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Review

APPLICATIONS OF SOCIAL NETWORK ANALYSIS IN PROMOTING CIRCULAR ECONOMY: A LITERATURE REVIEW

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Abstract. Circular economy (CE) is a sustainable alternative to tackle global challenges like climate change, waste, and pollution. The relations, perceptions and behaviors of stakeholders in circular economic activities may form barriers that hinder the circular transition. The promotion of CE requires investigating the interactions and information flow between CE stakeholders from a network perspective. This study revisits the applications of social network analysis (SNA) in promoting CE. Related concepts of CE and the research contents of SNA are reviewed. A bibliometric analysis is conducted to provide a bird's eye on the research status and trend. On this basis, we summarize the challenges of promoting CE and refine specific problems, around which we review the research status of network modeling methods and statistical measures, information diffusion models, mining methods of perceptions, and social influence analysis. This study outlines the pathways through which SNA contributes to promoting CE, such as through revealing the relational structure and characteristics of stakeholders, forming and changing perceptions of stakeholders, improving behaviors of stakeholders, and examining the development of CE. The lessons learned from the review and future prospects are extensively discussed in combination with the features of the information age from both theoretical and practical perspectives.

Keywords: circular economy, sustainable development, social network analysis, stakeholder analysis, information diffusion.

JEL Classification: D85, M48, O30, Q56, Q57.

Introduction

Circular economy (CE) is a sustainable alternative to tackle global challenges like climate change, waste, and pollution. In practice, CE-related policies and initiatives may involve multiple stakeholders in the process from formulation to implementation, including governments, businesses, foundations, citizens, and consumers (Shen et al., 2020; Niang et al.,

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2022). Different CE stakeholders have extensive and complex social connections, including interactions and information flows. The social connections between CE stakeholders give rise to uncertainty in social relations, perceptions and behaviors, and may create barriers in the transition from a linear economic system to a circular one. For instance, the public may refuse to cooperate with the waste sorting policy (Zheng et al., 2020); consumers' poor perceptions of returning products may impede the reverse logistics in circular models (Shahidzadeh & Shokouhyar, 2022). To remove such barriers and introduce high efficiency to the operation of CE systems, many scholars studied how to promote CE (Schraven et al., 2019; Ghinoi et al., 2020; Doussoulin & Bittencourt, 2022). The promotion of CE can be performed from the technical and practical perspectives. The former seeks technological breakthroughs, such as the invention of renewable materials, while the latter focuses on tackling barriers in practical circular transition, often related to relations, perceptions, and behaviors of multiple stakeholders (Ghinoi et al., 2020). This study focuses on the promotion of CE at the practical level.

Today's information age makes it easy for social entities to connect with each other without geographical restrictions. The Internet also facilitates information retrieval and data analysis (Blazquez & Domenech, 2018), thus supporting the modeling process and analysis of networks. Social network analysis (SNA) refers to an interdisciplinary methodology that provides a quantitative method for analyzing various social interpersonal relations, behavioral characteristics, and the laws of information diffusion. Regarding the promotion of CE at the practical level, SNA shows great applicability due to its merits in quantifying relational structure and social interactions of CE stakeholders, and the interpretability of information diffusion (Gong et al., 2022; Marques & Manzanares, 2022; Venegas et al., 2022).

SNA involves multiple aspects including network structure, actors, and information (Fang & Jia, 2017). The CE context is also related to resources, regenerative processes, waste management, and many other subfields (Mirzynska et al., 2021). To promote academic innovations and advancements in the application of SNA to promote CE, it is essential for scholars to grasp the research status and clarify the correspondence between different functions of SNA and practical challenges associated with circular transition. In this regard, a literature review can help understand the academic development, summarize lessons, and provide insights for further investigations. Despite much literature addressed the applications of SNA to promote CE, till now, we do not find a literature review on this topic. In view of this, this study dedicates to reviewing the applications of SNA in promoting CE, outlining specific pathways through which SNA contributes, and answering the following questions:

1) What are the publication status, subfields, and research trends regarding the applications of SNA to promote CE?
2) What are the challenges of promoting CE in practice?
3) How does SNA contribute to tackling the challenges?
4) What are the lessons and future research directions as per the research status?

To achieve our objectives, firstly, we introduce the definition and related concepts of CE, and the research contents of SNA. To facilitate understanding, a closed-loop presentation of CE concepts based on CE principles and the logical relations between the research contents

of SNA are presented. Then, a bibliometric analysis is conducted to provide a bird's eye on the research status and trend, by which we identify specific research hotspots. We summarize the challenges of promoting CE in four aspects: the complexities from multiple stakeholders, the difficulties in modeling information diffusion, the difficulties in mining stakeholders' perceptions, and the need to change perceptions and improve behaviors. Specific issues below each challenge are also refined. Around these challenges and issues, we review the research status of network modeling methods and statistical measures, information diffusion models, mining methods of perceptions, and social influence analysis. This study outlines the pathways through which SNA contributes to promoting CE. Briefly, SNA helps to reveal the relational structure and characteristics of CE stakeholders, form and change perceptions of stakeholders, improve behaviors of stakeholders, and examine the development of CE. The lessons learned from the review are summarized from both theoretical and practical perspectives. Future prospects are discussed around the practical fields of focus, massive stakeholders, variable data, and unstructured information.

The remaining parts of this paper are organized as follows: Section 1 introduces the related work and concepts about CE and SNA. Section 2 conducts a bibliometric analysis. Research challenges of promoting CE are summarized in Section 3. Section 4 reviews the research status of applying SNA to promote CE. Lessons and future prospects are presented in Section 5. The paper ends with conclusions in the last section.

1. Preliminaries

In this section, the related work and concepts about CE and SNA are introduced.

1.1. Circular economy: an economic embodiment of sustainable development

Natural resources are scarce, while the linear take-make-dispose logic prevalent in the economy is wasteful (Marques & Manzanares, 2022). It threatens the future availability of resources and thus is not sustainable (Nobre & Tavares, 2017). From a circular perspective, the waste of one may become the resource of the other in a closed loop (Patwa et al., 2020). To reduce consumption and increase yields, CE has become a sustainable alternative. The economics of the "Spaceship earth" proposed by Boulding (1966) is considered to be an early representative of the CE. Boulding (1966) claimed that the "cowboy economy" that consumes resources recklessly should transition to "spaceship earth" to realize the recycling of resources so that the earth can last forever. As for the conceptualization, the concept of CE was first formulated in a book by environmental economists Pearce and Turner (1990). It has attracted the attention of governments (Yuille et al., 2022), non-profit organizations[1], and scholars in the fields of economy (Suchek et al., 2021), energy (Yan & Xu, 2021), and materials (Doyle et al., 2022). Scholars regarded CE as an economic embodiment of sustainable development (Esposito et al., 2017; Stewart & Niero, 2018), and argued that CE-related practices must follow economic, environmental, and social sustainability (Ozkan-Ozen et al., 2020).

[1] Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org/

To clarify a conceptual boundary, this study borrows Ellen MacArthur Foundation's definition of CE: *a circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times.* It should be noted that many definitions have been proposed over time by introducing new economic and environmental understandings, new societal challenges, and new materials (Burmaoglu et al., 2022), but we can always reveal the core of CE based on its three principles summarized by Ellen MacArthur Foundation[1]: *regenerate nature*, *eliminate waste and pollution*, and *circulate products and materials* (at their highest value).

Based on the definition and principles of CE, many concomitant concepts have been derived. A clear understanding of various CE-related concepts can facilitate the practical implementation of CE initiatives. However, Mirzynska et al. (2021) found that there exist conceptual ambiguities about the topic of CE and a gap between the public perception and scientific significance of various concepts. They identified the concomitant concepts of CE from bibliographic databases and Twitter posts aimed at general audiences, and compared the results from these two sources. We group the concepts they identified into three categories as per the three principles of CE:

1) concepts related to resources and energy (the principle "*regenerate nature*"), e.g., resource-saving, renewable energy,
2) concepts related to waste, (the principle "*eliminate waste and pollution*"), e.g., waste reduction, green packaging,
3) concepts related to production and design process (the principle "*circulate products and materials*"), e.g., cleaner production, regenerative design.

The three categories of concepts form a closed loop as shown in Figure 1. These concomitant concepts correspond to the subdivided terms of CE in public discussion and scientific literature. Their classification is convenient for presentation and can constitute the retrieval strategy for the bibliometric work in Section 2.

The practical implementation of CE initiatives requires the support of various stakeholders (Ghinoi et al., 2020; Shen et al., 2020), including governments, business associations, foundations, citizens, and consumers. Many barriers may result in inefficiency to hinder the

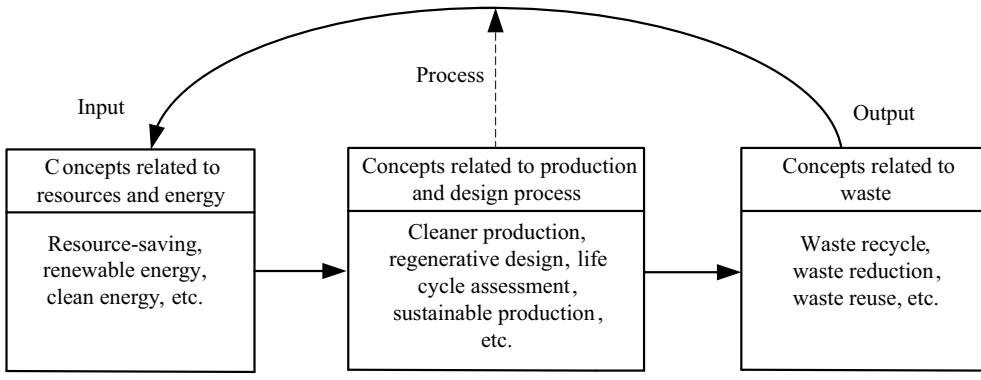

Figure 1. The closed-loop presentation of the concomitant concepts of CE

implementation, such as the previously mentioned perception gap on CE-related concepts (Mirzynska et al., 2021), which can lead to situations where stakeholders refuse to cooperate. To promote the CE and efficiently realize the transition from a linear economic system to a circular one, the interactions and information flow between multiple stakeholders need to be investigated, which requires a network perspective. In this regard, SNA shows great applicability. For example, Boumaiza et al. (2018) studied how the information in an online social network and a city neighborhood network may influence the residential adoption of renewable energy technologies; Ghinoi et al. (2020) investigated the stakeholders' knowledge exchange networks on CE subtopics, aiming to improve stakeholders' behaviors. Next, we introduce the related work of SNA.

1.2. Social network analysis

SNA refers to an interdisciplinary methodology based on informatics, mathematics, sociology, management, psychology, and so on. It provides a quantitative method for analyzing various human social relations, behavioral characteristics, and the laws of information diffusion. According to the survey of Freeman (2004), regarding the structural perspective of society, Comte (1853) who developed sociology as a science between 1830 and 1842 was the first scholar to look at society in terms of the interconnections among social actors. Comte (1853) advocated a systematic comparative perspective in sociology. As for the collection of relation data for social empirical analysis, it can be traced back to Huber's (1802) study in the early 19th century about social patterning among nonhuman animals. Network analysis methods were originated from graph theory, where a network consists of a set of nodes and edges connecting these nodes. Tree-based images were used in sociology as early as the ninth century to display the general patterning of kinship (Freeman, 2004). With regards to the conceptualization of SNA, Moreno (1934) developed the sociometry and wrote explicitly about "networks" and "the effects beyond the two persons and the immediate group". Radcliffe-Brown (1940), an anthropologist, described the social structure as the "network of social relations", which is regarded as the origin of SNA conceptualization. SNA focuses on networks whose nodes are social entities like nations, organizations, and individuals (Hsu et al., 2020; Feng et al., 2022). Accordingly, the edge of the networks corresponds to a certain connection or relation between social entities. In this sense, SNA coincides with practical scenarios that require the study of interaction patterns between multiple stakeholders.

SNA involves three aspects of research contents: 1) network structure, e.g., network modeling methods (Xu et al., 2021; Sweet & Adhikari, 2022), quantitative analysis of statistical measures (Marques & Manzanares, 2022), community detection (Mansoureh et al., 2022), 2) the actors (stakeholders) on the network, e.g., individual influence analysis (Tabassum et al., 2022), opinion mining (Zarrabeitia-Bilbao et al., 2022), 3) information on the network, e.g., information diffusion model (Granovetter, 1978). As shown in Figure 2, the network structure is the carrier for the interactive relations of actors and the information flow. Actors in a network are the subject that promotes the diffusion of information, and the information in a network is the object that induces actors' behaviors and perceptions. Both the subject and object affect the network structure.

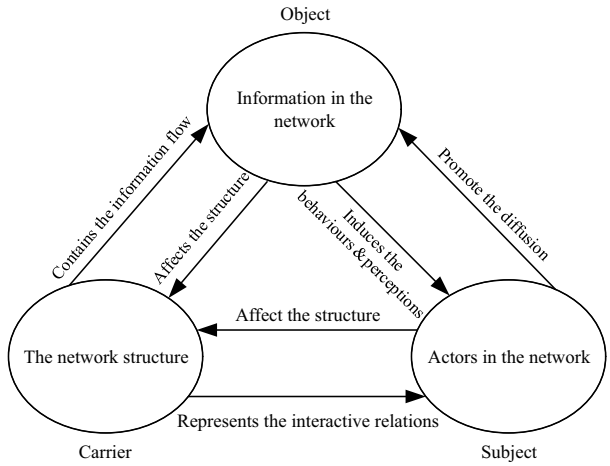

Figure 2. The research contents of SNA

In terms of the network structure, the common task is to investigate the relations between multiple actors to model the network and then apply statistical measures for analysis. The network can be modeled by interview (Schraven et al., 2019) or automatic algorithm (Watts & Strogatz, 1998). The statistical measures include those at the node-level, meso-level, and network-level (Oliveira & Gama, 2012; David-Barrett, 2023). The node-level measures serve to find key actors. For example, the degree of a node can identify the actors who involve many relations with others while the betweenness of different nodes can find actors who connect different regions of the network and thus control the information flow (Ghinoi et al., 2020). The meso-level measures aim to measure the statistical characteristics of communities containing different stakeholders, promote cooperation, and analyze resource flow and circulating paths. The meso-level measures include not only the aggregation result of node-level measures, but also special measures such as modularity for measuring the degree of separation between different communities (Jokar et al., 2022) and clustering coefficients for measuring the internal connectivity of communities (David-Barrett, 2023). The network-level measures can be used to describe the characteristics of the whole network, or the distribution of node-level statistical results from a macro perspective. For example, the density reflects whether a network is dense or sparse (Marques & Manzanares, 2022), and the degree of centralization indicates whether a relation is centralized on specific actors (Zarrabeitia-Bilbao et al., 2022).

As for the research related to actors in a network, SNA provides a network perspective to analyze the behaviors of actors like consumption (Watanabe et al., 2021) or adoption (He et al., 2022). The most influential actors can be identified using statistical measures in SNA. Additionally, mining methods of actors' perceptions or opinions, such as traditional sentiment analysis methods and topic modeling methods, have been investigated in SNA. When applying these methods, the context of SNA gives rise to the necessity to consider information diffusion (Debnath et al., 2022) and the features of information on the network like informal text and linguistic ambiguities (Saranya & Usha, 2023).

Regarding the information in a network, the research content includes various information diffusion models, such as the linear threshold model (Granovetter, 1978), the independent cascade model (Goldenberg et al., 2001), and the epidemic model (Kumar & Sinha, 2021). The diffusion of information results in the behaviors and perceptions of actors, and thus is the basis for behavior analysis and opinion mining in the context of SNA. Also, the information diffusion model can be used to predict the implementation effects of CE initiatives (Boumaiza et al., 2018), trace the source of information, and serve as a further step of individual influence analysis to maximize the influence (Chang et al., 2018).

In recent years, various online social platforms such as Twitter and Facebook have flourished with the development of the Internet (Enikolopov et al., 2020), making it easy for social entities to connect with each other without geographical restrictions. Meanwhile, the Internet facilitates information retrieval and data analysis (Blazquez & Domenech, 2018), and thus lays the groundwork for the modeling process and analysis of networks. The above factors make SNA popular, but also bring challenges such as the massive nodes, the evolution of a network, the variability of group perceptions, and the concurrency of information diffusion (Fang & Jia, 2017).

2. Bibliometric analysis on the applications of social network analysis in promoting circular economy

To show the research status of the application of SNA in promoting CE, this section performs a bibliometric analysis of relevant publications.

We retrieve publications for bibliometric analysis based on the Web of Science Core Collection database[2], which covers six mainstream online index databases and has an index range from 1900 to the present. According to the concomitant concepts of CE identified by Mirzynska et al. (2021), the retrieval strategy is determined as:

> (*TS* = (*circular economy OR resource saving OR renewable energy OR clean energy OR waste recycl* OR waste recover* OR waste reuse OR waste reduce OR green packaging OR cleaner production OR cradle to cradle OR regenerative design OR life cycle assessment OR remanufacture OR sustainable production OR old for new service*) *AND TS* = (*"social network analysis"*)).

In the retrieval strategy, "TS" means topics. The Boolean operator "OR" connects the three types of concomitant concepts (subdivided terms) of CE to focus the retrieval scope on CE. The Boolean operator "AND" makes the retrieval results related to SNA. The wildcard "*" allows for possible variations of the keywords in the retrieval. Since it is not clear when SNA methods began to be applied to promote CE, for the sake of objectivity, the time range of the retrieval is not specifically set. It is noted that we use a quotation mark on "*social network analysis*" for precise querying in Web of Science, which would exemplify thoroughness and careful attention to detail in database search.

[2] Web of Science. https://www.webofscience.com/wos/woscc/basic-search

A total of 245 publications were obtained on January 4, 2023. We deleted the publications that did not involve the network of social entities and did not relate to the promotion of CE, and finally got 175 publications. Figure 3 shows the annual publication volume and annual citations of these publications. As per the retrieval results, the applications of SNA in promoting CE can be traced back to 2007 in which scholars applied SNA to promote sustainable agricultural production and energy adoption (Verbong & Geels, 2007). In recent years, the numbers of publications and citations have increased, showing the increasing popularity of the SNA method and the CE topic. Due to the intensification of global challenges such as climate change, biodiversity loss, waste, and pollution, the CE, as an economic embodiment of sustainable development, has gained great attention. To promote CE at the practical level, the relations, perceptions, and behaviors of multiple stakeholders need to be studied. In this regard, the SNA shows applicability due to its merits such as a network perspective, the quantifiability of social interactions, and the interpretability of information diffusion.

Using the VOSviewer software package[3], we obtained the co-occurrence relations of keywords in all retrieved publications, which refer to the occurrence of keywords together within a paper, and assist in identifying frequently appearing keywords in publications and their relationships. As shown in Figure 4, each node represents a keyword, and the node size represents the frequency of occurrence. An edge indicates that both the two linked keywords have appeared simultaneously. Colors are mapped according to the score value normalized by the average published time of keywords. The warmer the color is, the closer the time is to the present, while the colder the color is, the farther away the time is from the present. We analyze the co-occurrence relations as follows:

1) The edges between the high-frequency keywords "barriers", "circular economy" and "transition" demonstrate that many publications have identified the barriers in the transition to a CE model.
2) The keywords "management", "governance" and "strategies" indicate that the CE topic in these publications is mostly based on the perspective of the government or enterprises. The focus is to obtain managerial implications.
3) "Resilience" and "sustainability" show a strong link between CE and sustainable development.
4) "Stakeholder analysis", "diffusion", "knowledge", "trust", and "behavior" correspond to the research hotspots, from which we can summarize major challenges related to the promotion of CE.
5) Some keywords in different colors imply the specific CE fields that these publications have focused on in different time periods since 2007. Specifically, in the first few years, "environmental performance", "symbiosis", and "bibliometric analysis" are hot fields where SNA was used to promote CE, while in recent years, "adoption" (of some energy, circular model or lifestyle), "food", "waste", "industrial symbiosis", "bioenergy", and "biofuel" become popular. The changing CE fields reveal the research trends leaning towards public life, industry, and energy.

[3] VOSviewer, a bibliometric analysis software, offers robust visualization capabilities and is readily accessible for free download at: http://www.vosviewer.com/

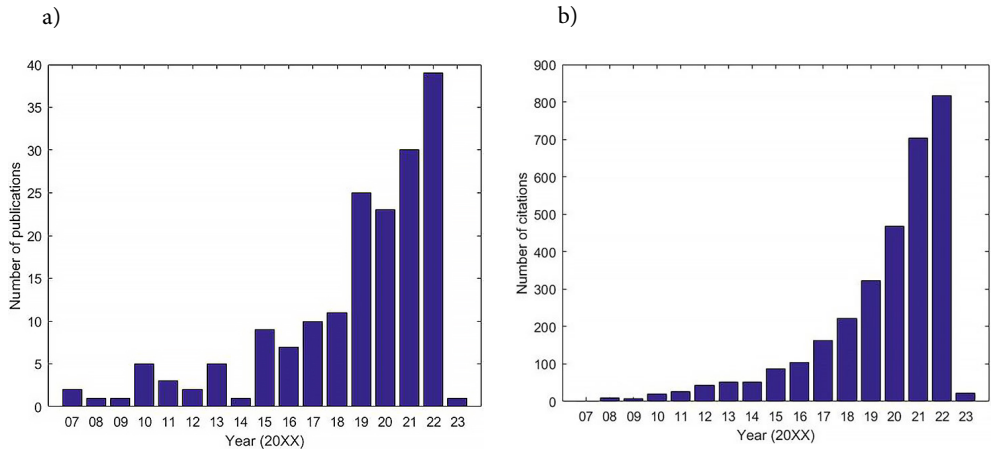

Figure 3. The annual statistics of publications (from 2007 to January 4, 2023):
a – the annual publication volume; b – the annual citations

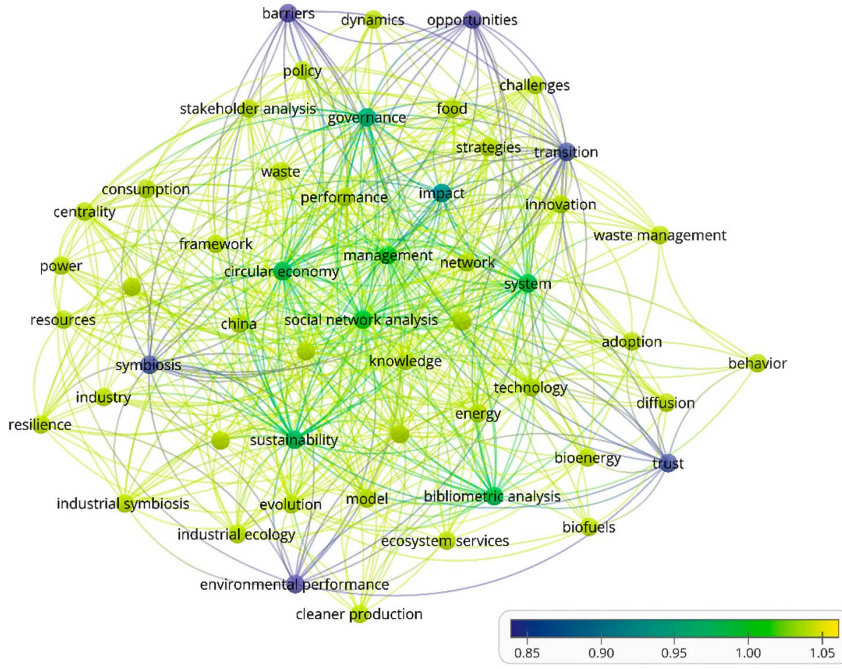

Figure 4. Keywords co-occurrence of publications retrieved on January 4, 2023

6) In general, the frequency of keywords related to energy and resources is higher than that related to waste. This may be because in the concepts shown in Figure 1, the input is directly related to public life and enterprise operation, but not all stakeholders pay attention to waste. Academia should pay more attention to waste management. Fortunately, research trends already have such a trend as shown by the "waste management" in a warmer color.

3. Challenges in promoting circular economy

During the transition from a linear economic system to a circular one, many barriers may hinder the implementation of CE policies and initiatives. In this section, based on the retrieved publications, we summarize the challenges in promoting CE at the practical level.

3.1. Complexities from multiple stakeholders

In the process from formulation to implementation, CE-related policies and initiatives may involve multiple stakeholders. This is because there are many parties involved in economic activities. Scholars have noticed this feature. To promote CE in the bio-based sector, Leipold and Petit-Boix (2018) surveyed the perceptions of stakeholders in the European Union and German bioindustry towards circular business models. The parties involved were policymakers, business associations, and individual companies, such as biotechnology businesses and manufacturers relying on biomass. Instead of the national level, Ghinoi et al. (2020) paid attention to the CE stakeholders at the local (urban) level, since here the community is more easily mobilized for collective action. They studied the role of knowledge exchange among local CE stakeholders in promoting CE in the city of Ferrara, Italy. The above work focused on the exchange of information or views among stakeholders. The exchange of material and energy was also covered in Niang et al. (2022)'s work. They studied the synergy relations of stakeholders in Cavigny (France) including co-product professionals, local residents' association, and local authorities to facilitate the energy transition to biogas. It is valuable to consider multiple stakeholders in practice. In the above studies, the perceptions of stakeholders helped to specify priorities and a clearer political scope for sustainable business practices (Leipold & Petit-Boix, 2018). The brokerage roles in pursuing common goals on specific CE activities were figured out (Ghinoi et al., 2020). The conditions of success and governance of biogas projects could be identified and discussed (Niang et al., 2022).

However, the need to consider multiple stakeholders also implies the complexities of promoting CE. Especially in the Internet age, information diffusion is rapid, potential stakeholders are massive, and their opinions and behaviors are ever-changing. All of these pose a challenge to formulating CE policies and advancing CE initiatives. We summarize the specific problems corresponding to this challenge as follows: 1) What methods and data are applicable for modeling the relations between multiple stakeholders, and studying the network evolution and group formation? 2) How to quantitatively analyze the characteristics of relations between multiple stakeholders? Here, the relation is understood as a broad concept, covering affiliation, cooperation, the exchange of knowledge, money, real materials, or other interactions. Clarifying the relations between stakeholders is an essential step to promote CE at the practical level.

3.2. Difficulties in modeling information diffusion

The interaction among multiple stakeholders is usually accompanied by information diffusion. In the practice of CE, stakeholders are faced with a transition from a linear mode to a circular one. To promote CE at the practical level, stakeholders' behaviors and perceptions

during the transition are worthy of attention, which are affected by information diffusion. The analysis of information diffusion can utilize simulation, prediction, and traceability to examine and explain the development of CE, for example, the implementation effects of certain CE activities, initiatives, or policies. Therefore, after clarifying the relations between multiple stakeholders, it is often required to grasp the law of information diffusion. The information diffusion analysis can be applied to viral marketing, prediction, and social recommendation (Chang et al., 2018). The counterparts related to these applications in the practice of CE include the marketing of circular business models (Lieder et al., 2017), the prediction of green energy adoption (Ernst & Briegel, 2017), and the recommendation of sustainable products (Wurster & Reis, 2022).

The basis of information diffusion is the relational structure of multiple stakeholders, based on which the law of information diffusion is modeled and then applied in simulation or prediction to guide the practice. The concurrency of diffusion, complex interactive patterns, and the evolution of relations and information bring difficulties to the analysis of information diffusion. The specific problems are as follows: 1) How to model the law of information diffusion among CE stakeholders in practice? 2) How to utilize the law of information diffusion to obtain enlightenment and guide the practice?

3.3. Difficulties in mining stakeholders' perceptions

As mentioned in Section 3.2, stakeholders' perceptions are valuable. It is necessary to mine the perceptions and gain enlightenment for promoting CE. In the circular transformation of a Dutch stony material supply chain, Schraven et al. (2019) analyzed the actors' perceptions of needed changes. They found that the diffusion of responsibility and differences in perceptions are barriers to the practice of CE and inspired the government to give right incentives. Gong et al. (2022) measured the communication effect of the zero-waste public environment policy based on the text data obtained from a social platform. They mined the topics of concerns to individuals and businesses, and suggested that the government should strengthen environmental policy communication by social media tools. The perceptions of stakeholders are also important at the corporate level. Zarrabeitia-Bilbao et al. (2022) analyzed public opinions on green energy and found that the proportion of corporate accounts participating in the online digital discussion was low. They emphasized that corporate business plans should incorporate public opinion trends.

The continuous development of the Internet and mobile technology makes it easy for stakeholders to participate in information diffusion, form perceptions, and influence the perceptions of others, which poses difficulties for the mining process of perceptions. The mining process needs to consider the mutual influence of stakeholders caused by information diffusion (Debnath et al., 2022). Additionally, specific to the method for mining perceptions based on the contents generated by stakeholders, it needs to be compatible with the contents that are often short and rich in linguistic ambiguities such as polysemy (Saranya & Usha, 2023). This is because the main parts that form the CE stakeholders are citizens, businesses, and governments. In addition to the forums or conferences related to CE, the interactions between CE stakeholders are often informal, which gives rise to unstructured contents. We

summarize the problems related to this challenge as follows: 1) The perceptions can be mined by questionnaire surveys or the analysis based on generated contents. Combined with the conditions of CE practice, which method is applicable? 2) How to make mining methods compatible with information diffusion and unstructured contents in the CE practice?

3.4. Needs to change perceptions and improve behaviors

The promotion of CE needs to change the perceptions of stakeholders in a positive direction, improve their behaviors, and remove the barriers that hinder the development of CE. This process requires the consideration of the relational structure of multiple stakeholders, information diffusion, and current perceptions of stakeholders. In this regard, to promote carbon-neutral certification for agri-food products, Birkenberg and Birner (2018) examined the roles of different types of stakeholders and their perceptions of emission hot-spots. They emphasized "double linkages" between stakeholders and recommended combined services, such as funding and advice when introducing the certification. Bai et al. (2022) found that most enterprises realized the importance of reducing pollution and saving energy, but paid insufficient attention to the green offices of employees. They reminded the enterprises to consider the measures of green offices or environmental certification. The above studies focused on improvement at the organizational or firm level. As for the public level, Zheng et al. (2020) considered the perception of the effects of household waste sorting and the public diffusion of pro-environmental and waste sorting information. Their simulation findings advocated for enhancing the connection of people in a social network and making policies that set appropriate penalties and incremental personal repayment to promote household waste sorting behaviors.

From a network perspective, the essence of the change and improvement is to exert positive influence through information diffusion based on the relational structure of multiple stakeholders. We summarize the problems related to this challenge as follows: 1) How to determine the roles and importance of different stakeholders in promoting CE? The answer to this problem can be used in practice to determine the key points in diffusion and give full play to the active role of stakeholders. 2) How to exert positive influences? This problem mainly corresponds to quantitative analysis processes, such as various algorithms to solve optimization models and simulation analysis to predict or control.

4. The research status of applying social network analysis to promote circular economy

As we mentioned before, the promotion of CE needs a network perspective to consider multiple stakeholders and their relations, perceptions, and behaviors. In this section, we review the research status of applying SNA to promote CE. As per the challenges of promoting CE, we conduct the literature review in four parts. The logic of the four parts is shown in Figure 5. Modeling methods and statistical measures of networks can reveal the relational structure and characteristics between CE stakeholders, and is the first step to take multiple stakeholders into account. On this basis, the law of information diffusion can be modeled, which can examine and explain the development of CE, influence the perceptions of stakeholders and

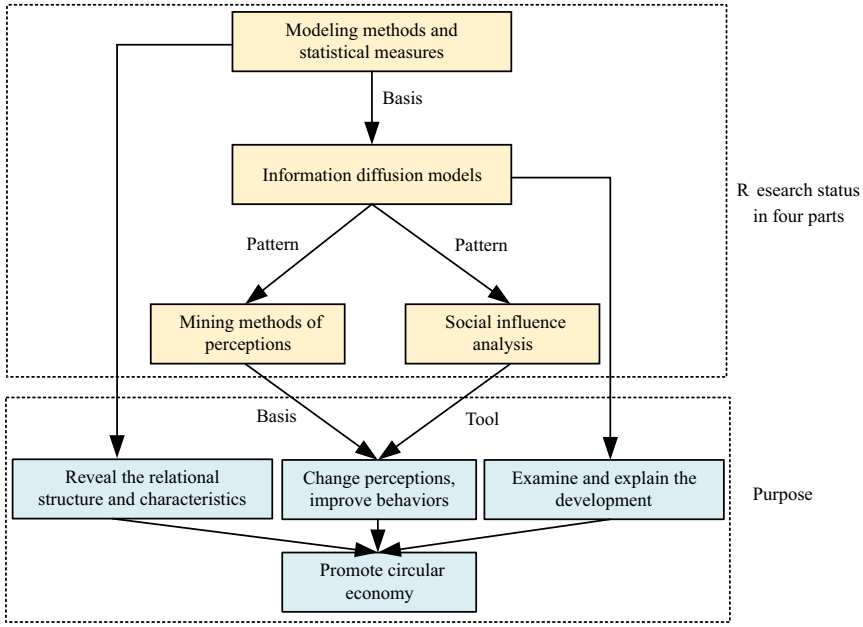

Figure 5. The logic of the four parts of research contents

support the social influence analysis. According to the current perceptions of stakeholders, the social influence analysis serves to change the perceptions in a positive direction, improve behaviors, and ultimately promote the development of CE.

These four parts constitute the application patterns commonly found in the existing literature. Particularly, we also note that SNA has been widely applied in bibliometrics related to CE to analyze academic collaborations or research trends. This kind of applications involve the fields of waste management (Sabour et al., 2020), luxury economy (Shashi et al., 2021), and energy (Khalili & Breyer, 2022), which promote CE by facilitating relevant academic research. However, such applications may also exist in bibliometrics in other fields, and cannot reflect the particularity of the CE field. Therefore, we will not review such applications in detail.

4.1. Modeling methods and statistical measures of social networks

Since CE-related policies and initiatives may involve multiple stakeholders, the promotion of CE requires the modeling methods of social networks to investigate their relations, and statistical measures to analyze relational characteristics. In the existing literature, the modeling methods fall into two categories: empirical methods and automatic generating methods. Empirical methods focus on gathering real data about relational principles, and are suitable for micro or local networks with few network nodes. For example, Ghinoi et al. (2020) used an online questionnaire to enquire stakeholders in a local CE system about the extent to which their organization received (provided) knowledge on waste management, energy saving, and other CE subtopics from (to) other organization(s), and which one provided

(received) knowledge. In this way, knowledge exchange networks were modeled to study how to support the development of CE. Marques and Manzanares (2022) modeled supply networks based on the physical flow of goods or materials between suppliers, retailers, and customers to study the circularity of supply chains. To measure the communication effect of the "zero-waste city" initiative in the public, Gong et al. (2022) collected forwarding relationships between relevant users on a social platform by a web page crawler for network modeling. In the above cases, the data about relational principles is available. However, when there are unavailable relational data or a large number of stakeholders involving large amounts of data, empirical methods become difficult to apply. In this case, social networks can be constructed by automatic generating methods according to certain rules, and are mainly used to explore the enlightenment of promoting CE from a macro level. In this regard, King et al. (2020) applied exponential random graph models to statistically estimate network parameters and modeled the social relations in a circular symbiosis network in Australia. In most real networks, despite their often large size, there is a relatively short path between any two nodes. Real networks may also exhibit the scale-free property (power-law degree distribution). However, these properties cannot be captured by basic random graph models. In view of this, Watts and Strogatz (1998) proposed the Watts-Strogatz model which could generate a small world network with an average shortest path length by rewriting or adding links on a regular network. Barabási[41] developed the Barabási-Albert model that follows the rule of preferential attachment to meet the scale-free property. These two models were also involved in the literature on promoting CE. Fan et al. (2017) applied the Watts-Strogatz model to study the relations between enterprises and strive for the optimal strategy for the government to supervise low-carbon subsidies. When studying the diffusion of new energy technologies, Boumaiza et al. (2018) applied the Barabási-Albert model to generate a social network that approximates the diffusion of messages about renewable energy on Twitter, and thus simulating the fact that there are key nodes monopolizing the network degree. We summarize the relevant modeling methods of networks in Table 1. The objects and characteristics reveal the applicability of various methods, which could serve as a reference for practitioners who want to apply these methods. In the current information age, the relational data involved in circular economic activities are ever-changing and mostly stored on the Internet in an unstructured form. As with the recent application of the web crawling method (Gong et al., 2022), in the future, more consideration should be given to advanced data mining methods for collecting primary data for network modeling. Also, the spatiotemporal evolution of network structures has also begun to appear in CE-related literature and is a hot topic for future research (King et al., 2020; Sun et al., 2022).

Besides the basic network structure, the modeling process of social networks needs to consider group formation, which corresponds to community detection and also makes sense for the study of CE stakeholders. To facilitate the adaptation of electricity policy and market rules to the transition to renewable energy, Yoo and Blumsack (2018) applied a heuristic method based on modularity optimization to detect strong coalitions of voting stakeholders. Zarrabeitia-Bilbao et al. (2022) used the Louvain multilevel algorithm to determine the

[4] Network Science. http://networksciencebook.com/

Table 1. The modeling methods of networks involved in the literature on promoting CE

Category	Objects	Characteristics	Methods	References
Empirical methods	Local & micro network	Primary data; strong specificity; static state	Critical case sampling method	Schraven et al. (2019)
			Interview & questionnaire	Ghinoi et al. (2020)
			Real physical/ information flow method	Marques and Manzanares (2022)
			Web crawling method	Gong et al. (2022)
Automatic generating methods	Global & macro network	Secondary data; objective rule; easy to generalize; allow for dynamic evolution	Watts-Strogatz model	Fan et al. (2017)
			Barabási-Albert model	Boumaiza et al. (2018)
			Exponential random graph model	King et al. (2020)

community partition of stakeholders discussing green energy. The essence of community detection is to identify closely connected stakeholders on the basis of measuring relational characteristics by statistical measures. Next, we review the statistical measures of social networks involved in applying SNA to promote CE.

The statistical measures of social networks are used to measure the relational characteristics of stakeholders, which helps to form quantitative analysis to guide practice. For example, Van Vlasselaer et al. (2017) applied the *degree*, *triangles*, and *neighborhood similarity* of a company network to detect social security fraud for reducing the loss and waste of governments. In a network about the relation of mention between stakeholders in the green energy discussion on Twitter, Zarrabeitia-Bilbao et al. (2022) utilized the *betweenness centralization* and *degree centralization* to show whether the brokers and mentions are concentrated in a few nodes. The roles of various stakeholders in the discussion were identified for a better understanding of the public dynamics and making strategic decisions. In the literature on promoting CE, in addition to the common applications mentioned above, recently, scholars have also associated the measures with the characterization of circularity. Marques and Manzanares (2022) applied a set of statistical measures of social networks, including the *betweenness centrality*, *eigenvector centrality*, and *network density*, to map the changes in network structure when systems transition from linear to circular. Their work filled a gap in past studies that only considered the inclusion of biomimicry roles to facilitate the transition to circular systems, but did not answer how to determine the circularity level for a given supply network. In the future, we could advance further based on the quantified circularity, for example, along the path of optimization to study the promotion of CE.

4.2. Information diffusion models of social networks

With the network structure and the quantified results of network characteristics at hand, the relations between stakeholders are clarified. Then, the information flow as an important basis for network governance should be investigated. On a social network of CE stakeholders, the

information involved includes public opinions on CE topics (Zarrabeitia-Bilbao et al., 2022), the publicity of CE policies made by the government (Gong et al., 2022), and the mutual influence of CE-related behaviors among the public (Boumaiza et al., 2018) or enterprises (Li et al., 2021). When promoting the CE, it is motivated to utilize the network perspective of SNA to analyze information diffusion, since it is not only the basis for studying the perceptions and behaviors of stakeholders, but also can examine and explain the development of CE.

According to the two specific problems corresponding to the challenges summarized in Section 3.2, we first review the information diffusion models used in the literature on applying SNA to promote CE. Boumaiza et al. (2018) applied a linear threshold model to study the information diffusion about peer adoption of renewable energy technologies in an online social network and a city neighborhood network. The model claimed that each household (node) will adopt renewable energy after the receiving influences meet a priori threshold. Similarly, Caprioli et al. (2020) referred to the linear principle to calculate the intention to adopt photovoltaic systems. However, they used the theory of planned behavior and thus considered not only information about peer adoption but also psychological information about attitude or perceived control. The linear threshold model simplifies the activation of each node after being influenced by information. More considering political, economic, and social factors, a game-theory-based model was applied by Li et al. (2021) to simulate the diffusion of clean energy in enterprise networks. Additionally, Nadar et al. (2020) applied a Bass diffusion model to study the diffusion of product adoption information in circular supply networks. Since the Bass model and linear threshold model are limited to the information diffusion on an overall level but fail to reveal the heterogeneity of individual nodes, Lieder et al. (2017) exploited an agent-based model to explore the information diffusion regarding consumer acceptance of new appliance business models in a CE context. In fact, the game-theory-based model can also reflect a certain degree of heterogeneity by grouping stakeholders into several categories of players, but the agent-based model is more specific to individuals. We summarize the mentioned models in Table 2 for comparison.

As for the second problem summarized in Section 3.2, the guiding significance of information diffusion for the CE practice is divided into two parts. First, the study on information diffusion can examine and explain the development of CE and thus facilitate the formulation of control measures to promote the development. For example, in Li et al. (2021)'s work we reviewed before, they figured out the influence of information in current enterprise networks regarding enterprises' green decisions and behaviors. The recommended control measures involved reducing the costs of cleaner energy and equipment, improving consumer preferences, and consolidating responses to public complaints on pollution. Second, the study on information diffusion can serve as a foundation for social influence analysis that would exert influence to guide the stakeholders. For example, according to the results of a linear diffusion model, He et al. (2022) pointed out that government officials, as key stakeholders, should actively promote the adoption of renewable energy technologies by leading by example. Moreover, the literature involved is mainly related to the field of renewable energy, which is consistent with the result of keyword co-occurrence analysis in Section 2.

Table 2. The diffusion models of network information involved in the literature on promoting CE

Methods	Parameters	Characteristics	References
Linear threshold model	Thresholds; weights	Simple activation mechanism	Boumaiza et al. (2018)
Game-theory-based model	Costs; payoffs	Strong specificity; complex calculation	Li et al. (2021)
Bass model	Innovation & Imitation coefficients	Temporal state	Nadar et al. (2020)
Agent-based model	Susceptibility parameter; follower tendency	Individual heterogeneity; temporal state	Marques and Manzanares (2022)

As we mentioned in Section 3.2, the concurrency of diffusion, complex interactive patterns, and the evolution of relations and information bring difficulties to the analysis of information diffusion. In the above studies, Boumaiza et al. (2018) comprehensively dealt with the multi-source concurrent diffusion of two networks: an online social network and a city neighborhood network. To cope with complex interactive patterns, Caprioli et al. (2020) applied the theory of planned behavior to cover the interactions between friends and neighbors, and psychological information like the attitudes, and values in the interactions. As for the evolution, both the BASS model and agent-based model involved the evolution of information by distinguishing temporal states. However, to the best of our knowledge, there is no study on the information diffusion through evolutionary network structure in the current literature on the application of SNA to promote CE, which needs to be studied with evolutionary modeling models in the future.

4.3. Mining methods of perceptions compatible with social networks

As shown in Figure 5, based on the network structure and information diffusion, there is a path to study the perceptions of CE stakeholders. In this section, we review the mining methods of perceptions in the literature on applying SNA to promote CE, answering the two problems summarized in Section 3.3.

The mining methods of stakeholders' perceptions in the literature fall into two categories: the survey methods and the methods based on generated contents of stakeholders (GCS). The former use questionnaires or interviews to explore the stakeholders' perceptions toward CE changes, initiatives, policies, etc. For instance, in the circular transition of a stony material supply chain, Schraven et al. (2019) developed a closed and structured interview protocol to capture the importance and the assignment of the responsible parties per change in the perception of stakeholders. The GCS-based methods refer to text mining methods that process unstructured data generated by stakeholders, which mainly include two subcategories in the literature: sentiment analysis and topic modeling. Luo et al. (2022) applied a support vector machine model for sentiment analysis and the latent Dirichlet Allocation (LDA) model for topic modeling with the online reviews of energy-saving refrigerators. In this way, consumer satisfaction and the features of refrigerators that consumers care about were captured, and were conducive to the formation of strategies for promoting green products.

The survey methods are suitable for the situation where the number of stakeholders is small and the generated content has not accumulated. However, real-time perceptions cannot be reflected, and the cost of data collection is high (Wu et al., 2023). The context of CE, such as mining urban residents' perceptions of a circular policy, often involves a large number of stakeholders, and has high requirements for real-time data. The era of big data also makes it easy to accumulate generated contents. Therefore, GCS-based methods become increasingly prevalent.

However, traditional methods for sentiment analysis and topic modeling are not compatible with the context of SNA, where the information diffusion and the features of information brought by unstructured data on the social network need to be considered (Fang & Jia, 2017; Debnath et al., 2022; Saranya & Usha, 2023). In terms of information diffusion, Xu and Qiang (2022), in their investigation of public perceptions of storm damage, applied kernel density maps to incorporate the diffusion across a Twitter network in sentiment analysis and topic modeling. The mining methods are combined with geospatial information diffusion. This is also an issue worth considering in circular transition, but the existing literature on applying SNA to promote CE has not taken this into account, implying a research gap.

As for the features of information on social networks, in the Internet era, the interactions between CE stakeholders are often informal, which may give rise to unstructured generated contents that are short, ever-changing, and loud (Saranya & Usha, 2023). Zarrabeitia-Bilbao et al. (2022) applied the Vader model to mine the public sentiment and support green strategic decision-making, which is a rule-based sentiment analysis model and can handle the short text by a lexicon-enhanced design. Wu et al. (2021) developed an LDA short text clustering algorithm embedded with the sentiment word co-occurrence to consider different short texts. The algorithm involved both sentiment analysis and topic modeling compatible with short texts, but the latter has not been adopted in the CE context to determine the concerns of CE stakeholders. The ever-changing generated contents require real-time performance of text mining methods. Shahidzadeh and Shokouhyar (2022) used both a convolutional neural network and a long short-term memory model to process Twitter data and analyze consumers' sentiments on reverse logistics of the circular supply chain in real time. The generated contents are loud, meaning that the stakeholder-generated information may contain grammatical errors or linguistic ambiguities. In response to this common feature of information on today's social networks, recently, Saranya and Usha (2023) offered a machine-learning-based sentiment analysis method and applied a deep intelligent wordnet lemmatizer to remove the noise of information before the text mining. In the future, it is promising to apply their method to improve the quality of information generated by CE stakeholders, thus facilitating the mining process of perceptions. We summarize in Table 3 the literature and the corresponding information features that can be processed.

4.4. Social influence analysis

As shown in Figure 5, after mining the perceptions of stakeholders, the social influence analysis based on social networks serves as a tool to change the perceptions of stakeholders in a positive direction, improve their behaviors, and remove the barriers that hinder the development of CE.

Table 3. The mining methods of perceptions coping with information features on social networks

References	Methods	Principle	Functions	Information features	CE field
Zarrabeitia-Bilbao et al. (2022)	Vader model	Rule-based; lexicon-enhanced	Sentiment analysis	Short text	Energy
Wu et al. (2021)	Enhanced LDA topic model	Sentiment word co-occurrence; Knowledge Pair Feature Extraction	Sentiment analysis; topic modeling	Short text	/
Shahidzadeh and Shokouhyar (2022)	Convolutional neural network; long short-term memory model	Machine learning	Sentiment analysis	Real-time data	Circular supply chain
Saranya and Usha (2023)	Intelligent wordnet lemmatizer; random forest algorithm	Machine learning	Sentiment analysis	Grammatical errors; linguistic ambiguities	/

First, the social influence analysis needs to determine the roles and importance of different stakeholders on the network, thus finding the key stakeholders who may exert positive influence. Most studies identify the key stakeholders by virtue of statistical measures of social networks. Ghinoi et al. (2020) calculated the *degree centrality*, *betweenness centrality*, and *brokerage* of knowledge exchange network on CE topics such as waste management and energy saving. They identified the most central stakeholders and broker roles for each network, aiming to ensure effective knowledge exchange and broad participation in promoting CE. By linking measures to circularity, Marques and Manzanares (2022) mapped the emergence of "scavengers" and "decomposers" in the transition to circularity, which are key stakeholders of circular supply networks from a biomimetic perspective. However, most modeled social networks may only record the presence of the relations, but not the strength, which limits the identification based on the measures of social networks. Social simulation and empirical methods can cover the strength of relations in the identification. For example, to identify key stakeholders in the energy transition, Ernst and Briegel (2017) applied the agent-based model to simulate social information diffusion, and He et al. (2020) used observational data to get empirical evidence.

The social influence analysis can exert positive influences on stakeholders' perceptions and behaviors to promote CE. To do so, after identifying the key stakeholders and their influences on the reuse network of biosolids by statistical measures, Venegas et al. (2022) determined the prioritization of the factors that can influence the reuse based on stakeholders' perceptions, and informed the prioritization through network interactions. Through an analysis process with more quantitative evidence, Ernst and Briegel (2017) conducted a simulation analysis to examine the combined effect of increasing frequency of personal interaction on social networks and the news reported by media, on the adoption behavior of green energy. Their study innovatively explored how to exert positive influence to boost diffusion

from the perspective of the correlation of social influence. Specific to the recycling of agricultural products, a social network-based simulation study was conducted to determine the factors that influence the behavior of agricultural growers in adopting recycling technologies (Tian et al., 2021). The results included the optimal distribution of new initial adopters and the optimal growth rate, and were meaningful for inspiring the behaviors and improving the promotion performance of recycling technology.

It can be observed that in the existing studies, some scholars put forward qualitative suggestions based on key stakeholders and the law of information diffusion to exert positive influence (Venegas et al., 2022), and some scholars further obtained quantitative revelations through simulation analysis (Ernst & Briegel, 2017; Tian et al., 2021). Besides the simulation, the influence maximization model can also find a subset of nodes that can maximize the final positive influence under an information diffusion model, which replaces the parameter adjustment of simulation with optimizing searches of algorithms. However, to the best of our knowledge, the existing literature on promoting CE has not applied the influence maximization model. Scholars should design algorithms that meet the requirements of accuracy and running time for applying the influence maximization model.

5. Lessons and future prospects

According to the reviewed research status, we summarize the following lessons with regards to the applications of SNA in promoting CE:

1) The promotion of CE at the technical level and that at the practical level should be distinguished. The former seeks technological breakthroughs, while the latter focuses on removing barriers in the practical circular transition, often related to relations, perceptions, and behaviors of stakeholders.
2) In the theory of SNA, the modeling methods and statistical measures of networks can reveal relation structure and characteristics between stakeholders in various CE activities, initiatives, and policies. On this basis, the law of information diffusion can be modeled, which can examine and explain the development of CE, influence the perceptions of stakeholders, and support the social influence analysis. SNA makes the mining methods of perceptions compatible with information diffusion and the features of information brought by unstructured data on the social network. According to the current perceptions of stakeholders, the social influence analysis serves to change the perceptions in a positive direction, improve behaviors, and ultimately promote the development of CE.
3) The existing studies on applying SNA to promote CE are mostly based on the perspectives of the government, organizations, or enterprises. The focus is to obtain managerial implications that help to implement CE policies, initiatives, and activities.
4) Regarding the specific fields in the relevant literature, there is a research trend away from broad policy designs towards public life, industry, and energy. This is partly because policies have evolved to a stage where they must mobilize the community for collective support. Also, the further exacerbation of resource scarcity makes industries

that may involve large-scale consumption and energy fields that may bring regenerative designs more attractive.

5) A biomimicry lens is conducive to study the promotion of CE, which regards various stakeholders as producers, consumers, scavengers, and decomposers, respectively. Different roles may exert different influences in boosting circularity.
6) The information diffusion across social networks can not only examine and explain the development of CE to facilitate the formulation of control measures, but also serve as a foundation for social influence analysis that would exert influence.
7) The agent-based model is a prevalent method for simulating social diffusions in the literature since it can capture micro node characteristics and interactions to predict macro system-level events. The difficulty of agent-based model lies in the proper initialization of a large number of parameters.
8) Social influence analysis can form qualitative suggestions based on key stakeholders and information diffusion laws, and can also derive quantitative revelations through simulation analysis or optimization model.
9) The information age facilitates frequent informal interactions among a large number of CE stakeholders, resulting in variable and unstructured relational data and generated contents. This is a focus of the latest research and promotes the innovation of classic methodologies.

As per existing challenges and the research status, future prospects are summarized as follows:

1) Academia should pay more attention to waste management, recycling, and sustainable operational management system (Goli & Mohammadi, 2022), which have been given less attention compared to the topic regarding resources in existing studies. Based on the data from social networks, it would be promising to develop relevant optimization models and algorithms to improve the operational efficiency of waste management and recycling (Tirkolaee et al., 2022).
2) More consideration should be paid to advanced data mining methods to collect primary data for network modeling. For example, the geographic information system at a regional scale can collect real and timely primary data for network modeling considering spatiotemporal evolution.
3) Scholars could advance further based on the quantified circularity, for example, along the path of optimization to study the promotion of CE.
4) It is necessary to further study the information diffusion across evolutionary networks since the interactions between CE stakeholders, especially the public, exhibit great variability in today's information age.
5) The mining methods of perceptions that consider social information diffusion are worthy of being applied to the context of CE. SNA can help reveal the network topology in the CE system to clarify the relations, information flow and resource flow between CE stakeholders. On this basis, decision-makers can identify key perceptions regarding CE activities, optimize resource flow paths, and design more resilient and sustainable CE systems.

6) It is promising to refer to the method based on the wordnet lemmatizer (Saranya & Usha, 2023) developed recently to improve the quality of information generated by CE stakeholders, thus facilitating the mining process of perceptions. It should be noted that the wordnet lemmatizer only fits English. Lexical databases in other languages can be introduced to handle large amounts of digital discussion or dialog information in different languages in the context of CE.
7) With the increasing of data volume and dimensions, scholars should design algorithms that meet the requirements of accuracy and running time for applying the influence maximization model to solve the diffusion problem of CE-related initiatives, policies, and products.
8) Explore the role of social networking platforms in promoting CE. By analyzing user behaviors and interaction patterns on social platforms, scholars can gain insights about users' participation, requirements, and challenges with regards to CE, so as to provide suggestions for optimizing platform functions and user experience.
9) Conduct research on decision support systems based on SNA regarding CE. SNA compatible with information diffusion can support the establishment of expert knowledge base, and help decision-makers grasp specific needs and perceptions of stakeholders in each link of CE. Introducing the information from SNA can formulate comprehensive policies and promote the circular transition.
10) Study how to utilize communities in social networks to identify and influence individual CE behaviors. The meso-level statistical measures of social network such as modularity and clustering coefficient are worth being used to accommodate the widespread existence of communities and alliances in the information age. In this way, key communities and their influence on the behaviors of others can be identified, which is helpful for developing effective social intervention strategies to encourage massive adoptions of CE lifestyles and consumption habits.

Conclusions

Like many common economic systems, CE involves many stakeholders. Promoting CE at the practical level requires removing the barriers that hinder the circular transition. To do so, the interactions and information flow between CE stakeholders need to be investigated from a network perspective. This study reviewed the applications of SNA in promoting CE. We introduced the definition and concomitant concepts of CE, and the research contents of SNA. Then, a bibliometric analysis was conducted to provide a bird's eye on the research status and trend. According to the bibliometric analysis, we summarized the challenges of promoting CE. Specific problems corresponding to each challenge were refined, around which we reviewed the network modeling methods and statistical measures, information diffusion models, mining methods of perceptions, and social influence analysis. These four parts of the literature review outlined the pathways through which SNA contributes to promoting CE. Briefly, SNA helps to reveal the relational structure and characteristics between CE stakeholders, form and change their perceptions, improve their behaviors, as well as examine the development of CE. Finally, the lessons learnt from the review and future directions were summarized.

It should be noted that the publications on the discussed field are so massive that exhaustive coverage is impossible. Perhaps some excellent papers have been unfortunately missed. However, we hope that this review can serve as a reference and provide convenience for scholars and practitioners in the fields of CE and SNA.

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Author contributions

Huchang Liao, Zheng Wu, and Fan Liu proposed the original idea and conceived the study. Huchang Liao, Zheng Wu, and Chonghui Zhang were responsible for developing the method, collecting and analyzing the bibliometrics data. Huchang Liao, and Zheng Wu were responsible for data interpretation. Huchang Liao, Zheng Wu and Fan Liu wrote the first draft of the article. Chonghui Zhang revised the paper. Zheng Wu is a co-first author.

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