CHAPTER

17

Artificial intelligence in circular economy—the next step for sustainable revolution

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17.1 Introduction

Circular economy (CE) is a concept that mainly involves the material loops closing or cascading the resources that are used, for the prevention of waste occurrence and transformation of the residual streams that are resulted into a new stream of resources that is secondary resources. The strategies involved and the legislative framework that is used for the management of waste in any country are considered as the important initiative toward the development of the CE. The resources of the country become a main driving force for the growth of the economy of the country and the protection of the environment.

CE is a system design that is restorative and regenerative that helps to maintain the products, components, and their materials along with their high value and utility. Even with the benefits that CE brings into the business, the transformation from the linear to CE model needs great efforts from the government and the policy makers along with the industrial cooperation and the cooperation of end users (Jinjarak, 2015). There are also some arguments that besides the merits of CE as a sustainable business model, the renewal and restoration of the materials are very costly for the industries. So, there is a need for bringing some changes in the business

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models that can produce some extra challenges to the companies. There are some things that the companies need to face that are operations needs for management of assets, novelty of supply chain, logistic approaches for waste management, and also the manufacturing and enhancing the quality of the products (Nurminen & Malhi, 2020). These designs can increase the workflow complexities of CE, so there is a need for development of product design and improvement of those related business models for fast-forwarding the move toward circularity (Kraaijenhagen et al., 2016).

The companies are in need for more innovative solutions based on the product design and their strategies for narrowing the resource loops. This article has given a discussion regarding the CE and sustainability, need for the CE in the companies and industries, strategies in regards to CE design, technologies used in the CE mainly the digital technologies like Internet of things (IoT), Machine Learning (ML), Artificial Intelligence (AI), and so on, product design and business model. There are also some views regarding the limitations and future of CE in the economy.

17.1.1 Scope of artificial intelligence in circular economy

The application of AI in the CE is vast, providing groundbreaking solutions that have the potential to revolutionize the approaches of industries toward production, consumption, and waste management. The capacity of AI to analyze extensive datasets and enhance processes makes it a potent instrument for optimizing resources, reducing waste, and enhancing the efficiency of supply chains. AI is essential in fostering circular practices by optimizing recycling procedures through computer vision and robots and by informing the design of products with extended life cycles. It aids in energy management by improving efficiency and incorporating renewable sources into the energy system. AI further involves customers by providing tailored recommendations, promoting responsible consumption patterns. The necessity of AI in the CE is underscored by regulatory compliance and data-driven decision-making, which offer significant insights for enterprises and politicians. AI plays a crucial role in the CE by encompassing the entire lifespan of a product and providing a transformational route toward a sustainable and circular future.

17.2 Circular economy and sustainability

Various companies are engaging increasingly in the concept of CE (Bassi & Dias, 2019). The companies are integrating the practices of CE into the sustainable strategies of the company. The CE and the sustainability in an organization has clarified with two concepts that are, the

transdisciplinary nature that is inherent to the sustainability development will lead to the difficulty in the formulation of single conceptualization (Sauvé et al., 2016). The reason for this is mainly because of interconnecting the various disciplines such as vocabularies and stakeholders. There are also some authors' suggestions regarding the CE is that, the interpretive flexibility of sustainability is a strength that helps in the adaptation of CE into various contexts and the organizations (Leach et al., 2010). Some other arguments are that the vagueness of sustainability prevents the operationalization process (Simon, 1994). There are efforts that have been taken for finding the consensus on the conceptualization of sustainable development, mainly based on the framework of sustainable development goals that is accepted globally (Calisto Friant et al., 2020).

Similarly the CE can also be interpreted in an umbrella concept like sustainability that helps in drawing some inspiration from a couple of concepts and ideas from the resource management and environmental sciences (Calisto Friant et al., 2020). There are various strategies of CE that exist and discussions regarding the impact of the strategies have been increasing at the core of CE. The core of the CE can be defined by the aim for retaining the values through the closing resource loop process (Urbinati et al., 2017).

Some of the perceptions regarding sustainability and the CE have been mentioned here. That is the interpretation of the relationship between sustainability and the CE can give insights regarding the decision-making process that are primarily concerning the trade-offs. They can also tell to what extent they consider the practices of CE can solve the issues of present sustainability (Urbinati et al., 2017).

The sustainability and CE are closely related to each other. The CE has been implemented as a way for achieving sustainability. The companies in all ranges and sectors have indicated that the CE can positively contribute to the impacts on sustainability. In a most particular way, the CE has been known by most surveys and the responses to the interviews as a very important pathway for achievement of sustainable development goals but not for only on repurpose. There are different views that have been encountered by the companies in the use of CE for obtaining the sustainability that does not have the circularity as the end goal (Schroeder et al., 2019; Walker et al., 2022).

17.3 Need for circular economy

Human activity on the earth has created various harmful effects as well as useful effects. To overcome the harmful effects, there is a need for industrial developments that can consider all the elements that have been involved.

Textile industry can be considered as one of the highest polluting industries in the globe. It is because they use a resource intensive supply

chain that can produce large amounts of wastes and release large quantities of toxins into air, water, and soil causing pollution (Leonas, 2017). This has caused various harmful effects on humans as well as the environment. In each stage, the textile industry produces large quantities of wastes that have been discarded. These wastes can be categorized into three stages that are: preconsumer textile wastes, postconsumer textile wastes, and postindustrial textile wastes (Gardetti, 2019).

As considered by the CE concept, the garment consumption by mass has to make a purchase decision process that is shorter than the clothes that have been purchased consciously. So time will be considered as one of the essential factors. In a purchase of mass garment, the process that has been involved is purchase, wear, and discard that happen in a brief amount of time. So the main reason for using the CE is that it says not only about the recycling of the materials but also the upcycling of the product. Because the recycling process will only provide a short-term solution and the 3R of this process is reduce, recycle, and reuse (Gullingsrud & Perkkins, 2015). As it is not enough for real improvement. But the usage of creating products that are made of materials that can be transformed and reused constantly can improve the quality of the end product each time (Goldsworthy & Earley, 2018).

17.4 Circular design strategy

The product designs in the way of the CE are increasing efficiency of the material, extension of the product life, and improving efficiency of the product recycling. CE can be divided into three fundamental categories that are narrowing, slowing, and closing the loop of resources. This strategy is mainly to categorize the mechanism that helps in the flow of the resources through the system (Bocken et al., 2016).

The three approaches relating to cycling of the resources and reduction in the flow of resources has been given as follows: (1) solving resource loops—throughout the long-life of goods and products along with their design the life extension of the product will be reduced. That means at long runs utilization of the products will be extended and intensified that leads to slowing down the resources flow; (2) closing resource loop—using recycling process, the loop that is going on between the post use and production will be over that results in the circular flow of all the resources; (3) resource efficiency or narrowing flow of resource—this is mainly aimed at using small amount of resources per product (Braungart et al., 2014). The linear and circular approaches for resource reduction has been depicted in Fig. 17.1.

At the end, the slowing is mainly about the use of goods for a long time and the reuse of goods over a period of time, via the long-life

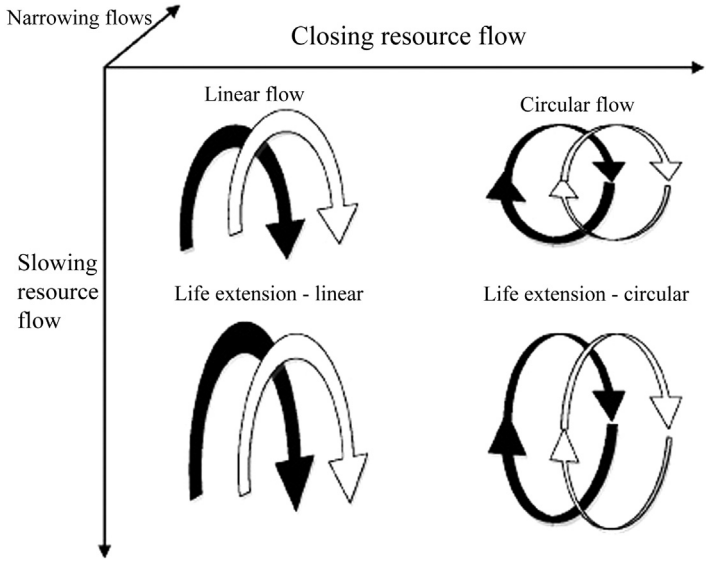


FIGURE 17.1 Categorized linear and circular approaches for resource reduction.

goods design and the extension of life of product while closing loops are mainly about reusing the materials through the recycling process. Narrowing the loop is regarding reduction of use of the resources that are associated with the product and the process of the production.

The correct function of the strategies is gained at the end of life design when the intentions of end users and the producers are common (Kumar et al., 2011). Revenue for the business was obtained from the circulation of the materials through the lifetime extension of products (Peres et al., 2020). The potential willingness of the users in purchasing the reused and recycled products are mainly related to the functional risk that has been perceived that makes a way for the implementation of the industry 4.0 products (Bocken et al., 2016). From this it is understandable that where the perceived risk is high and low margin price, then users are likely to buy the new products. Furthermore, the tolerance of the users for the uncertainty will define the willingness to get the perceived quality of refurbished products and pay for it (Jose et al., 2020). The circular design options can be able to make a downstream circularity hence becoming a part of the business model.

17.5 Circular economy product design

The expanding population has led to the usage of limited resources. As the resources are limited, the price of the products increases rapidly.

CE focuses on maintaining a closed loop that can economically be beneficial (Ijomah & Danis, 2012). CE tries to make use of the remaining valuable products left after complete usage of the material or a component. CE works by five principles: (1) designing out from waste, (2) building resilience through distinctiveness, (3) using renewable energy sources, (4) cascades, and (5) thinking in systems (Lopes de Sousa Jabbour et al., 2018).

Circular design is a little to no explored field in the field of CE. There is not much research and definition involved in circular design. The biggest hurdle in designing the model is the terminologies. It is fairly important as the process design (Abbas et al., 2022). It is important to have jargon terminologies as they can be understandable by anyone in the field. The lack of jargons in the CE has led to a great confusion (Bocken et al., 2016). This resulted in misunderstanding, hindering the further research. The CE runs only if no quality loss is detected by recycling the resources, and if green energy is used to run the systems. There are four steps that need to be taken care of before a product design proposal (Calisto Friant et al., 2020). The five principles of CE is shown in Fig. 17.2.

17.5.1 Disassembly

Disassembly is the very first that most of the products undergo. The two things that disassembly does for a product is to give a new life for it, or extend the working of the product. Optimization of disassembly products should be performed when the design state is between 80%

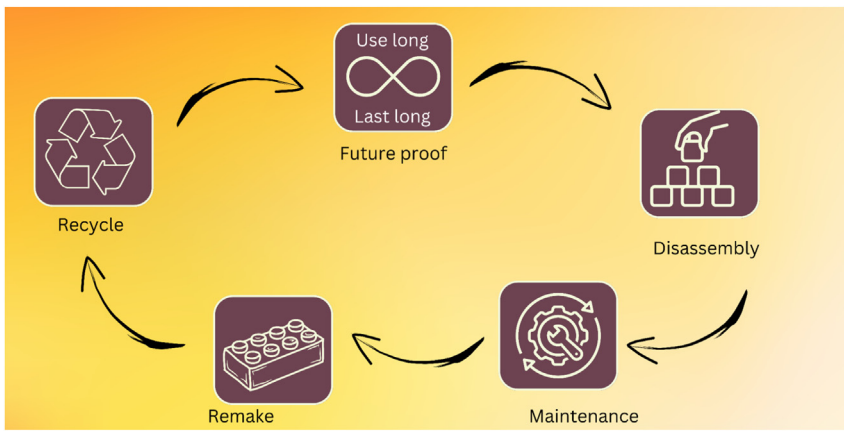


FIGURE 17.2 The five principles of circular economy and artificial intelligence (AI) (van den Berg et al., 2021).

and 90%. Recycling undergoes destructive disassembly. Nondestructive disassembly is handled if the product needs remake or maintenance. Disassembly is again divided into architecture, and connections. The product connections and the way the architecture is built play an important role in disassembly (Peeters et al., 2012; van den Berg et al., 2021).

17.5.2 Maintenance

Maintenance usually describes the time that the product has run without disturbances. Maintenance includes cleaning, performance, repair, and lifetime prediction. In the view of designing, a product should be designed in a way that ensures certain lifelong predictions. The prediction of lifetime working allows defecting the future performance of the product. Businesses that are based on services use predictive tools to keep a track on the usage conditions of the product (van den Berg et al., 2021).

17.5.3 Remake

Remake is preferred when the customer has used the product for a long time, and exhausted all the actions that the product is meant to perform. Remaking differs for industrial sectors and they normally use remanufacturing, reconditioning, and refurbishment terms to define the process (Cole et al., 2017). Successful repair and up leveling of the products are performed by modularity. Modularity is a key component. Depending on the location and transportation, design products can differ when reverse logistics is considered (van den Berg et al., 2021).

17.5.4 Recycling

Once the product has reached its limit of usage, a recycling process is performed. Recycling is the recovery of material at-end-of-life. Recycling is the last option that primarily focuses on retaining the remaining value of the product or component. Choice of material, and to which wing they can be separated are the factors that are considered during recycling. Some materials should be recycled entirely as they contain valuable components. Electric boards contain high material value in spite of their complexity they can be revived by biological means. Business models need different kinds of recycling design as they do not want to sell second hand products, and they need long-life products to attract customers (van den Berg et al., 2021).

Circular product design based on these four topics is important and is depicted in Fig. 17.3. The designing of the component or economy should be able to meet all these four conditions in order to be fully beneficial.

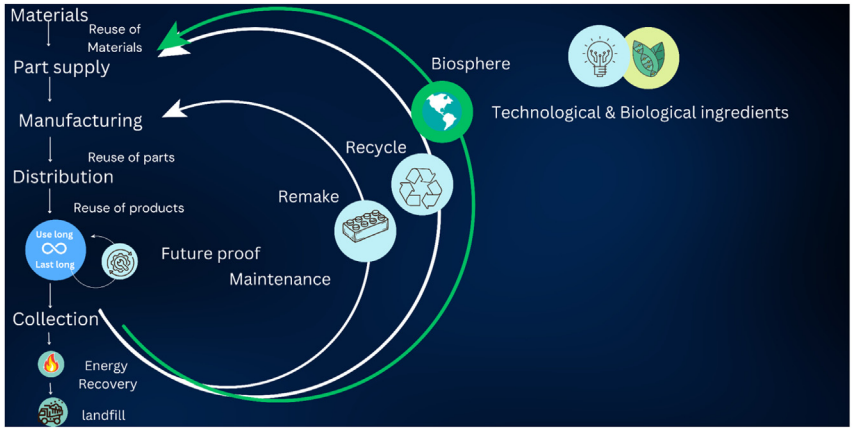


FIGURE 17.3 Circular product design (van den Berg et al., 2021).

17.6 Digital technologies in circular economy

The intersection of digital technologies and the CE is a fast-growing field. The field of CE mainly depends on the concepts and the studies obtained from the adjacent fields such as PSS, industrial ecology, and green supply chain logistics. Majority of the studies regarding the CE are conceptual or only in reviews as there are only a limited number of the qualitative cases for the evaluation of digital technology applications in the CE context. Digital technologies can be grouped for the CE concept. In this study the three-layer architecture grouping is done. The three layers are data collection, data integration, and data analysis (Amatucci, 2022).

The methods or technologies involved in data collection are RFID (radio frequency identification) and IoT. RFID is a data collection technology that uses electromagnetic fields for automated identification and tracking tags attached to the object. In the CE context, the RFID is mainly used for the tracking of material flow, which helps in enabling the value recovery implementations. IoT is defined as the connection of sensors and actuators by the networks for computing systems that helps in monitoring and managing health and actions of the machines or objects that are connected (Garrido-Hidalgo et al., 2019). In CE context, IoT can be used for the collection of information that is generated by sensors that connect the stakeholders in the value chain. The use of IoT in CE, which IoT helps in describing the CE models as the dynamic feedback control loops. This becomes a fundamental basis for the evaluation of the consequences of numerous stakeholders throughout the physical products' life (Pagoropoulos et al., 2017).

The systems involved in data integration systems are (1) RDBMS (relational database management systems) and database handling

system, (2) PLM (product lifecycle management). RDBMS are the systems that are mainly involved in the data organization in the tables that are described formally. These systems allow the integration of the heterogeneous data sources, by specifying the architecture of the data that enables the requirements of the information architecture (Chauhan et al., 2022). The combination of RDBMS and data handling systems can support the idea of a CE and its goals. Their main function is that they can integrate the large amount of information that is produced by data collection systems like IoT, Customer Relationship Management (CRM), and Enterprise Resource Planning (ERP) systems. PLM is also an information management system that helps in integration of data, processes, and business systems. These systems help in the transition of the CE as they can help in the integration of the information across various life cycles of the products and stakeholders in the value chain. The PLM systems in the level of the company can enable the products monitoring and multiple lifecycle parts (Lieder & Rashid, 2016). The PLM system enables the near time consumption and the stock and material flow optimization.

The technologies involved in the data analytics are machine learning and Big Data analytics. Machine learning is a practice that is mainly based on the algorithms that learns from the data without any dependency on the rules-based programming. This can also be called AI. The AI is a ML algorithm that is applied as neural networks that depends on the large data processing rather than predictions. In the context of CE, ML can be applied for supporting the process and the optimization of a system that has a large quantity of data. Usage of AI for designing the intelligent enterprise system can leverage the next generation of the computing theory and its application on CE (Weichhart et al., 2016). Big Data analytics are introduced because of the increase in the technical collection of data capacity because of the proliferation of the processing equipment that are inexpensive that resulted in the increase of datasets. Big data have been characterized by volume, variety, velocity, and veracity. So big data are the sets of data that are large and changing rapidly to be analyzed with traditional database techniques (Rusch et al., 2023). In the use of big data in the CE, better decision-making has been identified by using various information from different systems such as IoTs, sensors, and so on. The usage of big data is mainly an approach for handling large quantities of data.

17.7 Artificial intelligence and industry

In the industry 4.0 context, AI can be regarded as one of the important technologies for achieving these capabilities and can redefine the process of manufacturing and structured business models. AI can be

defined generally as the subdivision of computer science that deals with data processing system development that can perform the functions that are commonly associated with the intelligence of humans as self-improvement, learning, and reasoning (Peres et al., 2020).

In the usage of AI in industries, it can be defined as the area that is focusing on the development, validation, deployment, and maintenance of the solutions of AI for the various applications in industries along with the sustainable development (Ghoreishi & Happonen, 2020). So AI can be considered as an interdisciplinary area that encompasses fields such as ML, NLP, and robotics (Peres et al., 2018; Zhang et al., 2018). There are considerable research efforts that have been done for the last decades on the concept of combining and embedding these concepts into the existing industry 4.0 manufacturing value chains (Clark et al., 2020; Lee, 2020).

The combination of these systems helps in the increase of adaptability and problem-solving ability in the predefined system boundary via a certain degree of autonomous actions. The industrial AI differs itself from the field of AI mainly in five dimensions that are: (1) infrastructure—that concerns hardware and software; (2) data—industrial AI needs the data that has been characterized by their volume, variety of velocity that is high, originating from different units, regimes, products, and so on; (3) algorithms—they need the integration of digital, physical, and heuristic knowledge. The high complexities that are derived from the management of the model, deployment, and the governance. (4) Decision-making—as the given setting is industrial, the error tolerance is very low and uncertainty handling being of utmost importance. For the large-scale optimization problems, the efficiency has to be of special importance. (5) Objectives—the most important thing that an industrial AI generally addresses with utmost importance is concrete value creation. Mainly through the combination of factors as reduction of scrap, quality improvement, performance of augmented operators or the ramp up times that are accelerated. Because of the heterogeneous nature of the industrial systems and application, it is useful for describing the autonomous actions through a graduated model of autonomy (Peres et al., 2020). The main aim of the industrial AI is for the validation, development, and deployment of ML algorithms along with the sustainable performance for applications in industries.

17.8 Artificial intelligence and circular economy

CE works on the theory of eliminating toxic substances of technology and biological wastes. Once the upcoming negative impact products are removed, an increase in utilization of products is focused. The useful

materials are preserved and are ready for reverse logistics. The material that was ready to be turned into a pollutant can now be remade into useful products. The finished products are used in cycles over and over (Hedberg & Šipka, 2021). CE should contribute to successful business. Remanufactured products must meet the demand in supply, and have a better return condition. Proposing a business model with AI can help in dynamic price pitching, demand forecasting, and helps to meet the demand supply by tracking the used product sellers. Stuffstr is one of the AI tools where competitive pricing is set with the algorithm based on the second end product conditions. Business model does require marketing, customer support, sales service, logistics, pricing, and sales. AI with a business model focusing on CE can increase the sales, product quality, durability, and promote business with a future insight (Sivarajah et al., 2017).

17.8.1 Business model infrastructure

Wastes are a cluster name that encompasses domestic, electronic industries, and other streams of deserted products. Waste is a mixture of complex substances that include products, by-products, and metals, including biological and technical. Separation of waste materials requires a monotonous flow of products. The valuable products sorted in a better way have useful components, levitated quality of materials, increased recovery margins, and good recycling values (Sivarajah et al., 2017). AI infused in a CE has better sorting of products. AI uses visual recognition of wastes and sorts them in a sequential manner. Zeno Robotics helps to sort out wastes that can be further reused. At the treatment facility, the operator can select the type of waste products that are needed when the waste passes through the conveyor belt. Zeno Robotics uses AI along with sensors to perform the task. Zeno Robotics can sort the same raw material into different products. Such as conductors, insulators, and resistors that are used in most of the electronic gadgets. About 95% of the wastes can be sorted using Zeno Robotics, and are reused into different products.

17.8.2 Innovative circular business model

Electronic goods are prioritized when compared to other sectors. These products have the ability to run until the end-of-life (EoL). The waste electrical and electronic equipment (WEEE) has advantages compared to other forums. Reuse of the waste products is preferred when compared to recycling. Reuse of electronic products have been said to increase the economy and environmental well-being (Habib et al., 2015;

Ijomah & Danis, 2012). Of the received products only 2% can undergo reuse, while 68% can be recycled. Business is oriented more toward profit, loss factors when compared to environmental factors. A successful business model embeds profit, innovation, and circularity along with other business factors. It is important that digitalization was able to build opportunities, ideologies, and create value for individual users, and companies. The two main forums needed to be considered are pricing, and aligning the exact material collection needed for the product. Since data collection and data analytics are made easier with the help of AI. Companies need not worry about the material demand as they can track them beforehand. Flea markets are another wonderful source of purchasing second hand products with margin ranges. The pricing of the desired products can be estimated both for local and global markets with different AI softwares. AI in a CE can ease the hurdles rooting for a better future (Parajuly & Wenzel, 2017).

17.8.3 Artificial intelligence uses in business model

AI powered in CE has unbounded opportunities in circular product design, materials, and components. Innovative design helps in reuse, refurbishment, recycling, and repair cycles in technology. In biological wastes, they play an important role in looping of nutrients. AI can rapidly analyze the structure and properties of a material data, this helps scientists in designing new products within a limited time. AI can also detect and eliminate hazardous chemicals or components with the help of algorithms. AI is rapid, effective, and economically safe when compared to human sorting. As AI is considered, algorithms play an important role in sorting the products. AI can detect faults in materials and slow down the manufacturing or prototyping process. Once the process is delayed, they can easily correct the faults eliminating less waste. AI can also detect hazardous substances, and vision out hard-to-recycle materials in the same product, says World Economic Forum and Accenture Strategy. AI in hands with CE increases product durability, modularity, and increases the circular indexing of the design (Ghoreishi & Happonen, 2020).

17.8.4 Applications of artificial intelligence and circular economy

Food industries are able to meet the global food demand in spite of increase in population. For every dollar spent on food, a person pays 2 dollars for it. This includes consumption and production charges. Food is cultivated on a local and global scale. Food engages in health,

regeneration, and the overall economy of the people. Food is regenerative so are its by-products. The by-products from food industrial waste contain valuable resources such as enzymes, proteins, and other compounds that can be recycled to new products. CE on food wastes follows three paths: (1) the food should be grown locally and regeneratively, (2) most of the food should be used, (3) healthier food products should be made or designed. AI plays an important role in achieving all these three aspects as they revolutionize the growth, production, design, and purchase of food materials. According to the data in the year 2030, AI in CE will be able to generate a revenue of 127 billion US dollars. FARMWAVE, Taranis, and Aerobotics use AI to interpret satellite, smartphone, and drone images in the field to detect pests, and eradicate them as early as possible. FarmBot and EcoRobotix have used AI in both outdoor and indoor farming based on aeroponics (Backman et al., 2023).

Life without electronic gadgets is not possible. They are part of our daily lives. The electronic machines generate around 10.5 million tons of e-waste every year. About 6 million tons of e-waste is generated from China alone making it one of the largest e-waste countries in the world. Among the huge mass of e-waste generation, only 20% of the waste is recycled and valuable materials are recovered by preventing environmental damages. Electronic devices are in the hands of the consumer for a longer period. Once the devices are disposed, they can be recycled, refurbished, and remanufactured with distinct functions to different users. As electronic devices are considered, new designs of products and materials play an important role. Once the product is collected, they need to be disassembled, recovered, and then reused or recycled into new ones. Investment for the infrastructure and innovative business model is necessary (Chen et al., 2021). AI in CE generated 90 billion US dollars in 2023 for electronic products. With the help of AI in business model and circular design, the period of product usage can be increased. This extends the potential value to USD 59 billion. Further, AI can also perform target marketing, pricing, maintenance, and designing better. AI can recover e-waste in a higher margin and can capture around 107 billion USD. AI reduces waste in production and increases efficiency in materials. AI helps in the research and development process, through innovation, rapid testing, and cost-effective grant for resources. Motivo provides insights and optimizes design using big data in integrated circuits (Agarwal et al., 2020)

Other digitalization in the CE such as IoT can provide new communications between devices, increasing the interconnections, and forming new networks. In Industrial revolution 4.0, IoT is a stepping stone to improve and achieve CE (Garrido-Hidalgo et al., 2019). IoT gives an insight on how product disassembly, and at the end of its life how the

product can be recycled (Lopes de Sousa Jabbour et al., 2018). AI is primarily used to study and understand complex functions. Machine learning and deep learning are some of the programs that AI is focused on (Vinuesa et al., 2020). Big data is used to analyze huge quantities of data and separate them based on value, variability, velocity, variety, and volume (Sivarajah et al., 2017). Big data in real time is used for lifetime prediction of the component, route optimization, distribution management, remote position reporting, and fuel efficiency optimization (Li et al., 2015). Smart contracts can be achieved by block chain technology throughout the life cycles. They are specifically used for controlling and tracking. These are some of the applications of AI in CE to attain sustainability (Rusch et al., 2023).

17.9 Impact of AI on circular economy and sustainability in biofuels and bioenergy production

AI in CE has a significant value in sustainable industry. The optimization of the products plays a huge role as they contribute to reducing chemical materials. With the help of AI, the generation of biogas is made smoother, which leads to better recyclable ability (Wang et al., 2023). In order to increase the yield and quality of biodiesel, the research makes use of AI and machine learning algorithms to anticipate the qualities of the fuel. The algorithms used for prediction are K-nearest neighbors, polynomial regression, deep neural networks (DNNs), and linear regression. A thorough analysis is conducted to determine how different transesterification process parameters affect biodiesel yield, viscosity, and density. Genetic algorithms (GAs) are proposed as a means of optimizing biodiesel production. Based on the desired characteristics of the biodiesel, the GA determines the best values for the transesterification process parameters. The transesterification process parameters needed to produce biodiesel yields of 72%, 85%, and 98% are shown in the results section (Khanna et al., 2023).

Utilization of information fusion and perturbation theory machine learning (IFPTML) approach to preprocessing the data after assembling a dataset of 1222 fuel mixes with precise chemical composition. A variety of linear and nonlinear AI/ML models, such as DNN methods, multivariate linear regression (MLR), radial basis function (RBF), and multilayer perceptron (MLP), were tested. The most accurate models estimated the fuel mixes' RON and MOM values with r2 values between 0.89 and 0.99. More than 10,000 data points about drop-in biofuels and environmentally friendly fuel mixtures were used in simulations. Experimental testing revealed that the top-scoring fuel mixes predicted by the algorithms met all requirements. The practical results

validated the computational simulations. Using the dataset and AI/ML models built, environmentally friendly fuel blends with reduced environmental impact can be designed. The GitHub repository makes the Artificial Neural Network (ANN) models' C++ code accessible to the general public for research purposes (Bediaga et al., 2023). The impact of AI in determining the chemical compositions and their alternatives has a proven impact on the CE and sustainability of bioenergy and biofuel.

17.10 Limitations of artificial intelligence and circular economy

Although the use of AI in the CE offers several possibilities, it is crucial to recognize a number of constraints and difficulties. A major obstacle arises from the reliance on substantial quantities of data, which may not always be easily accessible or comprehensive, impeding the efficiency of AI algorithms. Moreover, the intricate nature of circular systems, which encompass complex supply chains, various materials, and varying regional rules, presents a formidable obstacle for AI models to offer universally applicable solutions. Additionally, the initial expenses linked to the integration of AI technologies in CE practices can provide a challenge for certain organizations, especially smaller enterprises. It is important to carefully evaluate ethical factors, such as the appropriate handling of data, issues regarding privacy, and the possibility of unexpected environmental impacts resulting from the rise in electronic waste. Striking a balance between the requirement for openness and responsibility and the safeguarding of confidential data is a tricky undertaking. To overcome these restrictions, it is necessary to adopt a comprehensive approach that involves collaboration between different disciplines, continuous technological progress, and a dedication to using AI in CE efforts in an ethical and sustainable manner.

17.11 The future of sustainability: artificial intelligence enabled circular economy

AI has the capability to improve garbage sorting and recycling procedures through the utilization of computer vision to precisely identify and classify materials. AI-powered intelligent robotic systems can automate the sorting and processing of recyclables in recycling facilities, thereby enhancing efficiency and minimizing pollution. AI-powered applications have the ability to enlighten consumers about the CE, offering knowledge on sustainable options and promoting conscientious consumption. Customized suggestions and rewards can be utilized to

encourage consumers to adopt circular behaviors. In the end, AI integrated with CE is a much needed novel area of research and development. Real practice could bring a change in society. It educates users on how to value products, and use them efficiently. CE can really surpass all the hurdles, increasing the economy, and health of the environment on a global scale (Ghoreishi & Happonen, 2020).

17.12 Conclusion

CE is a fresh start that allows centrist and people to see the valuable materials in wastes. With new emerging technology day by day, ideas and practices became boundary less. CE focuses on reusing waste compounds without discarding them. AI is an intriguing topic that intervenes in all industries. Circular economies powered by AI can solve most of the complex problems. From designing, manufacturing, to final product, AI plays an important role in CE. AI can detect defects ahead, helps in pricing, increasing market margin, customer service, reduce waste, and sort different compounds in the same product. AI eliminates hazards ahead of manufacturing. AI in CE helps in achieving sustainability of the environment. Circular design strategy and circular design are two major processes that need maximum attention. Once these two are achieved with maximum output, the manufacturing and reverse logistic process become easier. Digitalization does play an important role along with AI. IoT, big data, deep learning, machine learning, and block chain models help in various dimensions to achieve CE. Business model, prototyping, and mapping between cross fields are necessary to take the ideologies into actions, if the research gap between the metrics of literature, and practices are met.

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