REVIEW ARTICLE

Waste management and green technology: future trends in circular economy leading towards environmental sustainability

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Abstract

The effective treatment of waste to be used as a resource in future has a major role in achieving environmental sustainability and moving towards circular economy. The current research is aimed to provide in-depth detail regarding prominent trends and research themes, evolution, future research orientation, main characteristics, and mapping of research publications on waste management, technological innovation in circular economy domain from the year 2000 to 2021. Different analyses including text mining and bibliometric and content analyses were applied to answer the research question and provide the details on aforementioned variables. From the bibliometric analyses, a total of 1118 articles were drawn out from the Scopus database to conceptualize the core body of research. As a result, the following themes were identified: electronic waste, circular economy transition, plastic waste, bio-based waste management, lifecycle assessment, and ecological impacts, and construction and demolition waste management. The highlighted features, future research orientation, and prominent research perspective can provide guideline for future research to enrich the literature through conducting studies on provided research directions and help lead waste management and technological innovation policymakers, professionals, and practitioners in moving towards circular transition.

Introduction

With rapid industrialization and economic development, the production of waste from various industries and sectors such as pharmaceutical, agriculture, logistics, and textile are enhancing throughout the world. According to Kawai and Tasaki (2016), the solid waste production will reach up to 2.2 billion tons by 2025. In such circumstances, countries across globe have been following measures to reduce waste by adopting green/circular practices, which is focused on closing the loop of supply chain. In simple words, it is the move towards circular economy (CRE)

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from linear method of production which creates more waste (Zhang et al. 2022; Tian et al. 2022). The circular practices are also focused on reducing waste at each level of production, i.e., from top to bottom, and intend to improve sustainable performance (Ranjbari et al. 2021). Although the adoption of green/circular practices can make better resource and waste management (WTM), the technological innovation (TI) has also revolutionized the way the industries operate and helped in effective implementation of green/circular practices. Through leveraging TI such as blockchain technology (BCT), Internet of Things (IoT), sensors, artificial intelligence (AI), and cloud computing (CLT) firms have redefined their business models such as redesigning personalized offerings to customers (Nambisan et al. 2017; Sheng et al. 2022; Umar et al. 2021a).

In recent years, studies have been conducted on WTM and TI corresponding to the CRE goals such as application of TI in WTM (Mastos et al. 2021) developing CRE indicators for WTM (Luttenberger 2020), drivers of CRE (Hina et al. 2022), drivers of WTM towards CRE through TI (Chauhan et al. 2021; Márquez and Rutkowski 2020; Khan et al., 2021a), and application of TI in CRE/green practices (Yu et al. 2022; Khan et al. 2021c; Umar et al. 2021a) managing e-waste in CRE (Gautam et al. 2022). Bibliometric analysis has helped scholars in gaining insight about publication in the area of WTM and TI towards CRE. Researchers have empirically analyzed the role of TI in WTM towards a CRE and developed various lines of WTM on broader outlook such as domestic waste (Yang et al. 2021), waste incineration (Matos and Sousa-Coutinho 2022), municipal solid waste (MSTW) (Molina-Peñate et al. 2022), and demolition waste (Yu et al. 2022). Nevertheless, the research on how TI can enable WTM in CRE context has not been elaborated in depth in the prior study (Chauhan et al. 2021) which is an impediment for TI, WTM and CRE professionals, and policy makers. Therefore, detailed map of trends and themes of WTM aligned with TI and CRE perspective is needed.

Thus, the current research work aims to provide in-depth detail about WTM with TI and its main characteristics, salient research trends and themes, evolution, and future research direction by scrutinizing the literature of WTM with TI in the context of CRE for the last two decades (2000–2021). To achieve the objectives of the current study, subsequent research questions were formulated:

RQ1. How much the research on WTM with TI evolved in the area of CRE?
RQ2. What are the prominent trends and themes of WTM and TI in CRE?
RQ3. What can be the future research orientation on WTM and TI towards the CRE transition?

According to best the knowledge of the researchers, very few studies have comprehensively considered bibliometric analysis (BMA), text mining analysis (TMA), and content analyses (CTA) simultaneously on WTM and TI within the CRE context.

Therefore, the current study contributes by providing the background, main trends and themes, prominent patterns, and future research direction of WTM and TI in the context of CRE over last two decades as a mechanism to support professionals and policy makers in transition towards CRE and provide in-depth detail regarding aforementioned variables that need further explanation.

The current study is organized as follows: the "An overview on WTM and TI in CRE context" section indicates the overview on TI and WTM in the context of CRE while the "Research methodology" section illustrates the research methodology adopted followed by the results of BMA, text mining, and content analysis on the WTM and TI in the context of CRE in the "Results and discussion" section. Moreover, the "Implications and future research directions" section elaborates the implications and avenues for future research while the "Conclusions" section demonstrates the conclusion and research limitations.

An overview on WTM and TI in CRE context

WTM is referred as a process of managing the discarded material from origin to disposal through gathering, transportation, and treatment (Tomić and Schneider 2020; Salmenperä et al. 2021). The implementation of sound WTM system can help minimize waste and harmful pollutants which caused the leftover of the waste (Nelles et al. 2016) to lead towards sustainable environment (Aghbashlo et al. 2019). In effective WTM system, wastes were recycled which help in lessening the excavating of primeval material (Ahirwar and Tripathi 2021; Zhang et al. 2021g; Satayavibul and Ratanatamskul 2021). Scholars have demonstrated WTM systems as an important element in CRE and mentioned some key strategies, namely Refuse/Rethink, Resell/reuse, Reduce, Repair, Remanufacture, Refurbish, Repurpose, Recover, Recycle, and Re-mine (Zhang et al. 2021d; Reike et al. 2018); all these strategies help mitigate pollution and prevent waste production. Although the implementation of WTM system can help attain sustainable environment, for its effective implementation scholars have given focus on the adoption of TI as innovation through technologies have the potential to improve and modernized the implementation of WTM systems (Umar et al. 2021b; Yu et al. 2021).

The literature on TI in the period surveyed shows that typical technologies include AI, autonomous robots, BCT, IoT, additive manufacturing, unmanned aerial

vehicle or drones, radio frequency identification (RFID), cloud computing, augmented reality (AR) big data, and analytics electric vehicles (Zhang et al. 2021e; Strandhagen et al. 2017). The concept of waste is the central idea in various definitions of circular economy, according to Kirchherr et al. (2017) waste is the 6th most cited term among the definitions of CRE. Researchers have illustrated that the current momentum for CRE is to take actions for better management of waste globally, in this regard, Fletcher et al. (2021) and Di Foggia and Beccarello (2021) have indicated that WTM system can become sustainable through adoption of innovative technologies which help in achieving zero waste. Similarly, Kurniawan et al. (2022) have also elaborated that effective implementation of TI is a driving force in moving towards zero carbon strategies in CRE framework. The scholars were also of the view that the deployment of TI has promoted recycling, prevention, reuse, and reduction in waste before dumping of waste in lands and conserve the resources. The research studies on waste management has indicated that although the practitioners and policy makers had embraced the concept of zero waste but still there is need of more advancement in the zero waste domain (Ranjbari et al. 2021; Chen et al. 2021; Zhang et al. 2021a) and more research studies are needed to that provide guidelines to industries regarding circularity of resources (Saidani et al. 2019) and more standardized indicators of waste management should be developed.

Research methodology

The current study used *quantitative and qualitative approaches* in examining the prior literature on TI and WTM in CRE; the detail of which is presented in the sections elaborated below. The design of current research is presented in Fig. 1.

Data collection, scrubbing, and sampling

To effectively gather published articles in the current study, Scopus database is one prominent source of published materials used for the collection of data. The current study used following the strings (waste AND management AND green AND technology) to search for relevant publications in the field. The initial research was held during the first month of 2022 and was restricted to English language and peer-reviewed journal articles and the time period selected was from 2000 to 2021. According, to the criteria 1118 articles were got selected and used for analyses purpose. From the outcome, 1118 articles fulfill the criteria of selection, and were utilized for analysis. The selected data set was cleaned as it is a fundamental step in keyword-based analyses.

Data analysis

To determine the structure and evolution of the current research field, various analyses were employed the detail of which are provided in the sub-sections given below.

Fig. 1 Research design
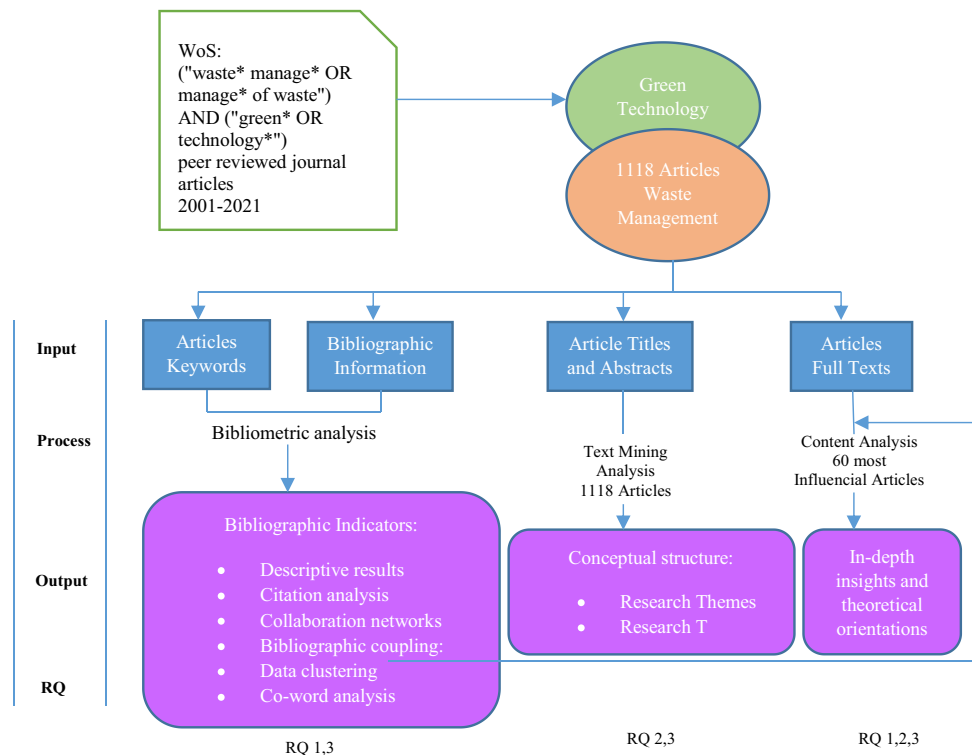
(i) Bibliometric analysis

In recent years, Bibliometric analysis BMA is being used in multiple areas for instance, in CRE (Sganzerla et al. 2021), open innovation (Gao et al. 2020), and sustainable supply chain, which is a powerful statistical analytical tool and a quantitative technique used to manage considerable quantity of scientific literature mapping and publications. It also helps in providing association between citations, articles, citation networks, and journals and provides in-depth detail about future research directions (Baker et al. 2020). In the current study, VOS viewer software was utilized to perform this analysis. Moreover, various bibliometric parameters were indicated to provide the bibliometric info of published articles in TI and WTM in the context of CRE.

(ii) Text mining analysis

It is a tool used for analyzing research trends and themes and helps in extraction of information from large number of documents in text form (Jung and Lee 2020), used by researchers in the field of CRE. This analysis captures the phrase pattern and semantic structures that best describe extensive amount of text data.

(iii) Content analysis

Content analysis (CTA) is a measurement method which is used to summarize and identify trends and can be used for both inductive and deductive research. In line with the research study held by Jia and Jiang (2018) and Schöggl et al. (2020), this analysis was applied in the current study to explain the findings. Moreover, the sample articles obtained in the current study were arranged in clusters with the help of data clustering technique, and through using qualitative CTA more than ten persuasive articles from each cluster were identified to examine the theoretical orientation of TI and WTM towards the CRE.

Results and discussion

To answer the research questions formulated in the current study, the results are illustrated in the section given below.

Delineation of prior research work

To address the first research question, indicators of BMA are elucidated below:

Q1: How much the research on WTM with TI evolved in the area of CRE?

### (i) Descriptive analysis: evolution of publications

Figure 2 demonstrates the published articles trend about WTM research with TI evolved within the CRE domain from 2000 to 2021. Out of the 1118 published articles, majority of the articles were published after 2009, indicating 90% of the current study sample. Thus, according to results, it can be stated that the WTM research with TI evolved within the CRE domain gained dominance from 2009. According to Goyal et al. (2021) and Singh et al. (2021), the significant increase in number of publications indicate that research on CRE has attained growing attention with in various domains such as TI and WTM .

### (ii) Citation analysis: main authors and articles

Figure 3 indicates the citation analysis in term of years, in which it can be seen that the highest number of citations received by WTM research with TI towards CRE is after 2010. On the other hand, Table 1 illustrates productive authors in the period of study in which Tsang with 11 articles, Ok with 7, and Poon with 6 articles were the most productive authors.

The highest number of citation received by any article in a research domain is known as influential publication

Fig. 2 Publication trend from 2000 to 2021

Articles by years
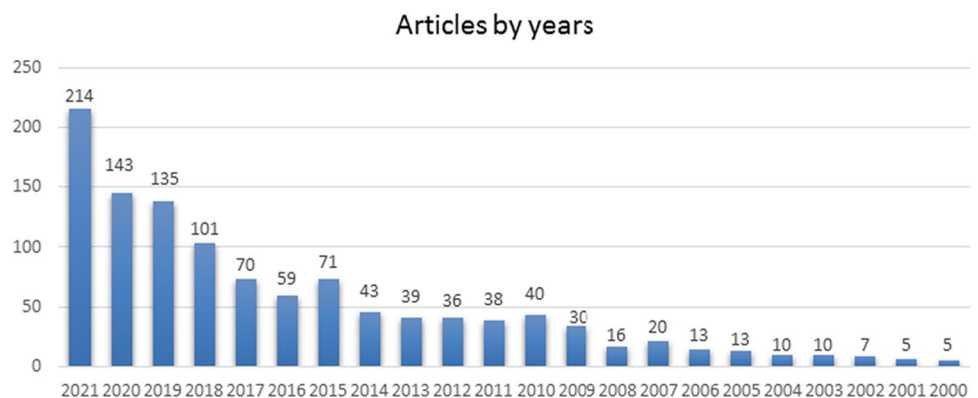
Fig. 3 Year wise citation
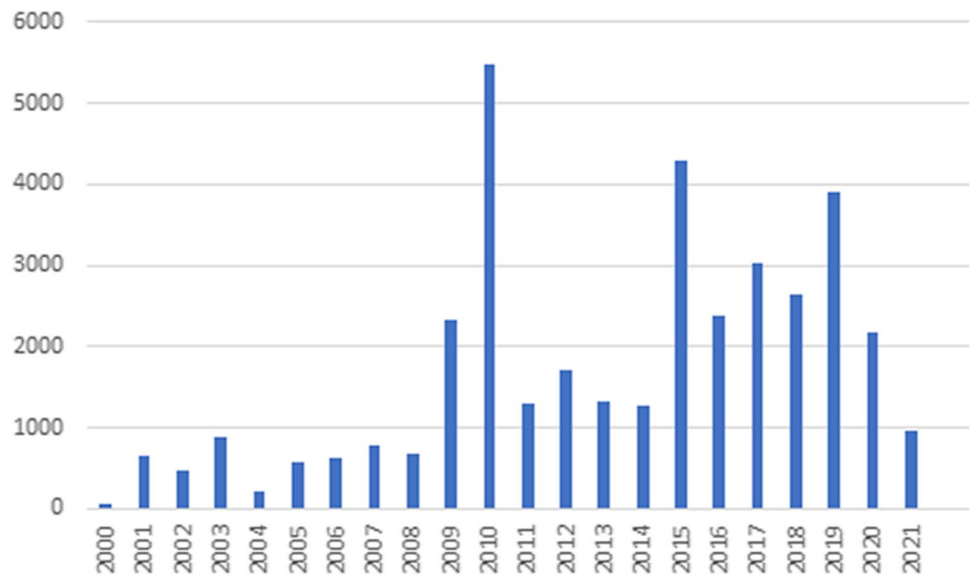
Table 1 The productive authors in the WTM research with technological innovation towards CE

S. no	Author names	Articles
1	Tsang, D.C.W.	11
2	Ok, Y.S.	7
3	Poon, C.S.	6
4	Chang, S.W.	5
5	Hou, D.	5
6	Pandey, A.	5
7	Show, P.L.	5
8	Wang, L.	5
9	Abdullah, S.R.S.	4
10	Bilal, M.	4
11	Chiang, P.C.	4
12	Gnansounou, E.	4
13	Hannan, M.A.	4
14	Iqbal, H.M.N.	4
15	Ngo, H.H.	4

(Reid and Chen 2007). The vastly cited research articles in this study data set are illustrated in Table 2. From the mentioned articles, the article published in Renewable and Sustainable Energy Reviews journal was the highly cited article. It can also be seen that the highly cited articles in the current research are review articles which focused on WTM and TI towards CRE. One reason for this is that the WTM and TI have become the subject area of interest for researchers from last few years because of their fruitful outcomes in terms of improved economic and environmental performance. Another reason behind this is that the implementation of WTM and TI are formidable for

policy developing bodies and still needs perfect guidance for professional entail in operations.

(iii) Collaboration analysis: institutions and countries

Figure 4 depicts the number of publications by each institution, in which it can be seen that Ministry of Education China is the dominant institution in WTM research with TI in the context of CRE with having 29 articles, while Hong Kong Polytechnic University, Chinese Academy of Sciences, Tsinghua University, and Universiti Teknologi Malaysia are the pioneers in WTM research with TI in the context of CRE with having 16, 16, 15, and 13 articles respectively. On the contrary, The University of Hong Kong and National University of Singapore with 9 and 8 articles respectively have slightest mature network out of the highest contributing institutions.

Out of 95 countries which are contributing to our sample, the top 15 which are contributing most to our sample are mentioned in Table 3 and Fig. 5. According to the results, China, India, USA, Malaysia, and Italy are those countries that have more focus on WTM and TI towards CRE and are pioneers in this research with 203, 178, 143, 74, and 69 articles respectively.

(iv) Coupling analysis for the clustering of data

Clustering is used to group the articles on the basis of similar properties to know and identify the research direction. VOSviewer software is used in the current study to employ bibliographic coupling analysis for data clustering. This analysis indicates the link between publications and cited references.

Table 2 Top nine articles and citation

S. no	Title	Journal name	Citations
1	Biofuels from microalgae-A review of technologies for production, processing, and extractions of biofuels and co-products	Renewable and Sustainable Energy Reviews	2977
2	Solar absorber material and system designs for photothermal water vaporization towards clean water and energy production	Energy and Environmental Science	522
3	Recovery and recycling of lithium: A review	Separation and Purification Technology	518
4	Biosorption of chromium(VI) from aqueous solutions by green algae Spirogyra species	Water Research	501
5	Transformation of vegetable waste into value added products: (A) the upgrading concept; (B) practical implementations	Bioresource Technology	464
6	Thermolysis of waste plastics to liquid fuel. A suitable method for plastic WTM and manufacture of value added products-A world prospective	Renewable and Sustainable Energy Reviews	431
7	Green supply chain initiatives among certified companies in Malaysia and environmental sustainability: Investigating the outcomes	Resources, Conservation and Recycling	429
8	Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives	Bioresource Technology	356
9	Removal of malachite green from dye wastewater using neem sawdust by adsorption	Journal of Hazardous Materials	349

Fig. 4 Number of publications by institutions
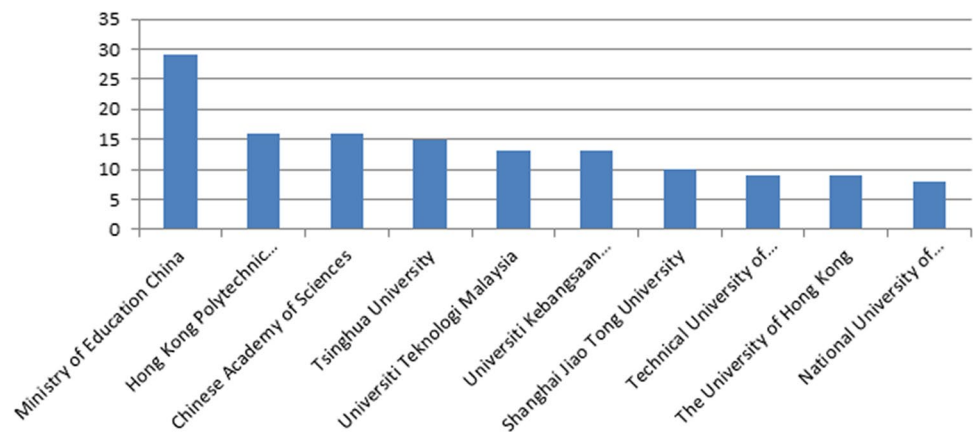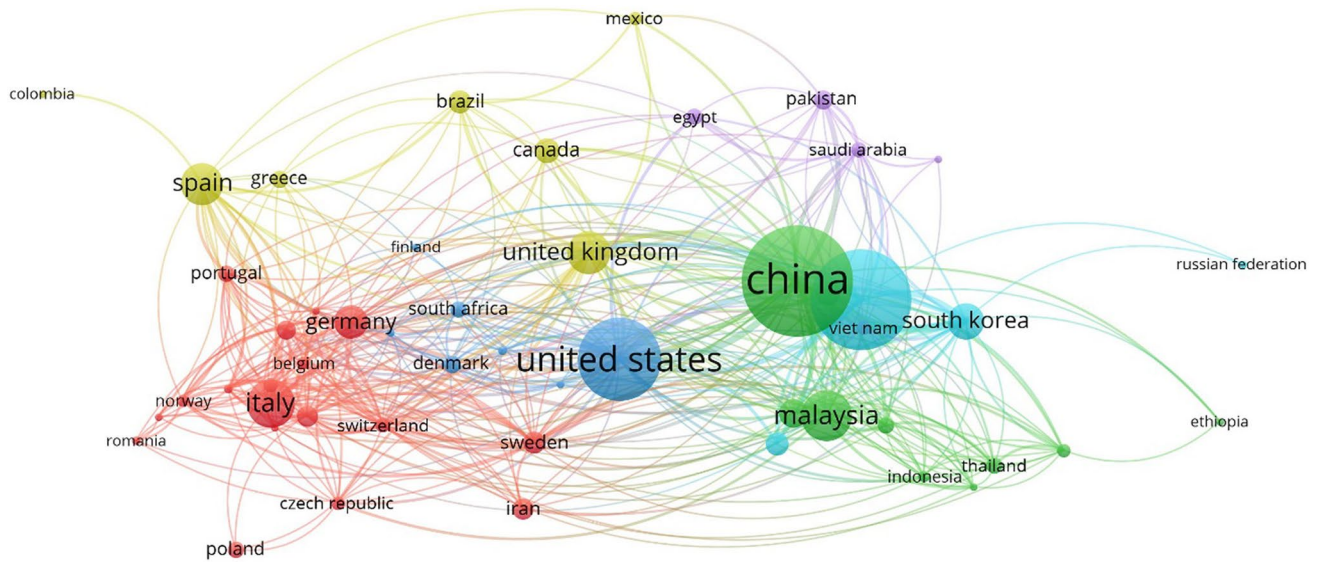

Table 3 Top fifteen contributing countries

S. no	Country	Articles
1	China	203
2	India	178
3	USA	143
4	Malaysia	74
5	Italy	69
6	UK	60
7	Spain	59
8	South Korea	50
9	Germany	44
10	Australia	38
11	Hong Kong	32
12	Canada	30
13	Taiwan	28
14	Brazil	28
15	Sweden	27

The following are the clusters of the articles CRE overview on TI and waste hierarchy: first cluster: conceptualization and implementation of CRE; second cluster: TI and WTM with in closed-loop SC; third cluster: CRE approach in plastic waste management. In each cluster, more than 12 top articles are listed (see Table 4). The detail on influencing articles and bibliographic coupling clusters are explained in the "Qualitative content analysis" section to uncover the research directions and main themes.

(v) Co-word analysis: identifying hotspots

The keywords used by the researchers in their research paper illustrate the main idea of the research. The co-word analysis can help in identifying research hotspots in research field on the basis of occurrence of words (Gao et al. 2020). The

Fig. 5 Top fifteen contributing countries

Table 4 The significant and persuasive research papers in clusters of TI and WTM in CRE

First cluster	`Second cluster	Third cluster	Fourth cluster
Mastos et al. (2021)	Lieder and Rashid (2016)	Govindan and Soleimani (2017)	Sakai et al. (2011)
Iacovidou et al. (2017a)	Dong et al. (2013)	Shahbazi et al. (2016)	Ramesh Kumar et al. (2020)
Liguori and Faraco (2016)	Ghisellini et al. (2016)	Krikke et al. (2003)	Brooks et al. (2018)
Iacovidou et al. (2017b)	Kushairi et al. (2018)	Abdallah et al. (2012)	Koop and van Leeuwen (2017)
Nižetić et al. (2019)	Wu et al. (2021)	Pedram et al. (2017)	Blank et al. (2020)
Bjørnbet et al. (2021)	Bachmann (2007)	Lee and Chan (2009)	Horodytska et al. (2018)
Egle et al. (2015)	Pan et al. (2015)	Ferronato et al. (2019)	Luttenberger (2020)
Shayganmehr et al. (2021)	Huang et al. (2018)	Gu et al. (2019)	Van Eygen et al. (2018)
Pan et al. (2015)	Alhawari et al. (2021)	Khan et al. (2021b)	Faraca and Astrup (2019)
Van Ewijk and Stegemann (2016)	Winans et al. (2017)	Islam and Huda (2018)	Jambeck et al. (2018)
Kacprzak et al. (2017)	de Jesus and Mendonça (2018)	Sazvar et al. (2021)	Iacovidou et al. (2019)
Haupt et al. (2017)	Merli et al. (2018)	Vahdani et al. (2013)	Payne et al. (2019)
Lopez de Sousa Jabbour et al. (2018)	Reike et al. (2018)	Dyczkowska et al. (2020)	Eriksen et al. (2019)
Reike et al. (2018)	Singh and Ordoñez (2016)	Mohtashami et al. (2020)	Tomić and Schneider (2020)
Yadav et al. (2020)	Hussain and Malik (2020)	Sazvar et al. (2021)	Salmenperä et al. (2021)
Sherwood (2020a)	McDowall et al. (2017)		
	Dantas et al. (2021)		

keywords list was cleaned properly, prior to co-occurrence analysis, only 2461 keywords were used in the analysis.

Core research trends and themes

The following research question is answered in the section explained below:

Q2: What are the prominent trends and themes of WTM and TI in CRE?

The results of text mining illustrate that studies on WTM and TI in the domain of CRE have focused on following research themes: e-Waste, CRE transition, plastic waste, construction and demolition waste management, lifecycle assessment, and ecological impacts, bio-based waste management, MSTW. Table 5 demonstrates the research themes and trends.

The demand for electronic and electrical products are increasing across the globe in such a situation the management of e-waste has become a priority in almost all the

Table 5 Salient research themes in TI and WTM towards CRE

Research theme	Key terms	References
1. E- waste	Government, Behavior, Consumer, Waste disposal, Policymaker, Incentive, Extended Producer Responsibility, E-waste	Mayers et al. (2005), Aboelmaged (2021), Sharma et al. (2020), Dhir et al. (2021), Marke et al. (2020), Cole et al. (2019), Lu et al. (2015), Ottoni et al. (2020).
2. CRE transition	Supply chain, CRE strategy, Industrial symbiosis, Waste reduction, CRE model, Sustainability, Resource recovery, Resource	Alvarez and Ruiz-Puente (2017), Upadhyay et al. (2021), Priyadarshini and Abhilash (2020), Guzzo et al. (2021), Okafor et al. (2020).
3. Plastic waste	Recovery, Packaging, Prevention, Recycling, Contaminant, Value chain, polymers, Single-use Plastic	Bassi et al. (2020), Zhang et al. (2021b), Eriksen et al. (2018), Martín et al. (2021), Umar et al. (2021c) Lederer et al. (2020), Sherwood (2020b), Klemeš et al. (2020) Leissner and Ryan-Fogarty (2019).
4. MSTW	Recycling rate, Secondary raw Material, Waste Hierarch, Household Waste, Separate Collection, CRE package, European Union, Biowaste, Municipality	Petryk et al. (2019), Nanda and Berruti (2021), Hadzic et al. (2018), Zamri et al. (2021), Mian et al. (2017), Kumar and Samadder (2017), Penteado and de Castro (2021), Singh (2019).
5. Bio-based WTM	Biomass, Circular bioeconomy, Organic waste, Food waste, Biochar, Composting, Biorefinery, Fraction of MSTW,	Tsai et al. (2020), Kaszycki et al. (2021), Santagata et al. (2021), Imbert (2017), Zaborowska et al. (2021), Elkhalifa et al. (2019), Wojnowska-Baryła et al. (2020), Rekleitis et al. (2020), Ramesh Kumar et al. (2020), Ng et al. (2020).
6. Lifecycle assessment and ecological impacts	Climate Change, Landfill, Energy recovery, Environmental burden, Decision Making, Incineration, Greenhouse gas Emission, Disposal, Recycling process	Boldoczki et al. (2020), Asselin et al. (2020), Gallego-Schmid et al. (2018), Su et al. (2013), Gallego-Schmid et al. (2018), Raymond et al. (2020), Arushanyan et al. (2017), Sauve and Van Acker (2020), Miksa et al. (2020), Thomsen et al. (2018), Manjunatha et al. (2021) Kouloumpis et al. (2020)
7. Construction and Demolition WTM	Sewage sludge, Energy consumption, Material Efficiency, steel, Concrete, Slag, Building, Construction industry, Demolition	Mak et al. (2019), Zhang et al. (2021c), Li et al. (2020), Yazdani et al. (2021), Ma et al. (2020)

countries including developing and developed (Wu et al. 2021; Sharma et al. 2020). The management of e-waste is of great importance as in-effective management of e-waste can adversely affect the social life and environment. Most of the studies on e-waste management are on pathways towards CRE in e-waste management (Xavier et al. 2021), e-waste minimization (Dzombak et al. 2019), valorization of e-waste (Ottoni et al. 2020), household e-waste awareness (Attia et al. 2021), and E-waste reverse logistics for CRE (Islam and Huda 2018).

The 2nd theme explains how the linear model transitioned to circular model with specifically focus on TI and WTM. Incapable mechanism for sorting, collecting, and distribution of waste and in-sufficient technological infrastructure make transition towards CRE complex and long (Shpak et al. 2020). For instance, creating industrial symbiosis and synergies on the bases of substitution of raw material, recycled material, or by product among industrial sectors (Alvarez and Ruiz-Puente 2017), mismanagement in end-of-life product management (Okafor et al. 2020), recovering of energy from waste (Priyadarshini and Abhilash 2020) and TI (Khan et al. 2021b), informal outlining of TI policies (Umar et al. 2021b), and CRE policies (Johansson and Henriksson 2020; Khan et al. 2022a) are some key challenges demonstrated in the literature towards implementation of CRE.

The increasing applications of plastic in businesses and social life have made WTM face many problems of ecological concerns such as limited recycling and pollution. The focused area in the context of plastic waste are explaining life cycle assessment of chemical recycling of plastic waste (Davidson et al. 2021), blockchain for plastic WTM (Steenmans et al. 2021), identifying key barriers in plastic recycling (Yin et al. 2021; Milios et al. 2018), responsibility of producer regarding plastic pollution in aquatic system (Chowdhury et al. 2021), recycling of polymers, plastic WTM strategies (Fletcher et al. 2021), evaluation of household recovery system and closing the loop of post-consumer plastic waste (Zhang et al. 2021f; Hahladakis and Iacovidou 2019), and quality of recycled plastic waste and contamination in plastic recycling (Khan et al. 2021d; Eriksen et al. 2018).

Construction and demolition waste which is generated during the construction process has been increasing across the globe (Kabirifar et al. 2020) and counted among the biggest waste stream (Gálvez-Martos et al. 2018). For green/sustainable operations, the waste generated through this stream must be recycled through green treatments (Jin et al. 2019). Researchers have conducted studies and developing strategies for managing this waste through circular principles (Esa et al. 2017; Khan et al. 2021d; Khan et al. 2022b), evaluation of barriers for effective deployment of CRE principles in Construction and Demolition WTM (Khan et al. 2; Mahpour 2018), application of TI in Construction and

Demolition WTM (Li et al. 2020), attitude and behavior towards recycling of Construction and Demolition waste (Aslam et al. 2020).

The adoption of efficient WTM system in CRE is concentrated towards reducing of detrimental effects of waste generation on ecosystem and enhancing resource efficiency. Assessing the ecological effect of waste has always been an arduous challenge for providing policy framework and support to decision makers (Tsai et al. 2020). The major impediments and challenges of environmental evaluation within WTM are indicated through TMA results in life-cycle assessment and environmental impacts theme. For instance, textile recycling and reuse effect on environment (Sandin and Peters 2018). Land filling effect of MSTW on environment (Sauve and Van Acker 2020). How climate is effected through plastic waste (Kouloumpis et al. 2020), potential benefits of recycling (Gigli et al. 2019), ecological behavior of firms across globe towards WTM (Parajuly et al. 2020), municipal solid WTM (Torkayesh et al. 2021), lifecycle assessment model of end-of-life scenarios for WTM (Hou et al. 2018), and multi-waste management concept for CRE (Hidalgo et al. 2019).

From past few years, the generation of waste from household use and industrial activities are increasing across the globe (Namlis and Komilis 2019). According to Mallum et al. (2022), in 2016, 2.01 billion waste was generated across the globe which will increase in the years to come, becoming a global issue. The research on municipal WTM are more focused on recycling, reusing, and reducing practices in order to reduce waste and enhance the positive behavior of inhabitants (Sinthumule and Mkumbuzi 2019), providing funds for public to engage in municipal WTM (Shang et al. 2021; Petryk et al. 2019), measuring synergy among thermal treatments and recycling (Abis et al. 2020), generation of energy through municipal solid WTM (Valenzuela-Levi 2019), ecological influence of MSTW (Istrate et al. 2020), use of technology in municipal solid WTM and land filling (Nanda and Berruti 2021), and life cycle assessment of municipal solid WTM (Khandelwal et al. 2019).

From the results of text mining analysis, bio-based WTM was also found to be a main theme of WTM in CRE domain. The WTM of food posed a complex challenge in transition towards circular approach (Imbert 2017). Research work on this theme is chiefly focused on converting food waste into valuable resources (Tsai et al. 2020), bio-based CRE in organic WTM (Kaszycki et al. 2021), smart and advanced approaches for final disposal of food waste (Cecchi and Cavinato 2019), and bio-based active food packaging material (Asgher et al. 2020).

The results attained from TMA regarding research theme of TI and WTM in CRE enable mapping of TI and WTM areas about the articles published over years.

Qualitative content analysis

The bibliographic coupling analysis illustrates the clustering regarding TI and WTM in CRE domain (see Table 4). The significant and persuasive research papers in clusters are anatomized for content analysis in the current section.

First cluster: CRE overview on TI and waste hierarchy

The first cluster includes the influential research papers of the last 20 years; the details are the following: 2 articles were published during the year 2015, 1 in 2016, while 4 were in 2017, 2 in 2018, 1 in 2019, 2 in 2020, and 3 in 2021. Out of the articles that made this cluster 9 articles were from Journal of Cleaner Production, two articles from Bio resource Technology and Resources, Conservation & Recycling, one article each from Annals of Operations Research, Environmental Research, and Journal of Industrial Ecology. Iacovidou was the leading author, as appeared more than two times in the cluster.

The first group of articles in the cluster was the generic articles, whose findings can be applied to businesses and sectors. For instance, Van Ewijk and Stegemann (2016) provided the solution for barriers faced by waste hierarchy, and Iacovidou et al. (2017a) develop the instruments for measuring and monitoring with the aim to reduce waste from materials for waste management. In recent years, researchers moved towards integrating TI for more sustainable management of waste operations (Khan et al., 2021a; Shuhui et al. 2021).

The second group in the current cluster is highlighting the various vital industries. Out of the group articles, the most important WTM practices highlighted were the use of technologies in recovering municipal waste water (Liu et al. 2020); sewage waste treatment (Rajasulochana and Preethy 2016); recycling of glass (Sankar and Timo 2020), end-of-life e-waste management (Mayers et al. 2005), and recycling and reuse of textile (Sandin and Peters 2018). The illustrated articles in this cluster indicate that the waste must be changed to resource through using circular principles and deploying technologies. For instance, the sludge of sewerage can be used in production of energy and concrete (Rulkens 2008). Researchers also demonstrated that for improvement in zero waste system more technologies and waste-to-energy plants are needed to develop (Malinauskaite et al. 2017).

Second cluster: conceptualization and implementation of Circular economy

Most of the articles in cluster 2 are review papers and are on various outlooks such as geographical and historical which are the attempts to clarify and conceptualize CRE (Reike et al. 2018). According to researchers, WTM is emerged as the most related concept of CRE (Merli et al. (2018). In this line, impediments and drivers to TI for WTM in CRE

domain are analyzed (De Jesus and Mendonça 2018; Pham et al. 2019). The remaining articles in the current cluster indicate the principles of CRE in various sectors such as construction (Adams et al. 2017), generation of energy from waste for CRE (Malinauskaite et al. 2017), and manufacturing industry (Lieder and Rashid 2016). The challenges regarding management of plastic waste are discussed in 4th cluster.

Third cluster: WTM in closed-loop supply chains

The mismanagement of waste caused severe environmental problems such as contamination of water, air, and land (Singh and Singh 2017) by effective execution of circular principles and valorizing WTM can be improved (Ferronato et al. 2019). In order to effectively manage and reduce solid waste and raw material for transition towards CRE, various impediments including budget, communication, employee, information technology and management with in supply chain must be managed (Shahbazi et al. 2016). The closed-loop supply chain facilitates WTM systems through forward and reserve logistics and effectively manages end of product life cycle in sustainable way (Shaharudin et al. 2017).

The design of product has a crucial role in term of recyclability and reparability in closed-loop supply chain (Krikke et al. 2003). The reuse and recycling of products are the best choices in reducing waste. The efficient management of product design regarding WTM and proper return management of products guarantees long-term sustainability. The use of TI in WTM process for providing online system to make appointments for collection of waste and monitoring performance within supply chain network was also effective (Gu et al. 2019). The adoption of TI also enabled design of closed-loop supply chains more transparent through providing interconnection and visibility in network. In recent years, e-waste management is critical challenge in WTM systems due to having adverse effects on social life and environment. Policy makers need to provide proper policy for e-waste management in unified way in context of closing the loop of supply chain (Shi et al. 2019).

Fourth cluster: CRE a pathway to manage plastic waste management

The alarming increase in plastic waste has pushed policy makers to provide effective strategies regarding management of plastic waste (Gill et al. 2021). European countries have set strict rules regarding plastic value chain, production, and consumption patterns in order to improve sustainability and adopted circular approach to reduce plastic waste (Foschi and Bonoli 2019). The plastic waste in form of packaging or products generated from household usage to be recycled was the top priority in transition to CRE (Khan

et al. 2021a; Eriksen et al. 2018) for reducing its adverse effect on environment, sea, and wildlife. The adoption of circular principles also help in reducing carbon foot print and resource depletion generated from plastic waste (Jambeck et al. 2018).

Studies on plastic WTM elaborated recycling of superior quality plastic material produces better quality as compared to low quality material, the researchers also stated a direct link between plastic waste and recycling (Faraca and Astrup 2019). From 2017, China had banned on import of low material plastic raw material in order to improve the WTM system and resource efficiency (Iacovidou et al. 2019). The scholars have also illustrated that in order to enhance the circularity of plastic waste and resource efficiency firms need to improve quality of output products as well as set targets for recycling process (Van Eygen et al. 2018). The transition towards CRE and closing the loop of plastic is challenging and could be paved through technological advancement and improving product design (Eriksen et al. 2019). Prieto (2016) indicated that governmental policy makers and regulators need to standardize the rule regarding plastic waste and bio-degrade plastic waste in order to facilitate CRE. Moreover, researchers have stated that the adoption of CRE practices is the best strategy to reduce plastic waste and is the necessity in order to maintain a sustainable environment.

Implications and future research directions

The implications of the current study are illustrated in the current section to answer the RQ3 and provide insight gained from text mining, qualitative content, and bibliometric analyses.

> Q3: What are the future research orientation on WTM and TI towards the CRE transition?

After carefully analyzing the research studies on TI and WTM in CRE perspective, the following were the research gaps and the future research directions of the current study:

The implementation of TI in developed countries enabled them to improve their global WTM system towards a sustainable environment. For instance, the development of smart reverse system needs online system for monitoring and interaction among users for effect collection of waste, for this purpose IoT devices, were deployed for transparency and monitoring human activities and alert WTM centers to take decision timely, are the example of using TI in WTM system. However, research on the role of TI in WTM towards CRE is still less explored area and needs further clarification and justification especially in developing and under-developing countries. Therefore, moving towards effective adoption of TI in smart WTM system enhance sustainability and

enable effective WTM process such as collection and separation. Minimizing the waste for improving environmental sustainability is timely and promising step and TI needed to be implemented to improve the WTM system towards CRE transition. Along with that, studies should be conducted on how humans and machines could interact to create value and long-term service to humanity within planetary boundaries in the context of industry 5.0.

As the two main streams of research regarding TI and WTM have gained momentous attention, firstly, the research on biosphere in CRE domain with the keywords (bio fuel, biochar, circular bio-economy, food waste, bio fuel) represents noteworthy research challenge which is needed to be studied to attain no or lesser waste in agricultural food sector. Secondly, plastic waste in recent years has gained increasing focus during COVID-19, where trade-offs between health safety of product and waste and environmental sustainability occur; these trade-offs still needed to be solved, optimized, and addressed by scholars. The resilience/flexibility of reverse supply chain can have a major role in responding the shortages or disruptions faced due to any future pandemic. More studies are encouraged to be held to provide a mechanism for managing the waste in times of disruption caused by any future pandemic.

Healthcare waste is also of great concern, as this type of waste contains infectious and hazardous material, which needs to be disposed sustainably. Deploying CRE models in healthcare especially dealing with clinical, pharmaceuticals, and medical waste is a great challenge which also needs greater engagements and efforts from various sectors. The core reason behind this is that the reusing or recovering and recycling of material in healthcare are more involved in hazardous, contaminated, and infectious sources that can render health risks to community. Based on results, research on WTM and TI in the context of CRE is still needed reliable and comprehensive research and policy framework regarding healthcare waste management. The research on healthcare sector is only limited to safely disposal of healthcare waste. Future studies are recommended to deploy TI for more advanced recycling and recovery of waste in healthcare sector. It is highly recommended that studies needed be held on how closed-looped supply chain can be managed in healthcare sector. Moreover, national plans for mitigating the waste generated and strategies for reusing non-hazardous waste to be drafted and provided with comprehensive discussion by the researchers.

The One Health approach is an integrated effort among interrelated sectors for environment and human health and linking food-producing organisms in order to attain health for environment, animals, and humans. However, research studies had conducted by the scholars on the effect of WTM on environment such as on textile recycling and reuse, MSTW management, and recovering resources from food

waste, but less attention has been paid on human and animals health and wellbeing, specifically minimal research has conducted on WTM practices. Thus, it is recommended that future studies can be held on WTM by including One Health framework in policymaking and planning of waste for health promotion and disease prevention.

Conclusions

The current study is aimed to provide the map on TI and WTM research in the context of CRE for over two decades, explained the crucial research trends and themes, provide in-depth explanation about future research for better positioning, develop TI and WTM research in CRE, and map the evolution placed in the field over time. To achieve this, BMA, CTA, and TMA and mixed method approach were used to extract the information from the 1118 peer-reviewed journal articles published on Scopus from 2000 to 2021.

The results gained from the analyses indicate four clusters of TI and WTM in the context of CRE, including CRE perspectives on TI and waste hierarchy, conceptualization, and implementation of CRE, WTM in closed-loop supply chain, and CRE approach to plastic waste management. Along with that, the following main research themes of TI and WTM in the context of CRE were also identified including CRE transition, food waste, e-waste, municipal waste management, lifecycle assessment, and environmental effects, plastic waste, bio-based waste management, and construction and Demolition WTM which gained momentous in recent years as compared to liquid waste, carbon emission, and industrial ecology.

The present study findings elaborate the agenda of WTM and TI research and contribute considerably in positioning TI and WTM practices and activities align with CRE principles in the future. The landscape, map, and the prominent features of the WTM and TI research provided by the current study findings serve as a baseline for policy makers and practitioners and provide lead to future researchers to move towards CRE and support circular transition. Lastly, future directions on WTM and TI research to facilitate circular economy, human wellbeing, and sustainable environment were proposed. The future research direction provided in the current research help in (i) development of smart and sustainable WTM system through deploying TI and moving towards industry 5.0, (ii) establishing a framework that could help manage waste system without any disruption of future pandemic, and (iii) Consolidating the efforts of multidiscipline sectors in attaining ideal health of environment, animals and human through one health approach.

Following are the limitation of this study: Firstly, in the current study, data were clustered on the basis of bibliometric coupling, and it is recommended that future studies can use other data clustering techniques such as co-citation analysis. Secondly, this research has only considered Scopus database; future researchers can use both Scopus and Web of Science databases which will provide more in-depth detail in BMA. Lastly, this study has targeted only English language articles, and future studies can conduct non-English articles together with English articles to harmonize the findings of research.

Data availability The datasets used and/or analyzed during the current study are available on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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