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Current Opinion in Environmental Sustainability

The sustainability impact of a digital circular economy

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Digital technologies — such as the Internet of Things, big data and advanced analytics, additive manufacturing and 3D printing, blockchain and online platforms — are regarded as key enablers for a circular economy. A systematic literature review and analysis of 48 scientific articles published in the last five years was conducted to identify the first-, second- and third-order sustainability effects of a digital circular economy. Second-order environmental effects such as improved resource efficiency and reduction of emissions, waste and material use in products and production processes are often envisaged. However, limited attention is given to social and economic impact, and rebound effects. Existing literature also lacks a solid assessment of actual (vs expected) impact, and a more balanced consideration of negative (vs positive) effects.

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Current Opinion in Environmental Sustainability 2023, **61**:101251

This review comes from a themed issue on **Open Issue 2023: Sustainability Science, Digitization and AI**

Edited by **Victor Galaz**, **Pauline Dube** and **William Solecki**

Available online xxxx

Received: 30 July 2022; Revised: 17 December 2022; Accepted: 22 December 2022

https://doi.org/10.1016/j.cosust.2022.101251

Introduction

Digitalisation is advocated in the scientific literature and public debate as an enabler and accelerator for the transition to a circular economy — an economic system in which resource use is minimised (*refuse*, *reduce*) and material value is maximised (e.g. thorough *reuse*, *repair*, *refurbishment*, *remanufacturing*, *recycling* and *energy recovery*) [1]. The use of Industry 4.0 digital technologies — including the Internet of Things (IoT), big data and advanced analytics, 3D printing and additive manufacturing, blockchain and online platforms — is expected to make business models, products and production processes more circular, while improving knowledge exchange and connections between different stakeholders in the value chain [2,3]. Moreover, digital technologies are deemed to strengthen the role of citizens and consumers by informing, educating and turning them into active participants in the move towards a circular economy [3].

Research on the so-called 'digital' or 'smart' circular economy has mostly focused on investigating the role of digital technologies as an enabler for circular strategies (e.g. [4–6]), and identifying use cases (e.g. [7,8]) and implementation challenges (e.g. [5,9]). Existing literature, however, fails to provide a comprehensive analysis of the opportunities and risks of digitalisation in achieving the triple bottom line (i.e. environmental, social and economic sustainability). Not surprisingly, many authors are urging for more research on the impact of digital technology applications in the circular economy context [4–7]. This article fills this knowledge gap by offering an overview of the (potential) positive versus negative environmental, economic and social impact of a circular economy enabled by data and digital technologies across a variety of resource-intensive sectors and geographies. The paper is based on a systematic literature review of scientific, peer-reviewed papers written in English and published in the last five years (2018–2022). Articles and reviews that included in their title and abstract the terms 'circular economy' and 'impact' or 'effect' in combination with one or more digital technologies[1] were searched in the Scopus database (with the last update of the search in June 2022). This led to the extraction of 293 documents whose title and abstract were read to determine the article eligibility. Studies that were out of scope or with the full text not available online were excluded in the screening phase. A final set of 81 papers was retained for the final full-text analysis and 48 articles served as the basis for this review. For each study, information on the digital technologies and sustainability impact categories examined

[1] In order to capture the wide range of digital technologies applied in the circular economy domain, the search strategy combined generic terms, such as 'smart' and 'digital', with specific technologies that are commonly associated to Industry 4.0 and a digitally enabled circular economy (see [6]). The search string included the following keywords: smart OR digit* OR iot OR 'Internet of Things' OR 'big data' OR 'artificial intelligence' OR ai OR 'machine learning' OR 'additive manufacturing' OR '3D printing' OR blockchain OR platform OR 'augmented reality' OR 'virtual reality.'

(i.e. environmental, social and economic), type of effect (i.e. first-, second- or third-order effects [10]; positive or negative; actual or potential) and methods used to assess the impact, geographical scope and sector of interest were extracted and thematically coded [11].

Review

Research on the sustainability impact of a digital circular economy is growing, with a steady increase in the number of publications and the majority of articles published in the last two years. While most papers can be classified as empirical research, the impact they identify generally comes from cited literature or anecdotal evidence, and is rarely measured or quantified. Few notable exceptions are the studies by [12–19], which assess the actual environmental and/or social impact of a variety of circular economy strategies enabled by Industry 4.0 technologies.

Most papers focus on a single digital technology or a combination of two technologies, for example the use of big data collected by means of IoT devices. The IoT and big data and advanced analytics are the most studied digital technologies in the context of a circular economy, followed by blockchain, additive manufacturing/3D printing and online platforms. Other digital technologies frequently mentioned in the papers reviewed are advanced robotics, cloud computing, cyber-physical systems and virtual/augmented reality. The manufacturing sector (including the automotive, aerospace, electronic equipment and textile and clothing industries) is the most common area of application; other sectors include transport and logistics, construction and waste management.

The impact of a digital circular economy is often described at the firm or supply chain level, for example [15,20], whereas a few studies take a consumer or community perspective, for example [13,14], or describe the impact at a city or country scale, for example [16,21]. While most papers focus on European countries [13,14,16,18,21–31] or emerging economies [15,17,19,32–39], many publications do not specify their geographical scope.

The majority of papers analysed describe environmental impact, while economic and social effects have received limited attention in the literature, as also pointed out by for example [31] and [40]. Moreover, several publications mention positive effects on business performances beyond environmental, social and financial gains, such as increasing operational productivity, for example [8,23,25], enhancing efficiency and accuracy in production processes, for example [6,15,24,33,35–37,40–43], accelerating production operations, for example [30,31], improving competitiveness, for example [27] and supporting decision-making, for example [6,28,38,46]. Most of the impact is positive, although half of the papers account for both positive and negative aspects.

First-order effects

First-order (or primary) effects are direct environmental (social or economic) effects associated with the production, transportation, use and disposal of digital technologies and devices [10]. Negative first-order effects described in the literature reviewed are the increasing demand for scarce raw materials to manufacture electrical and electronic devices [24,47], and the high energy consumption (and, as a consequence, a high volume of carbon dioxide emitted into the environment) required to power the blockchain [24,34], operate data centres and digital infrastructures [25,47,48] or being consumed by connected IoT devices [24,47]. Moreover, several authors highlight the increased amount of (e-)waste created by digital devices and RFID tags [24,47–49]. These negative effects seem to be only marginally offset by the development of ‘Green IoT’ devices with a lower environmental impact, for example improved energy-efficiency features [47,50]. Nevertheless, none of the first-order effects identified in the literature are empirically grounded, and the few numerical estimates provided often rely on secondary data available in grey literature or lack a clear reference source (see e.g. [47,48]).

Second-order effects

Most of the sustainability impact identified in the literature can be classified as second-order (or secondary) effects. These are indirect environmental, social or economic impact related to changes in products and production processes caused by the deployment of digital technologies [10]. Virtually all papers analysed report benefits arising from the use of data and digital technologies in the context of a circular economy. Improvements in production processes are the most frequently cited and include reductions in resource/energy consumption and waste production, as well as higher operational efficiency and production capability, i.a. by reducing errors and costs, increasing speed and supply chain flexibility (see e.g. [18,33,41,46]). Other impact relates to improvements in the design and operation of products and services, for example a reduced use of virgin resources and waste generation thanks to eco-design informed by the IoT and big data analytics [6,15,41,51] or additive manufacturing technologies [44,45,52]. Environmental and economic benefits also derive from improvements in distribution and logistics: these range from reduced transport costs and emissions [6,34,44,45], to lower consumption of scarce resources and waste generation achieved through a digitally optimised planning and control of fleets [37]. By contrast, social impact is frequently associated with changes in seller–buyer relationships or work organisation. For example [14] argue that the use of 3D printing technologies creates new skills and job opportunities, supports community cohesion and promotes personal satisfaction; whereas blockchain is often believed to foster trust, accountability and communication between actors in the supply chain [21,29,34]. Negative second-order effects are more difficult to find in the literature and are mostly related to the potential of digital technologies to increase costs for firms [29], or displace low-skilled jobs [33].

Third-order effects

Third-order (or tertiary) effects are generally defined as indirect impact on the environment caused by the stimulation of more consumption or higher economic growth resulting from the use of digital technologies [10]. Environmental rebound effects, for example, occur when material or energy efficiency gains in the production of a good lead to cost reductions that, in turn, increase demand for that good or other products and services, thereby partly or fully offsetting the initial environmental gains [13,51,52]. Despite a digital circular economy is often associated with an increase in production efficiency, only a few authors warn against the risk of fostering higher volumes of consumption and consequent environmental degradation. Rebound effects are especially acknowledged for 3D printing technologies (e.g. higher demand for customised products, higher rate of product obsolescence [50]), blockchain (e.g. improved traceability across the supply chain can encourage more consumption of products that are seen as sustainable [53]), IoT (e.g. optimised design can make a product more desired and cost-effective for the consumer to purchase [46]) and sharing platforms (e.g. increasing transportation, cost-savings that ultimately increase consumption of other goods [27,30,54]). However, [13] is the only study that empirically quantifies rebound effects stemming from the use of an online platform for peer-to-peer leasing of boats in Finland: based on survey data, the authors calculated that reductions in CO2 emissions achieved through sharing were largely offset by an increase in use and air travel by a minority of users. Therefore, it remains unclear to what extent rebound effects outweigh the positive changes in consumer behaviour and environmental benefits that a digital circular economy is expected to create.

Conclusions

Digital technologies are widely regarded as a key enabler of circular economy strategies that aim to slow, close and narrow resource loops. Nevertheless, research that analyses the environmental, social and economic impact of a circular economy enabled by data and digital technologies is still scarce and scattered. This paper contributes to extant literature by reviewing the sustainability impact and types of effect of a broad range of digital technologies. The results show that existing studies tend to focus on the benefits of a digital circular economy for single firms, and oftentimes address just one sector, digital technology, or circular economy practice at a time. Most of the impact identified in the literature are positive second-order environmental effects, for example maximising the use of available resources and minimising emissions and waste through a digital technology-led improvement of circular processes and products. Future research should thus pay more attention to economic and social benefits, along with the risks associated with the use of data and digital technologies to achieve a circular economy. Many of the sustainability gains identified in the existing literature, as well as their intensity, also appear to strongly depend on the industry, circular economy strategy or geographic location under investigation; for instance, higher gains are expected in sectors, products and materials that are particularly impactful, for example [12,24,55]. Additional studies could further examine the specificity of impact in different contexts. Finally, most of the papers reviewed in this study describe expected rather than actual effects: there is a urgent need for empirically grounded assessments of the sustainability impact of a digital circular economy. From a policy perspective, evidence-based data could better inform interventions aimed at reducing the environmental burden of digital devices and e-waste management (first-order effects), supporting more beneficial technological applications (second-order effects), and preventing rebound effects (third-order effects). Nevertheless, it is important to also acknowledge some limitations of this study deriving from the search strategy adopted. The review strived to identify papers that focus on the impact of digital technologies and, thus, include the terms 'effect' or 'impact' in their abstract. This implies that (potentially relevant) studies that only mention environmental, social or economic impact in other sections, for example as part of their introduction, might have been overlooked. Similarly, the use of the keyword 'circular economy' in the search string might have excluded from the analysis pertinent articles that refer to circular economy strategies with a different terminology. Yet, this study represents an important first step in taking stock of the opportunities and risks of a digital circular economy, and paves the way for further research into its sustainability promises and perils.

Data Availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was supported by the Research Council of Norway under Grant number 295021.

References and recommended reading

Papers of particular interest, published within the period of review, have been highlighted as:

- • of special interest
- •• of outstanding interest.

1. Reike D, Vermeulen WJV, Witjes S: **The circular economy: new or refurbished as CE 3.0? — Exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options**. *Resour Conserv Recycl* 2018, **135**:246-264, https://doi.org/10.1016/j.resconrec.2017.08.027

2. Hedberg A, Šipka S: **Toward a circular economy: the role of digitalization**. *One Earth* 2021, **4**:783-785, https://doi.org/10.1016/j.oneear.2021.05.020

3. Hedberg A, Šipka S: The Circular Economy: Going Digital. European Policy Center; 2020.

4. Cagno E, Neri A, Negri M, Bassani CA, Lampertico T: **The role of digital technologies in operationalizing the circular economy transition: a systematic literature review**. *Appl Sci* 2021, **11**:3328, https://doi.org/10.3390/app11083328

5. Chauhan C, Parida V, Dhir A: **Linking circular economy and digitalisation technologies: a systematic literature review of past achievements and future promises**. *Technol Forecast Soc Change* 2022, **177**:121508, https://doi.org/10.1016/j.techfore.2022.121508

6. • Bressanelli G, Adrodegari F, Pigosso DCAA, Parida V: **Towards the smart circular economy paradigm: a definition, conceptualization, and research agenda**. *Sustainability* 2022, **14**:4960, https://doi.org/10.3390/su14094960.

This paper explores the role of digital technologies (i.e. the IoT, big data and advanced analytics, 3D printing, blockchain, and virtual and augmented reality) as enablers for a smart circular economy. Based on the results of a systematic literature review, the authors describe how each technology can facilitate the implementation of circular strategies and practices. The paper also highlights the need to assess the environmental impact of digital technologies on the circular economy to demonstrate that environmental gains offset their intrinsic environmental cost.

7. Ranta V, Aarikka-Stenroos L, Väisänen JM: **Digital technologies catalyzing business model innovation for circular economy—multiple case study**. *Resour Conserv Recycl* 2021, **164**:105155, https://doi.org/10.1016/j.resconrec.2020.105155

8. Kristoffersen E, Blomsma F, Mikalef P, Li J: **The smart circular economy: a digital-enabled circular strategies framework for manufacturing companies**. *J Bus Res* 2020, **120**:241-261, https://doi.org/10.1016/j.jbusres.2020.07.044

9. Ingemarsdotter E, Jamsin E, Balkenende R: **Opportunities and challenges in IoT-enabled circular business model implementation – a case study**. *Resour Conserv Recycl* 2020, **162**:105047, https://doi.org/10.1016/j.resconrec.2020.105047

10. Berkhout, F., & Hertin, J. (2001). Impacts of information and communication technologies on environmental sustainability: Speculations and evidence. Report to the OECD. Brighton, UK: SPRU-Science and Technology Policy Research. https://www.oecd.org/sti/inno/1897156.pdf.

11. Gibbs GR: Analyzing Qualitative Data. SAGE Publications Ltd.; 2007.

12. •• Laskurain-Iturbe I, Arana-Landín G, Landeta-Manzano B, Uriarte-Gallastegi N: **Exploring the influence of industry 4.0 technologies on the circular economy**. *J Clean Prod* 2021, **321**:128944, https://doi.org/10.1016/j.jclepro.2021.128944.

This paper empirically investigates the influence of Industry 4.0 technologies (i.e. the IoT, big data and advanced analytics, artificial intelligence, additive manufacturing, artificial vision, cybersecurity, robotics, and virtual and augmented reality) on the circular economy. The authors found that digital technologies enable industrial companies to reduce material and energy consumption, and the generation of waste and emissions. However, the study shows large differences in the level of impact of each technology and the circular strategies affected, with most evidence of a strong positive impact of additive manufacturing and robotics.

13. •• Warmington-Lundström J, Laurenti R: **Reviewing circular economy rebound effects: the case of online peer-to-peer boat sharing**. *Resour Conserv Recycl X* 2020, **5**:100028, https://doi.org/10.1016/j.rcrx.2019.100028.

This article examines environmental rebound effects in the context of resource sharing. Using a peer-to-peer boat sharing platform as a case study, the research provides empirical evidence of rebound behaviour from re-spending (due to additional purchasing power) and substituted consumption (such as an increase in personal use of a boat or other forms of travel) in both lessors and lessees. In particular, the study shows that a third of lessees increased their annual emissions as a result of leasing a shared boat, thereby offsetting the reductions in CO2 emissions achieved through avoiding primary production and extending the lifespan of existing boats.

14. Millard J, Sorivelle MN, Deljanin S, Unterfrauner E, Voigt C: **Is the maker movement contributing to sustainability?** *Sustainability* 2018, **10**:2212, https://doi.org/10.3390/su10072212

15. Tang YM, Chau KY, Fatima A, Waqas M: **Industry 4.0 technology and circular economy practices: business management strategies for environmental sustainability**. *Environ Sci Pollut Res* 2022, **29**:49752-49769, https://doi.org/10.1007/s11356-022-19081-6

16. Maiurova A, Kurniawan TA, Kustikova M, Bykovskaia E, Othman MHD, Singh D, Goh HH: **Promoting digital transformation in waste collection service and waste recycling in Moscow (Russia): applying a circular economy paradigm to mitigate climate change impacts on the environment**. *J Clean Prod* 2022, **354**:131604, https://doi.org/10.1016/j.jclepro.2022.131604

17. Khan SAR, Razzaq A, Yu Z, Miller S: **Industry 4.0 and circular economy practices: a new era business strategies for environmental sustainability**. *Bus Strateg Environ* 2021, **30**:4001-4014, https://doi.org/10.1002/bse.2853

18. Khan SAR, Umar M, Asadov A, Tanveer M, Yu Z: **Technological revolution and circular economy practices: a mechanism of green economy**. *Sustainability* 2022, **14**:4524, https://doi.org/10.3390/su14084524

19. Sun S: **How does the collaborative economy advance better product lifetimes? A case study of free-floating bike sharing**. *Sustainability* 2021, **13**:1434, https://doi.org/10.3390/su13031434

20. Upadhyay A, Mukhuty S, Kumar V, Kazancoglu Y: **Blockchain technology and the circular economy: implications for sustainability and social responsibility**. *J Clean Prod* 2021, **293**:126130, https://doi.org/10.1016/j.jclepro.2021.126130

21. de Filippi F, Carbone C: **ICT as innovative tools for circular planning in urban areas**. *Techne* 2021, **22**:96-103, https://doi.org/10.36253/techne-10610

22. Govindan K: **Tunneling the barriers of blockchain technology in remanufacturing for achieving sustainable development goals: a circular manufacturing perspective**. *Bus Strateg Environ* 2022, **31**:1-17, https://doi.org/10.1002/bse.3031

23. Luciano A, Cutaia L, Cioffi F, Sinibaldi C: **Demolition and construction recycling unified management: the DECORUM platform for improvement of resource efficiency in the construction sector**. *Environ Sci Pollut Res* 2021, **28**:24558-24569, https://doi.org/10.1007/s11356-020-09513-6

24. Magrini C, Nicolas J, Berg H, Bellini A, Paolini E, Vincenti N, Campadello L, Bonoli A: **Using internet of things and distributed ledger technology for digital circular economy enablement: the case of electronic equipment**. *Sustainability* 2021, **13**:4982, https://doi.org/10.3390/su13094982

25. Moreno M, Court R, Wright M, Charnley F: **Opportunities for redistributed manufacturing and digital intelligence as enablers of a circular economy**. *Int J Sustain Eng* 2019, **12**:77-94, https://doi.org/10.1080/19397038.2018.1508316

26. Rocca R, Rosa P, Sassanelli C, Fumagalli L, Terzi S: **Integrating virtual reality and digital twin in circular economy practices: a laboratory application case**. *Sustainability* 2020, **12**:2286, https://doi.org/10.3390/su12062286

27. Cerreta M, Mura F, Della, Lieto L, Poli G: **Short-term city dynamics: effects and proposals before the Covid-19 Pandemic**. *Aestimum* 2020,147-169, https://doi.org/10.13128/aestim-9428

28. Del Giudice M, Chierici R, Mazzucchelli A, Fiano F: **Supply chain management in the era of circular economy: the moderating effect of big data**. *Int J Logist Manag* 2020, **32**:337-356, https://doi.org/10.1108/IJLM-03-2020-0119

29. Di Maria E, De Marchi V, Galeazzo A: **Industry 4.0 technologies and circular economy: the mediating role of supply chain integration**.

Bus Strateg Environ 2022, **31**:619-632, https://doi.org/10.1002/bse.2940

30. Faria R, Lopes I, Pires IM, Marques G, Fernandes S, Garcia NM, Lucas J, Jevremovic A, Zdravevski E, Trajkovik V: **Circular economy for clothes using web and mobile technologies-a systematic review and a taxonomy proposal**. *Information* 2020, **11**:161, https://doi.org/10.3390/info11030161

31. García-Muiña F, Medina-Salgado MS, González-Sánchez R, Huertas-Valdivia I, Ferrari AM, Settembre-Blundo D: **Industry 4.0-based dynamic Social Organizational Life Cycle Assessment to target the social circular economy in manufacturing**. *J Clean Prod* 2021, **327**:129439, https://doi.org/10.1016/j.jclepro.2021.129439

32. Sun X, Wang X: **Modeling and analyzing the impact of the internet of things-based industry 4.0 on circular economy practices for sustainable development: evidence from the food processing industry of China**. *Front Psychol* 2022, **13**:866361, https://doi.org/10.3389/fpsyg.2022.866361

33. Abdul-Hamid AQ, Ali MH, Tseng ML, Lan S, Kumar M: **Impeding challenges on industry 4.0 in circular economy: palm oil industry in Malaysia**. *Comput Oper Res* 2020, **123**:105052, https://doi.org/10.1016/j.cor.2020.105052

34. • Ajwani-Ramchandani R, Figueira S, Torres de Oliveira R, Jha S: **Enhancing the circular and modified linear economy: the importance of blockchain for developing economies**. *Resour Conserv Recycl* 2021, **168**:105468, https://doi.org/10.1016/j.resconrec.2021.105468.

The paper investigates the application of blockchain technology to foster a circular economy in developing economies. The authors argue that circular strategies are not fully applicable to certain product categories, for example disposable sanitary material such as diapers and pads. Sanitary waste has a negative impact on the environment and society especially in countries like India, where waste separation is still performed manually. Blockchain technology is proposed as a solution to enhance the traceability of products and the communication between different actors (e.g. firms, users and governments) to minimise the impact of hazardous and high polluting waste.

35. Bag S, Wood LC, Mangla SK, Luthra S: **Procurement 4.0 and its implications on business process performance in a circular economy**. *Resour Conserv Recycl* 2020, **152**:104502, https://doi.org/10.1016/j.resconrec.2019.104502

36. Bag S, Yadav G, Dhamija P, Kataria KK: **Key resources for industry 4.0 adoption and its effect on sustainable production and circular economy: an empirical study**. *J Clean Prod* 2021, **281**:125233, https://doi.org/10.1016/j.jclepro.2020.125233

37. Bag S, Yadav G, Wood LC, Dhamija P, Joshi S: **Industry 4.0 and the circular economy: resource melioration in logistics**. *Resour Policy* 2020, **68**:101776, https://doi.org/10.1016/j.resourpol.2020.101776

38. de Souza M, Pereira GM, Lopes de Sousa Jabbour AB, Chiappetta Jabbour CJ, Trento LR, Borchardt M, Zvirtes L: **A digitally enabled circular economy for mitigating food waste: understanding innovative marketing strategies in the context of an emerging economy**. *Technol Forecast Soc Change* 2021, **173**:121062, https://doi.org/10.1016/j.techfore.2021.121062

39. Khan SAR, Zia-ul-haq HM, Umar M, Yu Z: **Digital technology and circular economy practices: an strategy to improve organizational performance**. *Bus Strateg Dev* 2021, **4**:482-490, https://doi.org/10.1002/bsd2.176

40. • Rejeb A, Suhaiza Z, Rejeb K, Seuring S, Treiblmaier H: **The Internet of Things and the circular economy: a systematic literature review and research agenda**. *J Clean Prod* 2022, **350**:131439, https://doi.org/10.1016/j.jclepro.2022.131439.

This article reviews the existing literature on the IoT (also in combination with other Industry 4.0 technologies like big data analytics, 3D printing and blockchain) as an enabling technology contributing to the shift towards a circular economy. The authors describe how the IoT supports circular strategies (e.g. reuse, remanufacturing, recycling, servitisation) and inter-industry collaborations, the barriers to IoT adoption in the circular economy, and the impact of the IoT on a sustainable circular economy.

41. Atif S, Ahmed S, Wasim M, Zeb B, Pervez Z, Quinn L: **Towards a conceptual development of industry 4.0, servitisation, and circular economy: a systematic literature review**. *Sustainability* 2021, **13**:6501, https://doi.org/10.3390/su13116501

42. Krstić M, Agnusdei GP, Miglietta PP, Tadić S, Roso V: **Applicability of industry 4.0 technologies in the reverse logistics: a circular economy approach based on COmprehensive distance Based RAnking (COBRA) method**. *Sustainability* 2022, **14**:5632, https://doi.org/10.3390/su14095632

43. Alves L, Ferreira Cruz E, Lopes SI, Faria PM, Rosado da Cruz AM: **Towards circular economy in the textiles and clothing value chain through blockchain technology and IoT: a review**. *Waste Manag Res* 2022, **40**:3-23, https://doi.org/10.1177/0734242×211052858

44. Vaccaro G, Buoninconti L: **3D print e circular economy: innovation and sustainability for the construction sector**. *Sustain Mediterr Constr* 2021, **13**:73-82.

45. de Mattos Nascimento DL, Mury Nepomuceno R, Caiado RGG, Maqueira JM, Moyano-Fuentes J, Garza-Reyes JA: **A sustainable circular 3D printing model for recycling metal scrap in the automotive industry**. *J Manuf Technol Manag* (5) 2022, **33**:876-892, https://doi.org/10.1108/JMTM-10-2021-0391

46. Khan SAR, Piprani AZ, Yu Z: **Digital technology and circular economy practices: future of supply chains**. *Oper Manag Res* 2022, **15**:676-688, https://doi.org/10.1007/s12063-021-00247-3

47. Fraga-Lamas P, Lopes SI, Fernández-Caramés TM: **Green iot and edge AI as key technological enablers for a sustainable digital transition towards a smart circular economy: an industry 5.0 use case**. *Sensors* 2021, **21**:5745, https://doi.org/10.3390/s21175745

48. Hoosain MS, Paul BS, Ramakrishna S: **The impact of 4IR digital technologies and circular thinking on the United Nations Sustainable Development Goals**. *Sustainability* 2020, **12**:10143, https://doi.org/10.3390/su122310143

49. Condemi A, Cucchiella F, Schettini D: **Circular economy and e-waste: an opportunity from RFID TAGs**. *Appl Sci* 2019, **9**:3422, https://doi.org/10.3390/app9163422

50. Demestichas K, Daskalakis E: **Information and communication technology solutions for the circular economy**. *Sustainability* 2020, **12**:7272, https://doi.org/10.3390/su12187272

51. Townsend JH, Coroama VC: **Digital acceleration of sustainability transition: the paradox of push impacts**. *Sustainability* 2018, **10**:2816, https://doi.org/10.3390/su10082816

52. Dominish E, Retamal M, Sharpe S, Lane R, Rhamdhani MA, Corder G, Giurco D, Florin N: **"Slowing" and "narrowing" the flow of metals for consumer goods: evaluating opportunities and barriers**. *Sustainability* 2018, **10**:1096, https://doi.org/10.3390/su10041096

53. Ellsworth-Krebs K, Rampen C, Rogers E, Dudley L, Wishart L: **Circular economy infrastructure: why we need track and trace for reusable packaging**. *Sustain Prod Consum* 2022, **29**:249-258, https://doi.org/10.1016/j.spc.2021.10.007

54. Arrigo E: **Collaborative consumption in the fashion industry: a systematic literature review and conceptual framework**. *J Clean Prod* 2021, **325**:129261, https://doi.org/10.1016/j.jclepro.2021.129261

55. Monteiro H, Carmona-Aparicio G, Lei I, Despeisse M: **Energy and material efficiency strategies enabled by metal additive manufacturing – a review for the aeronautic and aerospace sectors**. *Energy Rep* 2022, **8**:298-305, https://doi.org/10.1016/j.egyr.2022.01.035