 Implications

6.1.1 Theoretical implications

The present study presents a bibliometric analysis and STM to understand the current status of research studies on AI applications in CE. Further, based on STM generated topics, a systematic literature review has been carried out. This article also provides a comprehensive understanding of AI applications in the context of CE by recognizing emerging research themes, namely industry strategy, sustainable development, CE models, economic development, waste management, system management, logistic and network design, product service system, design strategies and research models. The present study also discusses the future opportunities for AI applications in CE.

6.1.2 Practical implications

The adoption of AI techniques can provide support to managers to systematically adapt industrial strategies and practices for the successful implementation of CE. The key understandings developed from this study would help the managers to utilize the AI techniques for transforming linear economy to CE. Moreover, the findings of the study will help industry practitioners to reflect on various AI techniques in the context of CE. Industry practitioners and managers can investigate the potential of AI techniques to develop strategies and sustainable development frameworks. The product designers can employ AI in executing faster designs which can help in reducing waste facilitating waste management. There is a requirement to operate circular business models in a smooth manner. In such cases, industrial practitioners can utilize AI, which strengthens the circular business models by merging the historical and real-time data from manufacturers, distributors, and users. This would help in optimisation of business processes and automated decision making.

7 Conclusions

CE aims to keep the materials at its best and highest use. AI is one of the potent tools to accelerate the transformation from the linear economy to the CE. The present study focusses on the research works conducted on AI in CE encompassing various aspects, namely Industrial strategy towards CE, Sustainable development, AI algorithms in CE, Economy development with CE, Waste management, System management with AI, CE in logistics and network design, PSS, Design strategies in CE and Research models. The present study conducts a bibliometric analysis and STM to understand the trends of research happening in the domain of AI in CE and generate the thematic topics for conducting systematic literature analysis. This study provides a deeper understanding of the significance of AI in CE and can help the industry for a smooth transition towards the CE.

As every research possesses few limitations, this study also has certain limitations. The authors have attempted their best to include the entire gamut of extant literature about AI in CE based on the themes identified. However, the study is partially limited in scope as white papers, field reports, book chapters, etc., have been excluded from the analysis. In addition to this, the review of case studies about AI in CE published as company reports in various countries has not been considered in this study. In addition, the present study deals only with studies in the field of AI applications in CE in general. This provides a future opportunity to explore the studies about specific AI applications in CE to enhance overall sustainability. The present study is restricted to only the SCOPUS database, and other databases could also be explored in the future. Moreover, the other bibliometric analysis packages, namely Gephi, Pajek, and BibExcel, can be considered in future research. This study proposed 30 propositions that provide potential future research directions in the field of AI in CE. Also, the adoption of AI techniques to enhance CE practices can be validated in different sectors such as healthcare, automobile, manufacturing, and so on. Moreover, the current study provides a literature review on the applications of AI which is one of the emerging technologies in the smooth adoption of CE but in future research, an exploratory review literature can be conducted by considering other emerging technologies i.e., blockchain, internet of things, argument reality, big data etc.

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