Circular Economy and Sustainability

Suhaib A. Bandh
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Renewable Energy in Circular Economy

Springer

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This book series aims at exploring the rising field of Circular Economy (CE) which is rapidly gaining interest and merit from scholars, decision makers and practitioners as the global economic model to decouple economic growth and development from the consumption of finite natural resources. This field suggests that global sustainability can be achieved by adopting a set of CE principles and strategies such as design out waste, systems thinking, adoption of nature-based approaches, shift to renewable energy and materials, reclaim, retain, and restore the health of ecosystems, return recovered biological resources to the biosphere, remanufacture products or components, among others.

However, the increasing complexity of sustainability challenges has made traditional engineering, business models, economics and existing social approaches unable to successfully adopt such principles and strategies. In fact, the CE field is often viewed as a simple evolution of the concept of sustainability or as a revisiting of an old discussion on recycling and reuse of waste materials. However, a modern perception of CE at different levels (micro, meso, and macro) indicates that CE is rather a systemic tool to achieve sustainability and a new eco-effective approach of returning and maintaining waste in the production processes by closing the loop of materials. In this frame, CE and sustainability can be seen as a multidimensional concept based on a variety of scientific disciplines (e.g., engineering, economics, environmental sciences, social sciences). Nevertheless, the interconnections and synergies among the scientific disciplines have been rarely investigated in depth. One significant goal of the book series is to study and highlight the growing theoretical links of CE and sustainability at different scales and levels, to investigate the synergies between the two concepts and to analyze and present its realization through strategies, policies, business models, entrepreneurship, financial instruments and technologies. Thus, the book series provides a new platform for CE and sustainability research and case studies and relevant scientific discussion towards new system-wide solutions. Specific topics that fall within the scope of the series include, but are not limited to, studies that investigate the systemic, integrated approach of CE and sustainability across different levels and its expression and realization in different disciplines and fields such as business models, economics, consumer services and behaviour, the Internet of Things, product design, sustainable consumption & production, bio-economy, environmental accounting, industrial ecology, industrial symbiosis, resource recovery, ecosystem services, circular water economy, circular cities, nature-based solutions, waste management, renewable energy, circular materials, life cycle assessment, strong sustainability, and environmental education, among others.

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Transition from a Linear to a Circular Economy

Showkat Rashid and S. H. Malik

Abstract Waste production, exposure to economic hazards, resource scarcity, rapid depletion of natural capital, etc. are only some of the problems that today's global economy must contend with, all of which point to the fact that the environment in which the linear economic model functions is posing increasing challenges to it, and that our economic framework needs a more fundamental overhaul. Major economies cannot avoid changing from a linear socioeconomic system to a resource-efficient circular economy considering these obstacles. In this chapter, we aim to highlight the significance of the circular economy, which provides a more efficient and long-term solution to these persistent issues. In addition, the 'circular economy,' which is founded on the 6R system of reducing, reusing, recycling, repurposing, remanufacturing, and rethinking will be compared with the 'linear economy,' which is based on the take-make-dispose approach. In a circular economy, the idea of sustainability is viewed from a different angle than in a linear one. Eco-efficiency or reducing environmental effects while maintaining the same level of output is a primary goal of sustainability efforts within a linear economy. The time it takes for the system to become overwhelmed will increase because of this. The goal of a circular economy is to maximise its eco-efficiency so that it can operate indefinitely. What this means is that not only is there less of a negative effect on the environment, but there are really good results across economic, social, and ecological dimensions.

Keywords Renewable energy · Environment · Circular economy · Wastes · Transitions

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1.1 Introduction

Circularity has been nature's guiding principle from the beginning (Stahel 2019). It is true that many of the world's less developed regions still function based on a non-monetary circular society driven by necessity, like the one in which early man lived (Stahel 2019). The goal of the circular economy was never to maximise the manufacturing of goods, but rather to maximise their useful life. Linear Economy (LE) is the current one-way economic paradigm, also known as the "take, make, and throw away" method. As a viable alternative economic model, Circular Economy (CE) has arisen in the last few decades to address the pressing global ecological concerns brought on by LE (Gallaud and Laperche 2016; Ghisellini et al. 2016; Benton et al. 2017; Kalmykova et al. 2018; Stahel 2019). To be more precise, the circular economy is the most environmentally friendly post-industrial economic business model since its participants are motivated by necessity rather than greed. While we feel more knowledgeable and capable than ever before, we are also maintaining and perpetuating a problem that is specific to our species: garbage. Waste does not exist in nature because everything is used. Insects and, in turn, the trees themselves will use the nutrients in this year's leaf litter to create new leaves the following year. Vegetation absorbs the carbon dioxide released by animal respiration and releases the oxygen needed to sustain animal respiration in the future (Ritchie and Freed 2021). Since both population and resource demands are expected to rise, as well as the rate at which materials and products are purchased and discarded, there will be a corresponding rise in waste production.

1.2 Historical Perspective

Although the name "circular economy" has only been around for a while, the principle has been there for centuries, if not millennia, and has been implemented in a natural way whenever human beings and human cultures have been in complete harmony with nature. We used our natural curiosity and innate brilliance to improve our quality of life alongside the rest of nature back then. When people began adopting a more sedentary lifestyle, it brought about significant changes to their mentality and the social fabric of their communities, particularly regarding the natural world. When we realised how feasible it would be to domesticate the local fauna, we reasoned that there was no reason not to attempt to control nature itself. As a result, we began inventing new methods and equipment to achieve this goal, and as we succeeded in domesticating the natural world, we began to consider ourselves increasingly civilised (Sillanpää Mika and Ncibi 2019). The industrial, agricultural, and technological revolutions that began in the middle of the eighteenth century have given humanity a new "virtual power" over nature (Sillanpää Mika and Ncibi 2019). The decline of humanity's connection with the natural world and with itself was exacerbated by the rise of new political and economic ideas and new societal ambitions that were gradually being adopted as worldwide standards of living rose (19). Indeed, severe animosities emerged around the world when groups of humans thought they had the right to control the resources of other groups because of the "nearly holy" quest for happiness for themselves, their communities, their tribes, and their countries (Sillanpää Mika and Ncibi 2019). To this end, it appears that the finest formula for economic development in the current era is the pursuit of one's happiness, regardless of the pain that is imposed on others, both human and non-human. Many researchers are not happy with the progress being made toward sustainability on a global scale. And some of them even think that clinging to unsustainable forms of mass production and consumption just made things worse at the time. Many factors can lead to "odd behaviour," including the globalisation of markets, the emergence of highly populated nations, putting a strain on resources, the deregulation of the financial sector, the development of new and highly efficient extraction and processing technologies, the rising trend of offshoring to reduce production costs (and sometimes to escape environmental regulations), etc. The above-mentioned pioneering endeavour was carried out at a period (about a century and a half ago) when economic expansion, national pride, and most of all avarice seemed to have blinded humanity, resulting in severe global environmental and societal implications (externalities in the economic terminology). The primary goal for which all this "sacrifice" was intended never materialised, as ongoing and widespread economic turmoil persisted arise, as do wars stoked by hatred and competition (often for control over the extraction and sale of natural resources). To avoid this predicament, modern material lifecycle management must make a change from a linear one to a circular system (Ritchie and Freed 2021). To accomplish this shift, decision-makers in the global economy will have to reject trash as an integral part of the economy, re-evaluate the management of material lifecycles to increase product resilience and recyclability, and reimagine the way humanity handles its resource management in the near future. Because of these benefits, they have attracted widespread support and interest from governments and businesses (Laurenti et al. 2018).

1.3 Defining Circular Economy

In the current economic system, corporations produce goods, which customers then consume and discard (Michelini et al. 2017). In simple words, the linear economy is defined as the take-make-dispose approach. The maximisation of output and supply is central to this economic model. Unnecessary resource losses resulted from the linear production model due to things like production chain and end-of-life waste, excessive use of energy sources, and ecosystem deterioration (Ketelaars 2019). The conventional system, which has been in use for a long time and is known as the linear economic model, does not provide a driving force toward sustainable growth (Ghisellini and Ulgiati 2020). The only goal of this economic system is the procurement of raw material, manufacturing, and converting it into a final product and disposal (Sharma et al. 2021). Wasteful value extraction, the problem of trash, waste landfills, a worsening environmental catastrophe, a loss of competitive advantage, and a bias against sustainable development programmes are just some of the problems that arise in a linear economy (Sharma et al. 2021; Luttenberger 2020). Due to the difficulties inherent in the linear economic paradigm, there has been a growing demand for a more sustainable economic model, and thus the Circular Economy has developed (Hartley et al. 2020). The value of products and materials is preserved for as long as possible in a circular economy, as stated by the European Commission (EC). Products that have reached the end of their usable life cycle are recycled instead of being thrown away, which has a positive impact on the environment and saves valuable resources. There could be significant economic gains from this, including increased productivity and new jobs (Kirchherr et al. 2017). The greatest possible results may be achieved with minimal waste and maximum efficiency thanks to the circular economy's focus on recycling and reusing products and materials (Kuah and Wang 2020). According to Stahel (2016), "a CE system would turn goods that are at the end of their service life into resources for others." In addition, the CE has been cited as a source of very substantial social and economic prospects (Wang et al. 2019). It is not just a way to save the planet; it is also a way to give people what they want while doing good for the environment (Zhang et al. 2019).

Although the name "circular economy" has only been around for a while, the principle has been there for centuries, if not millennia, and has been adopted organically and instinctively by human cultures wherever they have been in complete harmony with the natural world (Sillanpää Mika and Ncibi 2019). With the existing unidirectional socioeconomic model, based on the take, make, and dispose of method (Sillanpää Mika and Ncibi 2019), the circular economy model has evolved as the most trustworthy alternative economic system in recent decades to address difficulties like sustainability challenges.

Instead of the more environmentally friendly and efficient circular economy, people are turning to the more traditional and less wasteful linear economy. Since the two economic models are so opposed, the literature on the topic typically presents them side by side to clarify the similarities and differences between them (Hermelin and Andersson 2017; Sillanpää Mika and Ncibi 2019).

The circular economy has been defined as an industrial system that is restorative or regenerative by intention and design. The circular economy is based on three principles such as preserve and enhancing natural capital, optimising resource yields, and fostering system effectiveness. To replace the traditional concept of end-of-life, the circular economy brings the idea of restoration and circularity, shifting towards the use of renewable energy, eliminating the use of poisonous chemicals, and aims for the elimination of wastage through the proper design of the material, products, systems, and business models (Michelini et al. 2017; Dieguez 2020).

As stated by the Dutch Council for the Environment and Infrastructure, "the Circular Economy emphasises the following focal points: reducing raw material consumption; designing products so that they can be easily taken apart and reused after use (eco-design); extending the lifespan of products through maintenance and repair; using recyclables in products, and recovering raw materials from waste flows. The goals of a circular economy include "the creation of economic value by increasing the economic value of materials or products; the creation of social value by minimising the destruction of social value throughout the entire system, such as by preventing unhealthy working conditions in the extraction of raw materials and reuse; and the creation of value in terms of the environment, such as the resilience of natural resources."

The concept of the circular economy is becoming increasingly popular among environmentalists and policymakers and in parts of the business community. It has been advocated for by groups like the Ellen Macarthur Foundation (2012) and included in the last two Chinese Five Year Plans (Zhijun and Nailing 2007; Sørensen 2017). Many countries around the world are presently contemplating strategies to promote recycling and more effective waste treatment considering the European Commission's (2015) proposal of an EU action plan for the circular economy. A circular stage with positive recycling that lessens the burden on the environment and slows down the depletion of natural-resource stock has been claimed to be the best development route for an economy that begins at a low point in economic development.

The difficulty in defining CE stems from the fact that it is an interdisciplinary term. The key challenge is coming up with a precise description of CE that is neither too narrow nor too broad, as such a definition of a holistic notion is impossible to create. Upon closer inspection, it becomes clear that most of the proposed definitions are merely aggregations of concepts and/or goals coming from different scientific and industrial fields. And since CE is such a crucial sustainability enabler, it needs to be characterised in a way that mirrors the tridimensionality of sustainable development (economy, environment, and society). Most existing definitions focus on the business aspect (how to make money off of circularity while protecting the planet (Sillanpää Mika and Ncibi 2019) (Fig. 1.1).

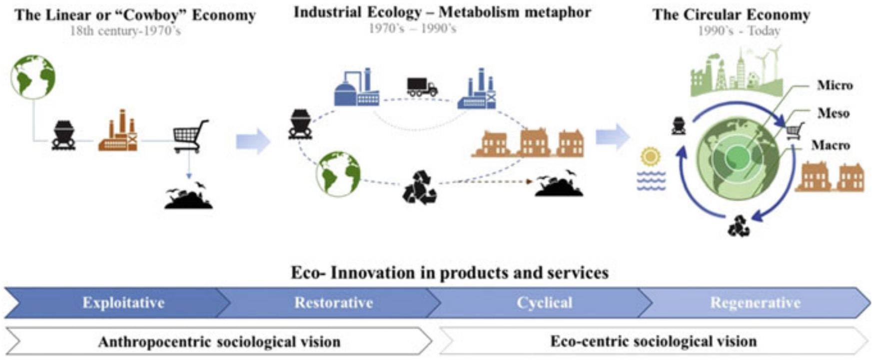

Fig. 1.1 Circular economy knowledge map proposed by Prieto-Sandoval et al. *Data source* Prieto-Sandoval V, Jaca C, Ormazabal M. Towards a consensus on the circular economy. Journal of Cleaner Production 2017; 179:605–615

1.4 What's Wrong with Linear Economy?

We know the world is at least 4.5 billion years old. We estimate that biological systems have existed for at least 3.5 billion years and will continue to do so for at least another few billion years. In contrast, human beings have only contributed to these ecosystems for the past few hundred thousand years. Humans have only been around for a relatively brief amount of time, but in that time, they have managed to disturb every single biological system on Earth. In the wild, there is no such thing as a garbage dump or the idea of trash. Everything in nature is ultimately a source of something else, whether it be sustenance, material, or power. There is nothing we need that is not already here on Earth. Sunlight is the only source of energy humans receive (and maybe the occasional asteroid or two). All living systems on earth (except humans) can live in harmony with that balance (Ritchie and Freed 2021). Species have a natural life cycle in which they reproduce, mature, and eventually perish, all while safely returning nutrients to the soil. The sun provides warmth and energy, and it all just works well, in an elegant, closed-loop—a circular approach to resources. Humans, on the other hand, take, make, use, and eventually throw away everything we create. We harvest natural resources until they are exhausted; we package items in containers that cannot be reused, and we design products that cannot be fixed so that consumers are obliged to toss them away and buy new ones. Instead of using the sun's free energy, which is constantly available, we are using what is left of the dinosaurs' energy store by burning it all up. It does not work—all the linear approach does is slowly convert our human resources into waste.

When humans use the linear method, we deplete our finite supply of natural resources and replace them with hazardous waste. We cannot continue in this manner indefinitely, and the harshest repercussions of our carelessness are still to come.

The linear take-make-waste approach to work depends on the use of a lot of materials. Raw resources are gathered by businesses, refined into a final good, and sold to customers. When a product no longer serves its purpose, it is discarded by the buyer. More than 90 billion tonnes of raw materials were fed into the linear system of manufacturing in 2020 (Jugovic et al. 2022). The sheer magnitude of all this pointless production is shocking.

Unfortunately, humans are harvesting materials that are limited in supply and difficult and expensive to extract—and the materials are not designed to be replenished. Throwing these items in the trash will not miraculously turn them back into their parts. As a result, materials become significantly more difficult (when we can even discover a sufficient supply) to extract safely and inexpensively, harvest a meaningful supply, and maintain quality. For instance, it has been more difficult to find enough oil and natural gas as easily accessible supplies have dwindled. To get the last of the energy reserves, firms have had to dig deeper, go further offshore, and use riskier methods like fracking. Therefore, the oil and gas they now extract are of poorer grade, purer, and more expensive to find. Products become more expensive and labour-intensive to make as practically all linear systems rely on fossil fuels for either their power source or the raw materials used in their creation. The false premises on which the linear economy is based are an infinite and cheap supply of raw materials and energy. Companies are beginning to re-evaluate their founding assumptions as the transition from a linear to a circular economy becomes increasingly apparent.

That "it's working good now, thus there's no need to change" is a familiar refrain from those who would rather not see anything altered. However, the diminishing resources, overflowing waste, and rising environmental problems show that the linear system is not foolproof. Beginning to draw out some of the assumptions of the linear economy and emphasise how they are not working is a fantastic approach to kick off the dialogue about making changes. Realizing the linear economy's fundamental flaws makes room for a more circular alternative. In experimenting with these two distinct models, you can begin to see why the circular economic approach is superior.

Many people think trash "disappears" because that is what they were taught as kids. When you toss your waste in a large, diesel-powered truck, your white plastic trash bag disappears into a foreign nation. However, this is a fundamentally flawed way of thinking about garbage, and one that is largely to blame for the current situation on a global scale. There is no need for a landfill a mile in diameter to hold all the garbage people produce or the energy that must eventually depart any system.

Humans can eliminate pollution and the natural inclinations of entropy if we rethink what trash is, recognise that it is unnecessary, and redirect it as nourishment for another system, like how energy flows occur in nature. That garbage equals nourishment is a principle that can be seen everywhere in nature. For instance, a leaf collects sunlight energy for the tree before gently falling to the ground, where it serves as shelter and food for a broad range of microorganisms. Soil insects digest the dead leaves, recycling the material into nutrients the tree can use to produce new leaves. The current linear economic system is stuck in a take-make-waste cycle. Understanding the environmental, economic, and social effects of this linear style of thinking has led us to the point where it can no longer be sustained. The linear economic model's grip on the economy is beginning to loosen. The concept of circularity, along with the demand for a truly circular economy, is gaining support. To businesses all around the world, it is no longer a novel idea but an integral part of strategic planning (Ritchie and Freed 2021).

1.5 Externalized Costs and Benefits

Waste prevention is priority number one in the circular economy. To accomplish this, you will need to consider and reduce externalised costs, such as wasteful by-products of producer–consumer interactions. A third party affected by this contact could be another human being, an organisation, or even the environment itself, in the form of the air, water, or soil. When resources are jointly owned, or when ownership is unclear, there is a higher chance of incurring external costs. Consider oceans as an example. Despite their vast size, the world's seas are not owned by any nation or organisation. As a result, anyone responsible for polluting the oceans cannot be held accountable for cleaning it up. In other words, the existence of externalised costs

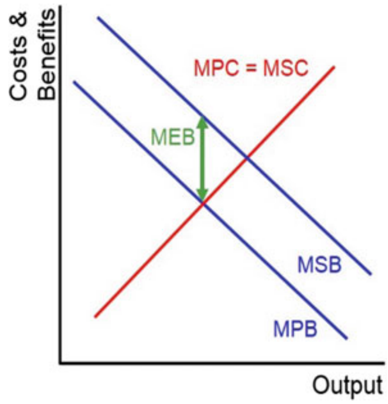

Fig. 1.2 Marginal private benefit and marginal social benefit

indicates a breakdown in the system or a failure of the market. When the market's flow of resources is not distributed efficiently enough to equalise the costs and benefits of a transaction, we have a market failure, and the inefficiency of the market's failure is transferred to a third party (Fig. 1.2).

1.6 Transition Towards Circular Economy

Markets around the world are beginning to show signs of shifting away from the linear economy toward the circular model (Ethirajan et al. 2020). The European Commission sees the shift from LE to CE as crucial to the EU's efforts to create a low-carbon, resource-efficient, and competitive economy because "the transition to a more circular economy, where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste is minimised" (Jones and Comfort 2017). Reducing waste and fostering new value-creation opportunities are two other goals of the CE strategy (Ranta et al. 2019). Most industrialised and developing economies are displaying a significant interest in the development of the CE as a viable replacement for the LE, and this desire is justified (Mathews and Tan 2011). Economic "regeneration" and "restoration" are fundamental goals of CE, as they contribute to more efficient use of resources (Jones and Comfort 2017). It has become clear that the existing LE is unsustainable and poses a long-term threat to human and non-human life on Earth, hence a change to CE is necessary (Bassi and Dias 2020). However, the expanding need for resources is incompatible with the LE model (Buchmann-Duck and Beazley 2020). The European Commission cites the CE's ability to preserve the long-term economic worth of a product or material as one of its most distinctive features. Reduced waste and increased availability of materials for manufacturing are the results of this phenomenon (Barquet et al. 2020). Though the CE's successful outcomes are enticing, the route from LE to CE is not without its challenges (Cramer 2020). According to research commissioned by the European Commission, businesses and consumers are two of the most important stakeholders in the shift toward CE (Barreiro-Gen and Lozano 2020). Many obstacles must be overcome in a new firm as it makes the shift to CE (Stewart and Niero 2018). Recovery, recycling, repurposing, remanufacturing, refurbishing, repair, reuse, reduction, rethinking, and rejection are all common CE strategies (Morseletto 2020). Value creation, value transfer, and value capture are the three pillars of the circular business model that are essential for creating a competitive advantage through CE (Centobelli et al. 2020).

Figure 1.1 shows how the general perception of LE and CE. The later relies on closed-loop systems and the former follows a linear "take-make-dispose" model (both symbolised by bold arrows). In this sense, the structure of LE can be summed up as the three simple steps of "production," "consumption," and "disposal," wherein raw materials are obtained, processed into finished goods, and then consumed, wasted, or burned. As a result, it hampered efforts to lessen the impact of or find uses for wastes generated during production and consumption (Sillanpää Mika and Ncibi 2019) (Fig. 1.3).

In contrast, a circular economy (CE) is based on a "production-consumption-recycling/recovering" structure that is more resilient, dynamic, and environmentally friendly because it keeps resources within the same process or network of processes, turning one process's output into another's input while preserving product value and minimising environmental impact (Kiyoka and Koichi 2017; Potting et al. 2017; Sariatli 2017; Rood and Hanemaaijer 2017).

The only term to describe this pivotal time in human history is "change." It may sound over the top, but it is not. Already too much is at risk due to our inability to recognise and effectively respond to major warning signs, such as catastrophic weather, breaches in planetary boundaries, geopolitical tensions over the allocation of scarce resources, etc. Some would argue that we were still unable to see the forest

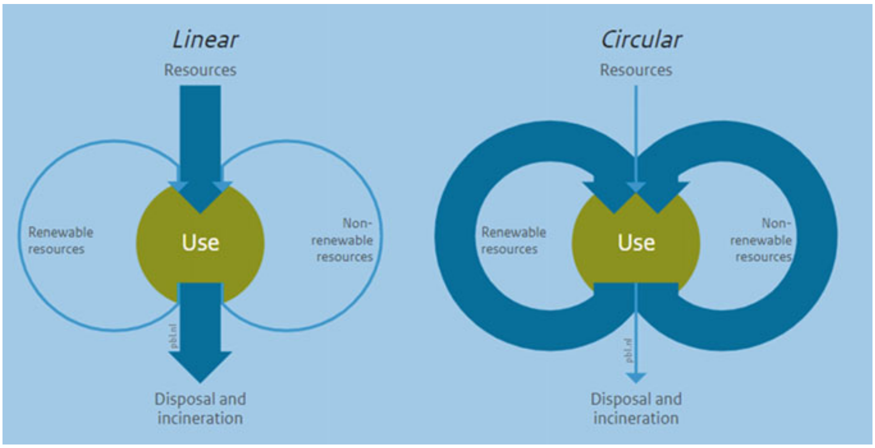

Fig. 1.3 The shift from a linear to a circular economy. *Source* Rood and Hanemaaijer (2017)

for the trees in our reckless quest for economic expansion (Beniston and Stephenson 2004; Humphreys 2005; Rockström et al. 2009).

From a psychological perspective, most people are terrified of change and will actively fight against even the most fundamental alterations to their lives. Even if the Circular economy is a regenerative and sustainable model developed to replace an unsustainable one, it is still a challenging task facing the circular economy since the fear of transformation is profoundly embedded in the psychological perspective of individuals, society, and some conservative firms. To be more specific, the current linear and fossil-based economic approach is viewed as the most effective means of achieving economic growth. Thus, no green or sustainable alternative economic model will be able to take over until it is at least as effective as the status quo. Unless appropriate efforts are taken, including incentive and remedial measures, this natural fear of transition will significantly hold down the implementation of CE. In general, when it comes to making a paradigm shift, some people are willing to make small concessions but none of us is willing to make serious concessions; thus, CE should involve the players that need to take the seriousness seriously, particularly in the policy-making process, the media, and the education sectors (Sillanpää Mika and Ncibi 2019).

When applied to the countries of the developed world, especially those of North America and Western Europe, the term "transition" can be understood to represent the efforts of those regions and peoples to achieve economic growth and development to improve their social and economic well-being. There is no reason why the term "change" should be associated solely with the underdeveloped countries that are striving for the goal. The goal of wealthy nations is to improve the quality of life for their population by creating the best possible conditions for social and economic growth. The economies of certain nations, however, have resisted the shift and provided a counterexample with which to examine and re-evaluate the neoliberal notion. The term "transition" refers to an "improvement process" that, on the one hand, involves the departure of the linear economy concept and, on the other, does not take refuge in a new concept until the final large economic, environmental, and climatic crisis in 2008. At that time, a new concept of the so-called circular economy becomes more visible. However, a shift in perspective around social responsibility, including sustainable development, is essential for a successful implementation of the circular economy.

The core principle of CE is that we can no longer "sustain" our current economic paradigm of "take-make-dispose" any longer because we just do not have enough resources left over to do so. A corporation (A) extracts and/or harvests resources, B uses those resources as feedstock to produce products, and C sells the product to customer X. This linear model has been the foundation of the economic system since the advent of the industrial revolution. X will get rid of a product once it has served its purpose. Eventually, the resources required to make this product vanish from the supply chain, and firm A continues to absorb more of it until the consequences of resource depletion become apparent to customers. As a result, commodity price volatility increases, and people become more worried about a potential shortage of essential materials. Eventually, customer X is no longer able to afford the product, and the slowdown in economic growth has caused him to fear for his job, while companies A, B, and C struggle to remain profitable.

With billions of tonnes of raw materials entering the global economy every year, it makes sense to abandon the conventional economic model. As a result, the potential of our resources is truly astounding if we continue conducting business in a linear fashion (Potocnik 2013).

Leaving the linear economic strategy involves adopting a non-linear economic model, such as the Circular Economy, which promotes resource recovery, product reuse, and material recycling. To abandon the idea of a linear economy, one must adopt an economically non-linear model, such as CE, which allows for the recovery of resources and the reuse and recycling of objects. The real advantage of moving toward a global CE is that it will encourage a gradual uncoupling of economic outcomes (such as growth, employment, prosperity, social and economic welfare, etc.) from factors beyond our control (such as limited resources, oftentimes especially in other countries) and a recoupling with factors we can influence (renewable resources and wastes).

Various measures aimed at the sustainable and efficient management of resources and goods need to be implemented on a worldwide basis to bring about this goal, which can only be achieved if CE methods are first adapted to local economies (Blok et al. 2016).

- Conserving resources by using less scarce or unspoiled commodities, maximising the value of what we already have, and decreasing waste.
- In the realm of materials, emphasising strategies for recovery and reuse, elongating useful life, fostering sharing and service models, creating a circular design, and leveraging digital platforms are all recommended.

1.7 Future of Circular Economy

Industry and the public also profit monetarily from CE, but its primary goals are the reduction of waste and pollution (Demirel and Danisman 2019). Adopting CE has long-term benefits, as shown by research and industry perspectives; it not only decreases waste but also maintains resource availability, two key factors in eco-friendly growth (Stewart and Niero 2018). Opportunities and benefits of implementing CE techniques have been the focus of various research across various industries (García-Quevedo et al. 2020). Prospects for CE include reducing waste, increasing energy efficiency, protecting the environment, and boosting the economy (Bastein et al. 2013; Singh et al. 2018). Benefits of CE strategy implementation in industries include preserving the economic value of raw materials (Morseletto 2020). Small-scale factories and enterprises can opt for CE since it is more practical than LE, and the government and other stakeholders are prepared to recognise CE's importance (Ferronato et al. 2019). The CE is critical for businesses since it fosters the expansion of product diversification strategies, which in turn aids in securing competitive advantage (Franco 2019). Successful adoption of CE is being facilitated by government intervention and the neo-technical idea in the production system (Barquet et al. 2020). The CE-based business model results in resource conservation, which, with the right kind of strategic leadership, can allow for long-term sustainable development (Kirchherr et al. 2018; Pla-Julián and Guevara 2019). CE measures, such as reuse, have been shown to reduce the price of scrap sheet metal by about 40% in the automotive industry, making it not only environmentally friendly but also a fiscally sensible practice (Ali et al. 2019).

Any place a difficulty can arise also has a remedy. In addition, there is always a solution to any problem. Everything in the business world revolves around this. Within the circular economy framework, the answers are already available, but they need the backing of enterprises, non-profits, and other organisations to be fully facilitated at a global level. Look around and you will observe an abundance of problems needing resolution: depletion of resources, scarcity of materials, and the continual demand for recovering, extending, and sharing products and resources. Problems on a planet with a growing population and limited resources require creative, flexible approaches (Ritchie and Freed 2021). We are familiar with that spiffy-looking triangle made up of three green arrows—the one that can usually be found on recycling bins and signs referencing the Reduce, Reuse, Recycle slogan. Although a focus on waste reduction, reuse, and recycling is a good place to start, it does not account for everything that has to be done to establish a truly circular business model. It takes you only halfway there. If you want to completely accept the circular economy as a strategy for designing out waste and pollution, keeping products and resources in use, and regenerating natural systems, you need to adopt three extra steps beyond these three well-known ones. Add the three new phases to the initial trio and you end up with six total steps to account for, in this order: Refuse, Reduce, Reuse, Repurpose, Recycle, and Rot.

1.7.1 Refuse: Just Say "No" to Unnecessary Things

A single person has some power to impact the world, but a collection of people has a much greater capacity to influence the world and create the change they want to see. That is why the first R—Refuse—is all about the ultimate power of decision-making: Does the consumer want to support your product or service? What if they decide to reject it, though?

As a potential business owner, you surely realise how enormous the research-and-development (R&D) sector has become. Corporations on a global scale spend a lot of money surveying consumers to learn what features they want to be included in their wares. In total, the top 1,000 most profitable firms in the world—including big names like Alphabet, Amazon, Microsoft, Samsung, and Volkswagen—spent a collective 858 billion USD on R&D in 2018. Finding out what people want to buy is an important part of the first stage of developing a product. Recognizing that the industry sees the value of serving consumer demand means that the consumer can stimulate a positive change and encourage the move to a circular economy (Benmoussa 2020). If your business is to thrive, you must adapt your product to meet the evolving demands of your customers. Customers can influence your organisation to adopt more sustainable practices by choosing not to buy goods that are not produced, distributed, and consumed within a regenerative economic model.

1.7.2 Reduce: Get by with Less Over Time

The second R emphasises conserving resources, whether it means cutting down on spending, cutting back on how much of a given material is utilised, or cutting back on the environmental damage done by a substance's lifecycle. You, as the company's intellectual leader, are tasked with coming up with foolproof methods that require no effort yet yield the greatest profit. With ride-sharing services like Lyft, for instance, not only does the number of cars on the road decrease but so does the cost of transportation for the average person. By switching to electric vehicles exclusively by 2030, Lyft stands to avoid tens of millions of metric tonnes of carbon dioxide emissions and more than a billion gallons of gasoline over the following decade. In the end, Lyft has created a unique programme called Lyft Up, which employs a variety of activities and products to drive change within underserved communities, such as linking people with the resources and health services they need through reduced or donated trips.

1.7.3 Reuse and Remanufacture: Extend Product Life

Some items, like engines or cell phones, are frequently too complicated for the entire product to be remanufactured after a single component breaks; but, if built properly from the beginning, new generations of these products can be crafted in a way to make them easily repairable. In addition, when manufacturers learn which parts of their products are the most likely to break, they may design the items such that the broken parts can be swapped out quickly and easily. This gives the owner more control over the product, allowing them to fix it rather than tossing it out because of a little problem.

1.7.4 Repurpose: Identify Alternative Uses

Sometimes items can fulfil purposes you never imagined they might. The idea of repurposing a waste source into a valuable one involves imagination and can frequently result in an evolutionary conclusion. Consider Toasted Ale Brewery as an illustration. Because of the widespread problem of food waste in the United States, the brewery works with local bakeries to turn their surplus of bread into beer ingredients. Toasted Ale's inventive minds realised that a lot of food goes to waste because of stale bread, so they came up with a solution to use the bread differently. Toasted Ale Brewery has been around for a while, and in that time, it has saved hundreds of thousands of slices of bread from going to waste, while also contributing to the reduction of food waste overall.

1.7.5 Recycle: Return Materials for Rebirth

Recycling is the final step in the lifecycle of technical materials. Dismantling technical goods into their parts and recycling the raw materials they are made from into new products is a common practice when they reach the end of their useful lives. The soles of Timberland Shoes and Boots are made using recycled rubber from used tyres, capitalising on the value of recycled materials. By doing so, Timberland has helped to extend the life of this raw material and has diverted vast volumes of garbage from landfills at the same time.

1.7.6 Rot: Return It to the Earth

Akin to how technical materials reach their destination in the form of recycled products, biological materials reach their destination in the form of decomposition (or, more euphemistically, "returning materials to the earth"). If you consider the two concepts—recycling and rotting the same for two distinct types of materials, you can see that the method and advantages are comparable. The objective of recycling is to break down a technical material into a form that can be reintroduced to the global economy so that a new material lifetime can commence. This is also true for biological substances when they are let out to rust; allowed to deteriorate. When organic waste is returned to the ground, it undergoes a chemical and physical transformation that allows it to be recycled back into the economy. The value of any product created from biological materials—such as wood, cotton, or vegetables—can be harnessed and reinvested in the natural landscape to produce new resources. The common, mutually beneficial relationship that has developed between brewers and farmers is a good illustration of this idea in practice. Breweries typically sell (or give away for free) their leftover grain to farmers, who can use it to supplement their soil with nutrients. The leftover grain is subsequently used by farmers to feed their animals. This pulp is fed to livestock, and once they have digested it, it is composted and added to the soil. This collaboration between brewers and farmers prevents tonnes of garbage from ending up in landfills while simultaneously providing food for livestock and revitalising soils.

1.8 Obstacles to the Circular Economy

The move from LE to CE has various acknowledged and proven barriers that present hurdles in efficiently executing it. The obstacles to CE have been the subject of several research. Recovering value from used or obsolete materials is a central focus of the CE, which is why waste management and recycling are its primary topics. However, several developing countries are unable to manage trash because of several obstacles. These include a lack of funding, a misunderstanding of the issue, a fuzzy policy framework, and a lack of information (Ferronato et al. 2019). Adopting the reuse and remanufacturing processes in CE requires sound technology, outstanding design, and technical experience with a professionally educated human resource, all of which can be seen as significant roadblocks (Barquet et al. 2020). Other important hurdles for adopting CE include huge capital requirements, the larger initial cost for updating capacity, risk and uncertainty, and a lack of institutional and legal backing (De Jesus and Mendonça 2018). Managers' negative attitudes toward CE implementation can be traced back to a lack of regulatory pressure and environmental understanding at the corporate level (Zhang et al. 2019). Betancourt Morales and Zartha Sossa (2020) conducted a comprehensive literature review to identify key challenges for industries transitioning from LE to CE. These challenges were found to include legislation, economy, education, training, availability of finances, and the attitude of management towards CE.

Savings from less extraction of virgin resources, additional jobs, and redesigned value chains are just a few of the economic benefits of the shift to circularity. In terms of global GDP, it has enormous potential and might add $4.5 trillion by 2030 (Lacy and Rutqvist 2015). Businesses and governments alike are advocating for a move to a circular economy as a means of boosting sustainability and fostering long-term human progress. Reusing materials and goods after they have served their initial purpose is central to the concept of a circular economy (Arthur et al. 2022).

Most of the materials and goods utilised in society are still part of a linear economy, despite the well-documented benefits of a circular economy. Therefore, one of the greatest challenges of the twenty-first century is making the shift from a linear to a circular economy (CE). A linear economy is one in which raw materials and finished goods are created from scratch, used only once, and then thrown away. As a result, natural resources will be depleted, and the practice will be essentially unsustainable in the long run. A circular economy offers an alternative by focusing on the development of reuse, recycling, and industrial symbiosis to maintain material resources within the economic cycle. Part of this process involves figuring out what is standing in the way of a fully circular economy so that corrective measures can be taken. It has been widely stated that there may be economic benefits to adopting a circular economy company model (Dieckmann et al. 2020).

1.9 Conclusions

Some have called the concept of a "circular economy" a "new revolutionary concept of the 21st-century economy" that provides a "high-quality response" to the world's environmental crisis and climate change. The circular economy takes a new tack on all aspects of the economy, including resource conservation and the distribution of wealth. Because of its high cost and inability to maintain long-term competitiveness, the linear economy paradigm is being discarded in this way.

The essential tenet of the transition from linear to circular economy is the existence of a feedback circle that incorporates recovered materials back into the production process. It is possible to recycle the same trash multiple times and reuse it in different manufacturing cycles, depending on the properties of the recycling technology.

The notion of the circular economy rests on the recycling of garbage, a part of the environment that formerly had a negative effect on the environment but is now returned to the production process as a valuable material resource, or raw material. In the end, just a tiny fraction of trash that cannot be recycled is disposed of sustainably. This idea underpins economic growth. The use of raw materials, waste management, recycling, and reusing output are all fundamental tenets of this philosophy. The circular economy is based on the notion of waste reuse, which includes efficient energy use, and mimics the logic of natural cycles. This method returns the consequences of consumption to the manufacturing process, rationalising and enriching the production and consumption cycle. When the by-products of one manufacturing cycle are incorporated into the next cycle as raw materials, the former junk no longer pollutes the environment and is instead a valuable material resource. 11 The production process is repeated in cycles to maximise the reuse of materials and prevent waste. That is, in a circular economy, products are used for longer until they reach the point of diminishing returns and are discarded. It occurs when a product reaches the end of its useful life but is still put to productive use in the form of recycled waste, in the form of raw material, in the next cycle of production. It is undeniably crucial to lessen the strain on the environment caused by the exploitation of resources to switch from a linear to a circular economy's pattern of production and consumption. Products that would have otherwise been thrown away in landfills or cremated can be reused, recycled, refurbished, and remanufactured with the use of the circular economy's reverse logistics, performance, and sharing economy. Sadly, the understanding of the circular economy is still blurred. Bringing the circular economy into the mainstream requires raising awareness on a local, regional, and international scale. Corporations should infuse circular thought into their product and process design from the very beginning. Additionally, the government should offer incentives and rules to support the development of a circular economy so that jointly we can move towards sustainability.

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Chapter 2
Circular Economy and Energy Transition

Dolores Hidalgo and Jesús M. Martín-Marroquín

Abstract The Green Deal commits Europe to the goal of being a climate-neutral continent by 2050, which would be impossible to achieve without moving towards a decarbonised economy and a sustainable energy model. That is why the systematic application of the principles of the Circular Economy in the new energy production model is the necessary tool to achieve a successful energy transition in Europe, as well as in the rest of the world. One of the consequences of this process is that renewable energies originating from waste will multiply in the coming decades, so the energy sector will require rapid implementation of circular principles to properly manage this waste and optimize the energy efficiency of its processes. On the other hand, it is expected that in the next 10 years the waste generated by the clean energy infrastructures themselves at the end of their useful life could multiply by 30. Although the promotion of renewable energies is indeed necessary for the energy transition, related technologies and the construction, maintenance and replacement of infrastructure in the energy sector can significantly increase the flow of waste. In addition, among these types of materials, there are many substances included in the list of critical raw materials. All this poses a scenario where recycling and correct waste management can allow economic and environmental savings, reducing the consumption of scarce raw materials. This chapter addresses the relationship between the circular economy and the energy transition from the two points of view mentioned above, laying the foundations to find a satisfactory way to apply a circular model integrally in the energy transition, which results in an optimization of the sustainability and improvement in the competitiveness of the companies involved.

Keywords Bioeconomy · Climate change · Sustainability · Bioindustry

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2.1 Introduction

Energy transitions indicate a temporary period, of relative extension, in which there is a change in the sources from which energy is obtained for the habitual development of a certain human group characterized by a socioeconomic, scientific, technological and also cultural context (Carley and Koninsky 2020). Energy systems can be defined based on two basic flows of their substantial element: the provision of energy and its consumption. In the first case, all the natural sources from which the community obtains energy sustenance (primary energy) are included, as well as the transformation processes that, in many cases, are necessary to adapt those original resources into a form of energy that can be useful within the sociocultural field in question (secondary energy). In modern societies, the most widespread form of this transformed form of energy is electricity. The other flow, that of consumption, is strongly defined by the characteristics of the community: its survival needs, its desires for a better quality of life or its purposes of control and prevalence over its geographical and environmental scope as well as its human environment, both internal and external. Given that energy systems, by definition, are complex structures and are characterized by multiple properties, there will also be different models of energy transition (Hainsch et al. 2022).

The concept of the energy transition is not new (Smil 2016). The use of biomass combustion (particularly wood) for heating and lighting together with muscle energy, human or animal, used mainly for transportation, has prevailed for several millennia. Between the fifteenth and eighteenth centuries, a new element began to be incorporated into the energy mix of societies, mineral coal. This new fuel was a decisive factor in enabling the so-called Industrial Revolution in the 18th century. Then came the oil age from the second half of the century. Currently, the energy transition seeks to abandon, or at least minimize, the use of fossil fuels, promoting all types of renewable energies. But to consider that in each of the energy transformation cycles of the past and the current present the appearance of a new component in the energy mix has more or less immediately displaced the other participants is wrong. Currently, in certain areas of Asia, Africa and some parts of Latin America, energy is obtained for heating or cooking with the ancient method of combustion of forest biomass (Smil 2016). Likewise, even today different energy sources coexist in the primary matrix of many countries, several of them with a high level of industrial development, such as Germany or China.

Another unavoidable chapter when talking about energy is that of infrastructure. The extraction and transportation of energy raw materials (mining operations, gas pipelines, oil pipelines, etc.), the facilities necessary for their transformation (refineries, thermal, atomic or hydroelectric power plants, renewable parks, etc.), the transmission or transportation (high, medium and low voltage lines, transformers, etc.) and, finally, the devices in the home or the industrial plant for their final use (motors, appliances, lighting systems, etc.) permanently remind that it is impossible to conceive the term "energy" without associating it with structures to dispose of and enjoy this vital element. And in the current times of energy transitions, a new category for energy infrastructure is added: the massive storage of electricity. Since all sources are more or less subjected to infrastructure, it represents an essential challenge for energy transformations. The processes of transformation of energy systems that are currently taking place in a large number of countries in the world differ from those produced in the past in their speed of evolution and their genesis. Today's energy transitions are political decisions of the states and one of the fundamental reasons that drive these actions is to mitigate the effects of climate change that puts the environmental health of the planet at risk (Leonhardt et al. 2022).

In the current scenario of changing energy production, the systematic application of the principles of the Circular Economy is the necessary and essential tool to achieve a successful energy transition. The implication of the circular economy in the energy transition has two well-differentiated aspects. On the one hand, the energy recovery of waste for the production of biofuels is one of the key aspects of a sustainable and climate-neutral economic model in which every currency has value (Fernando et al. 2022). On the other hand, one of the consequences of the energy transition is that waste originating from renewable energies (wind turbine blades, batteries, solar panels, etc.) will multiply in the coming decades, so the energy sector will require rapid implementation of circular principles to properly manage this waste and optimize energy efficiency (EEA 2021).

2.2 Biofuels from Waste Strems, Closing the Cycle

The amount of organic waste discarded worldwide increases considerably every year, and the management of this waste not only requires economic resources but also generates greenhouse gases that negatively impact the environment. An emerging philosophy that allows the revaluation of this organic waste is biorefinery, which is aligned with the concept of circular economy and from which biofuels and value-added products are obtained (Rabell et al. 2022). In this section, a review of the biorefineries proposed for the conversion of organic waste into energy in the framework of the circular economy is carried out, in addition, the raw materials used and the products generated are highlighted.

According to the Food and Agriculture Organization of the United Nations (FAO), one-third of the food produced globally is wasted annually (FAO 2011). This represents approximately 1,300 million tons, so its management is of great social and environmental interest, as well as economic. In the social aspect, the management of this waste and its transfer to treatment facilities enables the generation of jobs. In the environmental aspect, the inadequate disposal of this waste causes its uncontrolled decomposition, releasing greenhouse gases, such as methane and carbon dioxide. The economic interest arises from the number of resources used in the management of this waste (Sánchez 2022). Food losses and waste account for $680 billion in industrialized countries and $310 billion in developing countries; this estimate comes from the generation of waste per inhabitant: in North America and Europe, it ranges between 95 and 115 kg/year, while in Africa and Asia between 6 and 11 kg/

year is generated (Dahiya et al. 2018). For this reason, the revaluation of organic waste has become an interesting strategy that makes it possible to solve the problem of waste management and, at the same time, generate new products, among which are some biofuels and chemicals. The great demand for such goods is forcing the economic model to change, infusing it with circularity. The circular economy makes it possible to take advantage of the waste that is discarded in a linear economy, to integrate it back into the production chain; thus, the gap between environmental sustainability and economic growth is reduced (Hidalgo et al. 2019).

These data show the need to promote research to reduce the pollution generated by these residues and obtain new products that provide economic benefits. This is where the concept of biorefinery becomes relevant since it is aligned with the circular economy (Broncano et al. 2015). A biorefinery is defined as a facility in which energy and various value-added products can be obtained from biomass (understood in the broad sense of biodegradable material) (Sperandio and Ferreira Filho 2019). Biorefineries can be classified according to the products they generate, the processes they require or the raw material they use. Regarding this last classification, the biomass or raw material is ordered by generations: the first generation covers agricultural or food biomass, which consists mainly of seeds or grains with a high content of sugars, starches or oils; these biomasses can be treated without specialized or expensive processes (Carpio et al. 2021). However, the main disadvantage is that this branch competes directly with human nutrition, which generates other problems, such as deforestation and water use, and impacts the environment and production costs. On the other hand, the second generation is mainly lignocellulosic biomass-agribusiness, food, agricultural or wood residues. This biomass does not compete with human nutrition, but its treatment to obtain valuable waste streams requires more investment (Rodionova et al. 2022); some of the products that can be obtained include biofuels and lignin derivatives (Liu et al. 2021). Finally, third-generation biomass includes genetically modified organisms to obtain better growth or a maximum production of oils or sugars; it also includes microalgae, which do not require arable land and from which nutraceuticals, organic fertilizers, food and biofuels can be obtained (Das et al. 2022; Shokravi et al. 2021).

As mentioned above, a biorefinery can use different types of biomass and, although different first-generation raw materials have been proposed, the use of organic waste is currently sought (Shah et al. 2022). So, an organic waste biorefinery promises to achieve a sustainable route for the generation of biofuels (and other products) with low environmental impact (Sarkar et al. 2021), hence its priority interest. From a technical point of view, obtaining biofuels and other value-added products from organic waste in a biorefinery scheme is possible. However, it is important to know whether the economic and environmental benefits outweigh the proposed technology. The use of biorefineries could reduce the environmental impact of waste since the effluents generated are used by integrating different processes to obtain maximum recovery of products (Clauser et al. 2021). In addition, biorefineries allow biomass to be reused and thus reduce the carbon footprint that would otherwise end up being generated by burning or burying it, in turn reducing its degradation time. They also make it possible to generate biofuels that partially replace fossil fuels. Finally, jobs would be created that would allow the integration of agricultural and industrial chains, which would promote a circular economy (Poponi et al. 2021).

Thus, a circular economy promises to be a sustainable economy that is based on recycling or reusing waste integrally; the foregoing to minimize them, also eliminates the concept of the "useful life" of a product. Biorefineries reflect the objectives of this economy, producing new chemicals and biofuels, reducing the generation of greenhouse gases and creating new business opportunities (Ding and Grundmann 2021). It is important to highlight that the economic potential will depend on the efficiency of the conversion strategies used, the raw material and the products to be generated. Regarding the production of biofuels, the integration of processes within a biorefinery is considered necessary to make it profitable. In this way, costs are reduced by scaling the process. However, the obstacles that still exist are related to the increase in the conversion and selectivity of the production processes (Igbokwe et al. 2022). Therefore, research regarding the use of residues in biorefineries should focus on the analysis of the composition of specific residues, as well as the isolation of compounds through pretreatment; the foregoing to increase productivity and simplify the processes used. Finally, it is suggested by several authors to evaluate the feasibility on a laboratory scale as a first step to able to scale the process, in addition to additional studies on the development of processes, their optimization and the quality of the products obtained (Banarjee et al. 2022; Monlau et al. 2021). The efforts of the scientific and industrial community have focused in recent years on seeking sustainable processes associated with four main biofuels: bioethanol, biodiesel, biogas and biohydrogen. The raw material used and the production processes are the basis for progress in obtaining these products.

Bioethanol is the biofuel that aims to replace gasoline, as an alternative to reduce the environmental impact it has, not only by its use but also by its production, due to greenhouse gas emissions (Rey-Porras et al. 2021). It is produced mainly from biomass that requires raw material with a high content of sugar (glucose, sucrose), starch and cellulose. The inputs mostly used are sugar cane, corn grain, sugar beet and sorghum, or lignocellulosic material from sugar cane waste and pineapple peel (Shenbagamuthuraman et al. 2022). The largest producers of bioethanol in the world are, in first place, the United States with approximately 53% of the total production, in second place, Brazil with 28%, China with 4%, India with 3% and Canada with 1%, in addition to other countries in the world with a lower percentage (Torroba 2020). In 2019, corn and sugarcane were the raw materials most used to produce bioethanol, requiring more than 170 million tons of corn (Torroba 2020), having The United States as the largest producer of bioethanol from this cereal since 2005 (Paredes et al. 2020). But the use of raw materials of food interest has meant that this biofuel is not appreciated by the most socially sensitive sectors of the population. On the other hand, the deforestation that has occurred in some regions of the world associated with the production of crops destined to manufacture bioethanol has provoked the rejection of many governments and the population in general to the maintenance of these practices. This is where the circular economy comes into action, promoting truly sustainable practices, using crop residues and residual products rich in sugars, to maintain the production of this biofuel (Aggarwal et al. 2022).

Biodiesel is the alternative liquid biofuel to conventional diesel; is a mixture of methyl esters that are produced by combining vegetable oils (soy, palm, sunflower) or animal fats (fish, pork) or algae (Cardona Alzate 2009), through transesterification processes with alcohol and a catalyst (Jiménez et al. 2020). In 2019, the most used raw material in the production of biodiesel was palm, soybean and rapeseed oil, in addition to used vegetable oil and animal fats. In that same year, 26% of the world's production of rapeseed oil, 18% of soybean oil and 16% of palm oil were required (Torroba 2020). The five largest producers of biodiesel in the world are Indonesia in the first place, with approximately 16% of the total production; in second place, the United States with 13%; Brazil with 11%; Germany with 8% and France with 5%, among others with a lower percentage (Torroba 2020). As in the case of bioethanol, the production of biodiesel to be sustainable must seek the use of residual fat and oil streams, so abundant in the agri-food industry.

Kougias and Angelidaki (2018) define biogas as a mixture of various gases (main methane) which are generated by the decomposition or anaerobic digestion of organic matter. In this process, the bacterial content of the organic material (substrate) is used, which in the absence of oxygen carries out a degradation process whose final products are the digested processed organic matter and biogas (Ortiz et al. 2019). The main sources of biogas production are manure from farm animals, sludge from water treatment, landfills, and crop residues (Marks et al. 2020). The anaerobic digestion of organic waste not only generates biogas but also after the digestion process a residue known as digestate or biol is generated, which can be used as biofertilizer since this product is quite enriched with nitrogen, potassium and phosphorus, chemical elements that nourish crops (Kapoor et al. 2020). Biogas is one of the most developed and studied biofuels worldwide, this may be due to its practicality of design and implementation, the use of a residue (such as cattle manure) and its energy potential. However, its production requires constant monitoring. That is why it is one of the biofuels with the most projection in the framework of the circular economy.

Finally, biohydrogen has entered the energy scene with great force, as hydrogen is one of the most interesting fuels for the coming years (Cavaliere 2022). Biohydrogen has become highly relevant as a biofuel due to its energy content of 122 kJ/g, which exceeds any other biofuel: methane (119.66 kJ/g), methanol (20.08 kJ/g), ethanol (26.78 kJ/g) and gasoline (44.35 kJ/g) (Sołowski et al. 2020). It is because of this characteristic that the main applications of biohydrogen are as a fuel for transport, combustion engines and turbines, in the same way, it is used for the generation of electrical energy using fuel cells that work with H_2 (Noblecourt et al. 2018). The production of biohydrogen is carried out by various microorganisms in different processes and metabolic pathways. However, they can be grouped into two categories: light-dependent processes and light-independent processes (Hidalgo et al. 2022a). Currently, the production of biohydrogen in the world is low due to the complications associated with its efficiency, cost of production, use, distribution and storage, for this reason, it is essential to improve processes and reduce costs. In addition, the purification of hydrogen requires sudden changes in temperature and pressure, which is why today's purification techniques are very ineffective and do not manage to ensure pure hydrogen (Xia et al. 2016). Due to the above, the research and work carried out are focused on improving the efficiency in the production of this biofuel, either by innovating in the production processes or looking for a microbial inoculum or consortium that is primarily a hydrogen producer. Experimentation and research in the production of biohydrogen must continue since this will allow an improvement in the processes and their use, implementation and distribution for their real use as bioenergy (Hidalgo et al. 2022b).

2.3 Renewable Energies as a Source of Waste, New Food for Thought in the Circular Economy Model

The materials and equipment associated with renewable energies, such as photovoltaic solar panels, wind turbines, and batteries, are essential for the energy transition towards climate neutrality. The manufacture, installation and replacement at the end of life of this technology require significant resources, including many elements included in the list of critical raw materials. This transition will also generate substantial amounts of new types of waste, as shown in Fig. 2.1. This situation creates a unique opportunity for governments to anticipate changes and prepare a policy framework to apply circular economy principles to this new model from an early stage. It is estimated that the waste generated from the renewable energy infrastructure will grow up to 30 times in the next 10 years, which will be the period in which it ceases to be functional and becomes a waste stream to be managed. But this management, far from being a problem, can present significant opportunities that involve a reduction in the consumption of other scarce raw materials through the recovery of metals and other elements of interest in the production systems. Circular economy approaches, such as equipment repair and upgrades and end-of-life recycling of infrastructure, can help bring about sustainability in the energy transition to renewable energy (Mulvaney et al. 2021).

But recovering these materials and reintroducing them into the production cycles will not be an easy task, since it will present challenges associated, for example, with processing difficulties due to the presence of composite materials, hazardous substances that require special safety conditions in their management and more valuable elements that may have the handicap of appearing in very small concentrations. On the other hand, part of the equipment to be recycled will not be designed, a priori, to facilitate its management at the end of life. Other challenges that may arise are logistical problems due to the remote locations of the renewable energy facilities or the size (such as turbine blades) and the safety requirements (e.g. in the case of batteries) associated with the energy infrastructure. The implementation of innovative circular business models is also hampered because the ecological and climate benefits of using recycled materials are not yet fully taken into account. Market conditions, when the time comes, may not adequately value the externalities of using virgin versus recycled materials. That is why secondary materials usually

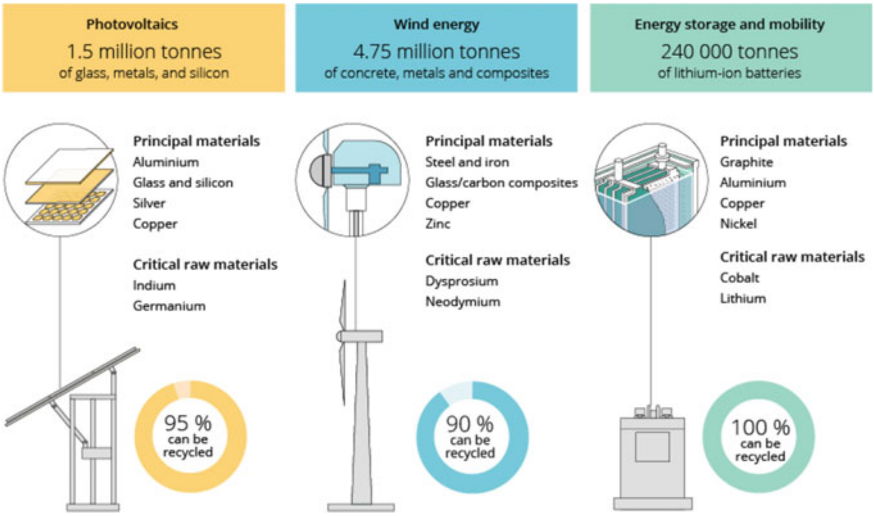

Fig. 2.1 Potential annual recovery of materials from the clean energy sector by 2030. Adapted from EEA (2021)

have to compete in price with primary materials, which can be even cheaper (Ralph 2021).

Time frames, when talking about renewable facilities with a relatively long useful life, are important when developing environmental and financial protocols, strategies and policies to deal with future waste generated by this sector. The application of the principles of the circular economy can help mitigate potential negative impacts that may appear. As proposed by the EEA (2021), these principles should include the application of circular business models to maintain producer responsibility, the design of the infrastructure always taking into account the precepts of circularity to facilitate the reuse of components and the support to the development of recycling to maximize the recovery of materials.

Seizing the opportunity to increase the circularity of the three types of energy infrastructure mentioned and their waste streams requires that the principles of the circular economy are applied throughout the entire life cycle of the infrastructure, even when it is being designed. Figure 2.2 highlights some key features of a circular clean energy system that need to be considered.

The first concept to take into account when analyzing the circularity of a renewable energy model is the materials used. Reducing the need for virgin raw materials through the increased use of recovered materials is the first step toward the circularity of the model. Criteria can be proposed to establish a mandatory minimum content of recycled material in new energy-generating products, either by a direct introduction (closed loop) or through the supply of waste materials for use in other manufacturing sectors (open loop) (Lapko et al. 2019). The second concept to consider is ecological design, in the sense of applying circular design principles to encourage reuse,

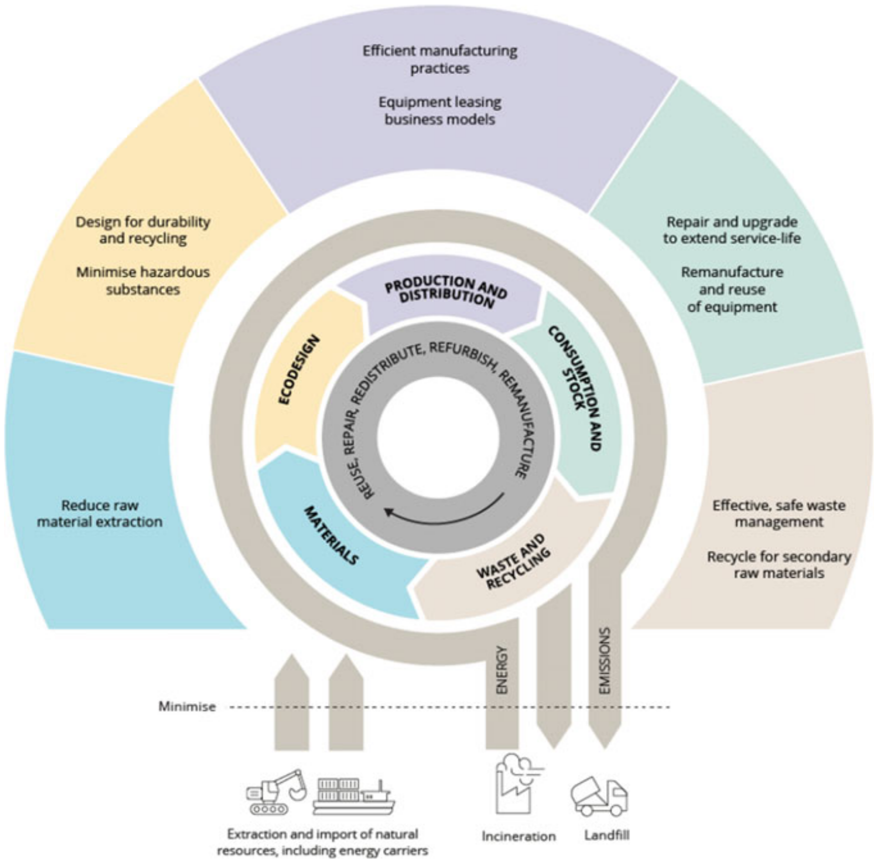

Fig. 2.2 Circularity principles applied to renewable energy systems. Adapted from EEA (2021)

and recycling, and improve the repairability, durability, and recyclability of future energy infrastructure (Cenci et al. 2022). The third key concept is the application of resource-efficient manufacturing practices and optimized logistics approaches. An example may be the implementation of digital product passports for equipment, which allows for detailed and up-to-date information on the constituent materials of each element of the system to detect the presence of materials of special interest, for example, valuable metals. Within the circular economy, servitization modalities can be applied, involving leasing models and service-based contracts to prioritize lifetime approaches to the operation and maintenance of equipment, rather than outright purchase (Shah et al. 2022). The next principle is related to consumption and stock. Extending the useful life of the infrastructure is relatively simple if preventive maintenance is carried out, with the periodic repair of defective components and gradual updating of modular elements (Gargari et al. 2021). Finally, ensuring effective waste management for infrastructure at the end of its useful life is another essential circular principle. It can be done by favouring high collection rates and proper processing. The rapid growth of the renewables sector indicates an imminent need for capacity expansion and the development of new treatment technologies. Efforts should be made to maximize the recycling of components and materials from decommissioning infrastructures to provide secondary raw materials for new infrastructures under construction and other manufacturing sectors. The implementation of all these waste materials is essential to guarantee recycled materials of constantly high quality (Valenturf et al. 2021).

2.4 Future Trends in Circular Economy and Energy Transition

The pillars of the society of the next generations are based on the foundations of the present. This happens in educational, regulatory, and economic terms and, especially, in everything related to the sustainability of the environment. In this way, both companies and governments have proposed to achieve neutrality of zero emissions by 2050 as mentioned in previous sections, which will lead to constant social and economic changes. In the specific case of the energy sector, companies will have to undertake an important transformation project, abandoning the traditional system of a linear economy for a new circular economy model. This model is articulated around several axes: the reduction and recycling of raw materials, the regeneration of waste and environments affected by the development of the energy activity, and the gradual reduction of spending on traditional energies, making it possible thus the search and exploitation of new, more sustainable energy sources for a planet that shows the consequences of overexploitation of its resources (Ogunkunle et al. 2019).

Sustainable development and circular economy are terms that are being assimilated among companies, organizations and people, in general, who must assume a greater degree of responsibility in environmental matters. This new business approach, however, will not have a negative impact on the creation of wealth or jobs, since both indices will continue to increase with the appearance of new companies and more sustainable energy management. Companies are aware that they have to open a new door to training in the recycling of traditional activities, which will imply that all stakeholders broaden their views towards the creation of a more sustainable and equitable sector. The circular economy represents a kind of paradigm to allow companies, governments and citizens to rethink the current development model by combining innovation, competitiveness and sustainability to respond to today's main environmental and social challenges. This transition has been pursued to achieve, in addition to the environmental and social benefits, clear economic benefits derived from (i) new income, through the recovery of the value of assets and materials or the development of new services; (ii) the reduction of costs and risks, through redesign, circular inputs and the preservation of the value of assets and; (iii) a permanent focus on innovation, thanks to the continuous improvements required by the circular economy approach (Salvioni and Almici 2020).

The circular economy strategy in the new energy transition model must be characterized by the reassessment of the business throughout the entire value chain, starting from the design and supply phases (Su and Urban 2021). The vision of the circular economy in this sector must be based on the following pillars, which define the areas and methods of application:

- Circular inputs: production and use models based on renewable inputs or inputs from previous life cycles (reuse and recycling). The proper collection and management of secondary materials or waste is essential not only to ensure compliance with environmental regulations but also to maximize their value through the development of markets for secondary raw materials that are capable of enabling circular flows creating, among other things, synergies between the different sectors;
- Product as a service: a business model in which the customer buys a service for a limited time while the company retains ownership of the product, thus maximizing the use factor and useful life;
- Exchange platforms: sharing between multiple users of products and goods;
- Life extension: approach to the design and management of an asset or product aimed at extending its useful life, for example, through modular design, ease of repair and predictive maintenance;
- End-of-life recovery: any solution aimed at preserving the value of an asset at the end of its life cycle through, in synergy with the other pillars, reuse, regeneration, upcycling or recycling.

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Chapter 3
Circular Economy and Renewable Energy: A Global Policy Overview

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Abstract This chapter provides a comprehensive overview of global policies pertaining to the circular economy and renewable energy. The concept of a circular economy, which aims to minimize waste and maximize resource efficiency, has gained significant attention in recent years. Simultaneously, the importance of renewable energy sources in mitigating climate change and ensuring sustainable development has become increasingly evident. This study examines the interplay between these two critical areas and explores the policies implemented to promote their integration. By analyzing key initiatives and strategies, this paper aims to shed light on the current state of global policy frameworks and identify potential areas for improvement. It contributes to a better understanding of the challenges and opportunities associated with transitioning towards a more sustainable and energy-efficient future.

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3.1 Introduction

Since the 1700s, humans have relied on fossil fuels as the main source of power. These non-renewable fuels have supplied almost 80% of the world's energy demand, enhancing the process that makes a huge range of products and reducing the need for labor. The rapid rise in the global population and the growth in industrialization have led to a dramatic increase in the world's energy demand over the past decade. However, it appears that conventional fossil fuels would not be able to satisfy this requirement due to their grievous challenges, such as price inflation, climate changes, and environmental damages (ClientEarth 2022; UNEP 2022). The consumption of fossil fuels leads to environmental severe consequences regarding greenhouse gas (GHG) emissions.

The use of renewable energy (RE) has been considered one of the most critical components of the sustainable development strategy over the past decades (Sueyoshi et al. 2022). Since 1997, the Kyoto Protocol has been signed by many participating countries to reduce GHG emissions and the dependence on fossil fuels for economic development. The protocol also proposed the promotion, development, and increased use of new and renewable forms of energy valuable plans to facilitate RE (UN 1998; Lau et al. 2012). However, the use of fossil fuels for energy production at this current state has not subsided effectively, while the global greenhouse gas emissions have increased to 40–45% (Ritchie et al. 2022). The task of reducing GHG emissions has always been challenging. The most renowned plans, including the Kyoto Protocol, the Paris Agreement in 2015, and the EU Climate energy package in 2020, also encountered problems. For instance, Kyoto Protocol failed to reduce global GHG emissions since there was a lack of a comprehensive global agreement (Rosen 2015), while the Paris Agreement succeeded in requiring all countries to set emissions-reduction pledges, known as nationally determined contributions; however, there are no enforcement mechanisms to ensure they meet their targets. Furthermore, the United States, the world's second-largest emitter, formally withdrew from the Paris accord in 2020; however, the country rejoined the Agreement in 2021 under Joe Biden Administration. Tackling GHG emissions requires a new strategy of manufacturing, transportation, and energy consumption, which are also imperative to reduce the dependence on fossil fuels, effectively extend the life of materials beyond their original use and lower the carbon emission to achieve net zero emission by 2050 (USAID 2022a, b). The transition to RE complemented by energy efficiency could be able to cut almost 50% of global GHG emissions (United Nations 2018), however the high demands of RE sources, such as solar and wind energies, and storage systems in the next few decades during the transition to clean energy are forecasted to require a large number of critical metals (Indium, Silver, and Neodymium, etc.) and materials for RE equipment. Generally, the quantity of RE equipment is expected to grow exponentially in the next 30 years, estimated to increase to 10 million tons annually in 2050 (Peplow 2022). It would be a great concern for the environment and human health since mineral extraction (mining), oil, and gas are still major resources that provide the raw materials to support RE production. Thus, the RE industries could pay more attention to their whole lifecycle processes, manufacture, installation, use, and disposal, in terms of sustainable, low-carbon, and safe processes.

The circular economy (CE) approaches have recently been critically necessary to achieve the upscale of RE generation and integration. In a CE system, the RE materials, parts, and equipment possess multiple life cycles, which also means providing a low GHG emission supply chain for the materials, reducing wastes, and creating optimum benefits for the community in a transition to a cleaner energy economy (OECD 2019; Mutezo and Mulopo 2021). The CE strategies would keep wastes out of the landfill option, reducing the demand for the material for energy equipment manufacturing, and also can be able to generate about 4.5 trillion USD in additional economic output by 2030 (OECD 2019). This new business model also offers innovation opportunities and jobs focused on the reuse, repair, and remanufacturing industries. In that manner, the more sustainable use of materials and energy could add an extra 2 trillion USD annually to the global economy by 2050, raising the global domestic products by 8% and benefiting the low and middle-income nations (Goldman Sachs 2022).

The reshaping of the RE industry into a more circular economy system is a critical paradigm shift that is benefited, encouraged, and very promising. In the CE, recycling becomes the last resort, not the first or the only option. This transition determines the role of product repairing and refurbishing, which may result in minimizing resource usage and contributes greatly to the reduction of global GHG emissions by almost 40% more (equivalent to 22.8 billion tons) (ECEEE 2021). According to the World Economic Forum (2020), the CE is vital for the energy transition in three ways, which not only solve the problem of GHG emissions but also strengthen the economy through (1) Recycling can conserve critical materials, (2) Using low-carbon, circular materials, (3) Designing circular systems (World Economic Forum 2020).

In order to achieve a successful transition to a cleaner energy economy, stakeholders, including government, industries in the whole supply chain, policymakers, and investors, would need to take concerted actions. RE policies oriented to CE could play crucial roles in promoting sustainable renewable energies on a large scale, which could overcome all existing barriers to achieving carbon neutrality by 2050. Such policies could affect the decision-making of producers, distributors, users, and disposers of renewable technologies. However, the energy strategies related to the targets of RE development may differ among the countries or regions, resulting in the different policies supporting RE and CE around the globe. In addition, there is currently a lack of connection between the CE and RE policies. The energy sector is rarely mentioned in the CE research and policies and vice versa. Moreover, policymakers are more interested in solar photovoltaic (PV) and wind energy technology than other renewable energy types. Also, except for the EU, the renewable energy development policy with a CE orientation is still unconnected, lacking coherence and systematicity.

Currently, national or regional policies on recycling, landfills, and extended producer responsibility are interested in the EU countries, the United States, China, India, and Japan. Despite the lack of national PV waste laws, some states in the US have introduced product stewardship policies, Sustainability Leadership Standard for PV Modules, Inverters, and the Silicon Valley Toxics Coalition's Solar Scorecard. These policies affect the design, manufacturing, and disposal management of PV modules and related products (Heath et al. 2022). According to the amendments by the Act on Partial Revision of the Electricity Business Act, Japan will start the decommissioning reserve scheme in 2022 (International Energy Agency 2021). Other countries such as the United Kingdom, Switzerland, Norway, Germany, France, Australia, Russia, China, and India have also introduced national regulations for recycling solar PV modules and storage (Sharma et al. 2019; Boelens et al. 2022).

To provide more insights into global policies of circular economy and renewable energy, we review specific policies on critical materials, scarce earth, manufacturing, installation/deployment, and disposal of renewable energy technologies with case studies. The critical material and element using, manufacturing and deployment of the RE system will be presented in Sects. 3.2, 3.3 and 3.4. On the other hand, Sect. 3.5 is devoted to the disposal solution following cases mentioned previously. Finally, we discuss the various aspects of mainstream CE in RE policy.

3.2 Policies on Circular Economy Oriented-Raw Materials and Elements

The flourishing of RE in transition to clean energy has a greater demand for virgin materials and rare earth minerals. According to Dang et al. (2021), millions of tonnes of composite and rare earth materials are extracted and processed. The wind turbine and PVs require rare earth elements for permanent magnets, while the battery energy storage systems (BESS) rely on lithium, nickel, cobalt, manganese, and graphite. The demand for minerals and rare earth elements would rise by over 40%; lithium would be up to almost 90%, and nickel and cobalt will be around 60 and 70%, respectively (IEA 2021). Mining is essential to the growth of renewable energy. The high demand for the minerals and elements may increase mining production, which causes negative environmental and social impacts, biodiversity loss, and even increases GHG emissions (Sonter et al. 2020; Rehbein et al. 2020). The mining policies related to BESS and RE also need to shift towards sustainability goals by recycling these materials. The materials used to produce components for renewable energy generation emit CO_2. In order to ensure that these sources are truly clean, policies to develop technology to reduce the CO_2 share in the entire equipment's life cycle need to be strengthened.

For instance, China is the largest producer of rare earth elements (REEs), including neodymium, dysprosium, and praseodymium, accounting for 58% of the world's rare earth element market (Mineral Commodity Summaries 2021). As promised to achieve carbon neutrality before 2060, the Chinese government has paid more attention to environmental impacts by issuing more stringent environmental policies and restricted export regulations (Mancheri et al. 2019).Additionally, China has considered recycling and waste management of REEs to improve resource efficiency since the waste collection and recycling system for rare earth elements is still ineffective (Ge et al. 2022). Currently, limited REEs have been recycled except for Nd-Fe-B permanent magnet due to high demand; other REEs containing final products have no or low recycled rate (Jo 2015). Changes in China's policies related to REEs and solid political tensions, such as the REEs war, scramble between the USA and China, or even the Russia-Ukraine war, could influence the global supply chain disruption (Hornby and Zhang 2019). This may influence other major REEs production countries, including Australia, the United States, Brazil, Russia, Myanmar, Burundi, India, Malaysia, Madagascar, Thailand, and Vietnam (Huleatt 2019).

Another example is Australia, which has become the second-largest REEs producer due to the above issue. The country plays a vital role in REEs production, reaching 21 kt in 2019 (Huleatt 2019; The U.S. Geological Survey 2020). The elevation of REE extraction and processing resulted in the country facing environmental challenges, which impulsed the development of eco-friendly mining techniques. However, at the same time, stringent policies were developed for reducing, reusing, and recycling strategies such as 2022 Critical Minerals Strategy (The Australia Government 2022). Countries with limited REE resources are considering circular economic strategies to mitigate the future shortage of materials and REEs (Metabolic 2021). For instance, The Netherlands proposes circular strategies, which focus on Rethinking, Reducing, Repairing, Refurbishing and Repurposing, and Recycle (Metabolic 2021). Even with the high demand for REEs, currently, recycling constitutes less than 5% of the global REE supply; many EU countries have paid more attention to critical raw materials, recycling, and sustainable waste management, particularly Critical Raw Materials Resilience (Communication COM 2020). Therefore, CE principles could be incorporated into REE mining to improve economic and environmental performance.

3.3 Policies on Circular Economy Oriented-Renewable Technology Manufacturing

RE technological manufacturing is one of concern regarding its environmental impacts. The manufacturing process uses and releases hazardous chemicals, requires a large amount of energy, components, and materials, including rare earth elements, and emits GHG (Peiró and Méndez 2013; Yue et al. 2014). However, there are currently no direct CE policies and regulations in the RE technology manufacturing phases. China is one of the world's largest producers of wind and solar energy, and the process of producing RE requires a tremendous amount of non-renewable energy (Lakatos et al. 2011), resulting in high carbon emissions (Xu et al. 2018). The solar industry in China has emitted twice the carbon footprint as that made in Europe due to a lack of environmental standards for solar PV production (Yue et al. 2014). After the COP26 summit in early November 2021, China has recently released more policies and regulations focusing on the stringent environmental protections related to energy production (Zhang et al. 2022). In 2022, China released the document "the Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-carbon and Recycling Economic System." Accordingly, broader goals for China to transfer to a green economy, which pays attention to the efficient use of resources, energy, and environmental protection industry, are set (China Briefing 2022).

In the United States, renewable energy manufacturing has good opportunities for renewal and growth in solar, wind, and energy storage. This country's goal is an annual of 30 GW between now and 2025 and 60 GW annually from 2025 to 2030 for solar power. Meanwhile, the goal is to deploy 30 GW offshore wind by 2030 and unlock more than 110 GW of deployment by 2050 (SEIA 2020). The new materials and manufacturing strategies are essential to reduce costs, waste management (no end-of-life challenges), and material use efficiency. A CE concept for energy materials has been mentioned (NREL 2020); however, there is still a lack of specific policies for CE. In the report, NREL emphasized designing clean energy technologies by reducing, reusing, and upcycling energy-relevant and energy-intensive materials, processes, and technologies. For instance, a study on Solar Futures showed that CE methods could be incorporated into the PV manufacturing stage (Garvin et al. 2022). Some manufacturers have designed for circularity by using secondary materials as end-of-life PV materials or used materials recovered from non-PV systems in PV manufacturing (recovering semiconductor materials, e.g., Cd and Te). Some used renewable electricity for PV manufacturing processes (Garvin et al. 2022). The closer CE policies regarding the RE may be defined in Regulation (EU) 2020/852, which aligns with Directive (EU) 2018/2001 in Europe. European Commission has mentioned CE in the manufacture of renewable energy technologies that postulated the RE manufacturers to produce much cleaner and safer energy through material efficiency, waste prevention, and recycling (EU Taxonomy Compass 2022).

3.4 Policies on Circular Economy Oriented-Renewable Technology Use (Installing/Operation)

The global transition to renewable energies is a concern when this makes conflicts over land use, land cover changes, graded soils, biodiversity loss, and food security (Hernandez et al. 2014, 2015). Power plants and transmission lines can damage forests, wetlands, and other natural areas (Biasotto and Kindel 2018). A global increase in large, centralized installations of RE systems, such as solar and wind energy, has received attention over the impact on land use and water resources. The deployment of these systems cleared large areas of aboveground vegetation, resulting in the degradation of soils and landscape that influence species movement, preying strategies, and natural selection (Leskova et al. 2022; Northrup and Wittemyer 2012).

In Japan, there are two ways to convert agricultural lands into renewable energy sites: switching the whole croplands and adopting shared-use systems (Kohsaka and Kohyama 2022). To date, the shared-use system, especially "solar sharing" is applied in most croplands, where land can be used for agriculture activities and renewable energy generation simultaneously (Kohsaka and Kohyama 2022). However, in March 2020, 80% of the cropland yield was not met due to the interference of solar power plants in farming activities, as recognized by the Ministry of Agriculture, Forestry, and Fisheries (MAFF) (Kohsaka and Kohyama 2022). Consequently, these regulations were deregulated drastically at the moment. MAFF decided to simplify the requirement by examining the proper and efficient utilization of cropland along the solar power plant, in place of requiring landowners to produce a yield of 80% in the converted cropland (Kohsaka and Kohyama 2022). Therefore, after ten years (expiration date), the operators of the solar power plants can renew the permit to convert cropland to other land uses without considering agriculture production yields (Kohsaka and Kohyama 2022). Recently, a draft amendment of the "Agriculture, Forestry and Fisheries Vitalization Act (Act No. 48 of 2007)" was submitted by MAFF (Kohsaka and Kohyama 2022). This will counter degraded croplands by allowing a collective transfer of cropland rights. In detail, when cropland is identified and categorized as degraded and is hard to reuse or cultivate again, the Agricultural Commission will notify the owners, municipalities, and other stakeholders (Kohsaka and Kohyama 2022). Then, there is a request for the recipient of the notice to send a notification to the Legal Affairs Bureau to change the land category (to "non-cropland" or "degraded cropland") (Kohsaka and Kohyama 2022). Under the Rural Renewable Energy Act, when the production conditions show the low-quality performance of cultivation for a considerable period, the law will be relaxed, allowing conversion from degraded cropland that is exempt from conversion to other land uses (Kohsaka and Kohyama 2022).

Enabling policies to ensure adequate operating conditions for renewables in energy systems and markets are usually recommended to promote the deployment and operation of RE (IRENA, IEA, and REN21 2018). Integrating policies, which account for technical issues in the installation and operation, and behavioral and social change related to the RE implementation are also needed. For example, the application of RE during the transportation phase is one of the promising approaches to reducing GHG and energy consumption. Companies in the field of automotive production can improve logistical circularity by implementing distribution-oriented strategies, including freight fuel economy improvements, the use of electric vehicles, and enhancing the efficiency of freight carriers and networks. These strategies involve several technical, social, and economic factors (Esteva et al. 2020). However, policies supporting logistics and transportation currently focus mostly on biofuels.

Integrating policies with several instruments for system integration, technology innovation, energy access, and sustainability considerations are therefore vital to enhance the operation of RE.

3.5 Policies on Circular Economy Oriented-Renewable Technology Disposal (Decommissioning)

With an average lifespan of 10–40 years, many of the world's RE, such as solar PV modules and onshore and offshore wind turbines, installed during the 1990s and early 2000s, come time for their decommissioning. Large amounts of annual waste, including solar panels, wind turbine blades, and used batteries, are anticipated worldwide in the early 2030s (Davis et al. 2021). Many countries have begun to express concern about managing the material flows of decommissioned wastes and energy storage technologies. Country-specific policies have been published related to end-of-life types of RE, landfill bans, and extended producer responsibility (EPR) (Invernizzi et al. 2020; USAID 2021).

EU is one of the leading countries or regions in implementing policies in managing wastes from electrical and electronic equipment used in the renewable energy industry, such as using solar PV modules, to contribute to sustainable production and consumption. The European Waste Electrical and Electronic Equipment Directive (EU WEEE Directive) was released in 2013 and is currently applied in 28 EU countries. This regulation mentioned that PV manufacturers are responsible for the costs of collection, handling, and treating PV module waste (Official Journal of the European Union 2012). To support the implementation of the PV module recycling program, Germany has introduced two financial mechanisms of Business-to-consumer (B2C) transactions, Business-to-Business (B2B) transactions (Sharma et al. 2019). While 85% of the turbine's components, including the tower, generator, and gearbox, can be reused or recycled easily, rotor blades made of composite materials are challenging to recycle. To avoid the landfills of turbine blades, several countries in Europe, including Germany, the Netherland, Austria, and Finland, have introduced blade landfill ban regulations and tax incentives (WindEurope 2021). Furthermore, most member countries have adopted a new Circular Economy Action Plan, a new Batteries Regulation, which ensures that batteries placed in the EU market are sustainable and safe throughout their life cycle within the overall Circular Economy Action Plan (EC 2020). Accordingly, the regulation intends to mandate labeling requirements and a carbon footprint declaration for all relevant equipment.

In the United States, solar decommissioning regulations have been prepared at federal and state levels, which vary by federals, states, and local jurisdictions (Curtis et al. 2021). These policies require solar developers to submit the decommissioning plan before construction or operation. In addition, acknowledging asset owner decommissioning responsibilities and what constitutes abandonment, a detailed cost estimation, proof of financial assurance, removal equipment, site restoration, and post-decommissioning monitoring, reporting, assurance, and closure requirements are also required provided (Curtis et al. 2021). The gap in these policies was not designed with the new solar technologies, but the importance of policies was to establish a framework for enabling a CE for solar photovoltaic energy generation (Curtis et al. 2021; BNEF 2021). Additionally, the US has prepared policies related to the secondary market for solar PV equipment components, which aim to keep solar PV modules and their constituent materials in use for extended periods (Boelens et al. 2022). Secondary markets and services are becoming increasingly essential to manage material flows and establish a circular economy for PV modules (Boelens et al. 2022).

Japan, China, and India have also introduced national recycling regulations for solar PV modules, wind turbine blades, and energy storage (Sharma et al. 2019). In China, the central government published a new policy, The implementation Plan for speeding up the "Promotion of the Comprehensive Utilization of Industrial Resources," related to the circular economy principle (Ministry of Industry and Information Technology 2022). The regulation was issued on the recycling of industrial materials, and the central government laid out plans to promote the development of technologies for the reuse of retired solar and wind facilities and to improve recycling systems for EV batteries (Ministry of Industry and Information Technology of China 2022). Unlike China, India has not yet had a policy on managing waste derived from used solar power panels or manufacturing processes (Jain et al. 2022). India considers solar waste a part of electronic waste under the Ministry of Environment, Forest and Climate Change (MoEF&CC). However, Ministry for New and Renewable Energy is considered to propose an action plan to evolve a "circular economy" in the solar panels through the reuse/recycling of waste generated (Jain et al. 2022).

3.6 Discussion

CE has the leading role in sustainable development policies, such as reducing reliance on fossil fuels and pollution by utilizing renewable energy, reducing the manufacturing sector's carbon footprint through mandatory carbon credit, cutting down on wasted consumption, and increasing energy efficiency. CE also creates the prerequisite and basis for sustainable energy development, keeping global warming within 1.5 °C and achieving net-zero targets. According to Black et al. (2021), net zero commitments globally cover at least 61% of global GHG emissions and 68% of the global GDP. Plans for CE have been developed in many regions and countries, such as Latin America, the Caribbean, Colombia, Chile, Uruguay, Mexico, Brazil, Peru, Ecuador, Paraguay, El Salvador, Cuba, and the Dominican Republic. RE uses many novel materials during its lifetime, divided into 4 stages: raw materials-production-consumption-disposal. CE will turn this process into a closed cycle, in which disposed products can be recycled into raw materials. In RE policies, the government needs to mandate the cost of project decommissioning after a 25–30-year lifespan for the developer, for example, collecting 78 million tons of PV panels or recycling

43 million tons of wind turbine blades by 2050 (USAID 2021). Possible solutions are lifetime extension or increasing funding for research in raising the recovery rate of decommissioned equipment, according to the 4R principle in CE: reusing, repurposing, recycling, and recovering (or reusing, remanufacturing, refurbishment, repairing, or even 6Rs, namely: reuse, recycle, reduce, recover, remanufacture and redesign) (Mutezo and Mulopo 2021; Hao et al. 2020). CE is related to processes such as Manufacturing, Supply Chain Management, Biogas for Electrification, and Waste Management (Hao et al. 2020).

Since the Fukushima Nuclear Power Plant accident in 2011 to replace decommissioned nuclear power plants or plants in the process of decommissioning around the world, the demand for renewable energy to fill the power generation gap has become more evident in many countries. Despite the Covid epidemic, the Feed in tariff (FiT) for RE has led to a spike in installed capacity of up to 825 GW of wind and 843 GW of solar power in 2021 (USAID 2021). The FiT policy shows the role of government in leading development, especially for the financial impact on RE projects. In most countries, the purchasing price of electricity produced by RE has been significantly higher than that of traditional energy sources, bringing reasonable profits to investors. It has helped attract significant financial investments for wind and solar power projects. After the FIT tariff period, when the market has been formed, and RE technology is mature, market liberalizing and auction mechanisms will become popular. Government policy would follow these routes to facilitate the market, ensuring that CE issues are integrated and avoiding focusing solely on selecting projects for low bids. During this energy transition, the development of RE associated with CE requires phasing out of traditional fossil fuel-powered power plants in a sustainable way to avoid labor loss and waste of investment capital while promoting environmentally friendly power sources at a reasonable cost. Most countries have undergone massive RE development due to the high FIT prices, followed by policies for sustainable development to gradually achieve 100% RE targets in some regions and countries.

However, it is also important to note that the source of policies promoting RE also has a part of CE, which is CO_2 emission reduction, mentioned from the very first years of RE development (Eric 2011). Calculations in countries such as China, the US, Canada, Germany, India, Russian Federation, Korea, Iran, and the UK all show that RE development can reduce a certain amount of CO_2 and reduce environmental harm in energy use, pursuing the goals of the Nationally Determined Contributions (NDC) (Dara et al. 2022). For example, India has a very persistent policy in developing RE to achieve climate change goals such as Electricity Act 2003, Integrated Energy Policy 2006, National Action Plan on Climate Change (NAPCC) 2008, FiT, renewable portfolio obligation, fiscal incentives, Optimal energy mix for 2021–2030, transition in energy mix and growth in RE based electricity in 2015–2020. However, CE policies such as solid waste treatment in RE have received almost no attention (Sawhney 2021). CE principles are also applied in Africa during the transition from fossil fuel to RE, especially across their Big Five economies (Algeria, Nigeria, Egypt, Morocco, and South Africa) (Mutezo and Mulopo 2021).

Among the types of RE, CE can be suitable and close to developing bioenergy sources when most of the fuels burned to generate electricity are products of other industries such as forestry, animal husbandry, and organic waste. The policy on bioenergy in some countries like Vietnam is also not suitable, leading to a very limited share of this source in power generation and national energy planning. In particular, CE-related policy approaches for bioenergy should also consider the side effects of these fuel-based power sources, such as relatively high CO_2 emissions, wood-burning fuels, and encroachment of croplands upon natural habitats (Kopnina 2017).

In order to ensure power supply security with high RE integration into the power system, it is necessary to rely on energy storage sources. In other words, BESS has a significant role and is used more and more with 2 million tons of waste per year from electric vehicles and grid-connected energy storage systems (USAID 2022c). Demand for mineral resources such as lithium, cobalt, or rare earth to produce BESS or wind generators will increase. The mining policies related to BESS and RE also need to shift towards sustainability goals such as recycling these materials. The sources of materials used to produce components for renewable energy generation are increasingly emitting more CO_2.

The issue of land and water reserved for building renewable energy sources should also be considered in the development of CE. Because these sources are often small-scale, scattered, and installed near residential areas, to preserve the land so as not to conflict with other uses, it is necessary to have clear guiding policies from the government.

Policies for RE development and CE will have an unavoidable trade-off. When developing RE, it is also possible that some aspects affect the natural environment, such as paving the way for wind turbines in the mountains, encroaching on marine life and the natural landscape of offshore wind turbines, particularly in vulnerable areas in Southeast Asia (Pratiwi and Juerges 2020). In these regions, if CE issues are combined, financial constraints, policy-making processes, public attitudes, harmonizing the interests of the parties involved, or even the limited scientific and technical potential for the construction, installation, and operation of RE sources are also significant barriers. The task of government policies is to be practical and remove barriers quickly and as much as possible so that the country can soon achieve its sustainable development goals.

Additionally, tax policies related to energy use are considered a powerful tool to shape economic activities and achieve green growth and recovery of the global economy (Taxing Energy Use 2019). For instance, the CO_2 tax introduction is considered a valuable and necessary tool for limiting CO_2 emissions from fossil fuel usage and promoting sustainable energy development. Until now, 46 nations and 32 sub-nations have been introduced or scheduled to apply carbon pricing mechanisms, namely CO_2 tax and emissions trading system (ETS). In fact, the CO_2 tax rate depends on every nation/sub nation and varies in a large range: from <1 USD/ton of CO_2 (e.g., Mexico, Poland, and Ukraine) to >100 USD/ton of CO_2 (e.g., for Sweden, its CO_2 tax is 119 USD/ton) (World Bank 2022). However, most carbon prices/tax rates are too low, with almost half of the covered emissions priced at less than 10 USD/ton of CO_2. According to the High-Level Commission on Carbon Prices, it is estimated that carbon prices of at least 40–80 USD/ton of CO_2 by 2020 and 50–100 USD/ton of CO_2 by 2030 are required to cost-effectively reduce emissions in line with the temperature goals of the Paris Agreement (World Bank 2022). The IEA Sustainable Development Scenario also stated that a carbon price ranging between 75 and 100 USD/ton of CO_2 is needed to stay on track with a Paris-compatible trajectory.

3.7 Conclusion

It can be seen that RE itself is not necessarily green development, but if RE is combined with CE, the goal of sustainable development and natural protection can be achieved. Equipment for the RE industry must be produced, distributed, and recycled responsibly, safely, economically, and sustainably. CE can help these devices to reach the lowest emission cycle, reduce waste, create jobs, achieve gender equality, and empower the community. Harmonious development and protection goals should be known to the people, and scientific and technical research should be promoted for the simultaneous development of RE and CE. Government policy could consider: incorporating CE concepts into all RE development strategies; creating a network for all stakeholders to actively contribute to sustainable development goals; developing safety and quality assurance standards in new and recycled products; developing human resources, tools, and resources for CE, etc. It can be said that, without CE, RE will take a turn that may not be as clean as people expect. The government should formulate long-term goals and strategies for circular economy-based RE development. Smart regulations will encourage product take back, recycling, and reverse supply chains. Designing the circular economy into the energy transition will allow us to move faster and more sustainably in getting to net zero.

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Chapter 4
Circularity and Sustainability Performance of Hybrid Renewable Energy Systems: Exploring the Benefits and Challenges Behind the Hybridization of Wind Farms

Dorleta Ibarra and Joan Manuel F. Mendoza

Abstract Accelerated deployment of renewable energy production technologies is instrumental in supporting a sustainable energy transition to mitigate greenhouse gas (GHG) emissions worldwide. However, renewable energy production imposes relevant economic, technical and environmental challenges that must be overcome for clean energy systems' resource-efficient and sustainable development. Some of these challenges include a high levelized cost of electricity (due to the large capital and operational expenditures), intermittency in renewable electricity production (leading to a lack or excess of energy supply that cannot be fully utilized to displace fossil-based energy sources) and high consumption of resources, including the critical raw materials, to manufacture technology components (which can be difficult to recycle for material recovery). Based on a systematic literature review combined with a bibliometric analysis and content analysis, this chapter provides an overview of all the potential technological pathways, business model solutions and circular economy strategies for the hybridization of wind farms to produce multiple clean energy carriers (e.g. hydrogen, methane, methanol, carbon-free fuels), to optimize the technical and economic efficiency of wind energy systems, while contributing to decarbonizing high energy and carbon-intensive sectors (e.g. heavy transportation, aviation, steel, cement, plastic, chemical industry). The results include a conceptual framework of three technological pathways, nine business model solutions and ten circular economy strategies for the sustainable hybridization of wind farms, including a discussion of related industrial and policy challenges.

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Keywords Circular economy · Wind farm · e-fuels · Green hydrogen · Hybrid renewable energy systems · Bibliometric analysis

4.1 Introduction

Accelerated deployment of renewable energy production technologies is instrumental to support a sustainable energy transition worldwide. The strategies of the European Union for the decarbonization of industry and mitigation of greenhouse gas (GHG) emissions seek an increase in renewable energy to at least 32% of total consumption and an improvement in energy efficiency to at least 32.5% by 2030 (Lux and Pfluger 2020). However, the efficient and sustainable development of clean energy system resources requires overcoming significant economic, technical, and environmental challenges.

The widespread adoption of renewable sources such as wind and solar poses intermittency and uncontrollability for reliable integration into the power grid (Buonomano et al. 2018; Xu et al. 2021). In addition, fluctuating feed-in from renewables is leading some countries to face excess energy production that cannot be harnessed (e.g., Denmark supplies 130% of the load in 24 h) (Dieterich et al. 2020). Moreover, grid congestion and power curtailments lead to high costs to compensate for the temporary mismatch between energy supply and demand (Balan et al. 2016; Schnuelle et al. 2020a, b).

Other economic challenges include the end of feed-in tariffs, which affects the profit generation of wind farms older than 20 years (Council of European Energy Regulators 2020). As repowering wind farms are costly, some wind farm owners opt for decommissioning wind farms (Kristensen 2020) even though the technical lifetime of wind turbines could be extended to 25–35 years (Rasmussen et al. 2020) through remanufacturing or refurbishment (Mendoza et al. 2022).

One promising solution to these challenges increasingly highlighted by academics and professionals is the hybridization of wind farms (HWF). HWF refers to the integration and management of multiple renewable energy generation and storage technologies (Carvalho et al. 2019) to increase the flexibility of electricity supply and use while producing multiple clean energy carriers (e.g., hydrogen, methane, methanol, carbon-free fuels) (Mendoza et al. 2022).

HWFs have significant advantages compared to pure renewable and storage power plants (Wind Europe 2019): Optimizing grid utilization (maximizing the use of the existing grid and solving bottleneck problems), reducing Levelized Cost of Electricity (LCOE) and infrastructure investment costs, eliminating wind and solar intermittency problems, providing a more stable power output or using land more efficiently. In addition, HFW's should be based on circular economy (CE) strategies and business models (BMs) that strive to minimize waste generation and emissions through efficient use of resources to optimize energy system efficiency and sustainability performance (Mendoza et al. 2022).

Several studies can be found exploring the environmental and economic challenges of HWF. Some authors provide frameworks and feasibility analyses of hybrid energy systems combining photovoltaics, wind turbines and storage systems on small-scale solutions and off-grid locations such as micro-grids (Zhang et al. 2016), residential buildings (Alhashmi et al. 2021), energy hubs (Eladl et al. 2020) or rural and remote communities (Olabode et al. 2021). Other studies explore the financial viability of producing green hydrogen from renewables (Lux and Pfluger 2020; McDonagh et al. 2020). Some reviews (Dieterich et al. 2020) can be found exploring the technological developments and pilot plants for the conversion of power to liquid fuels (e.g., methanol, DME and Fischer–Tropsch-fuels).

However, none of these studies offers an integrative view of potential technological pathways, BM solutions and CE strategies for HWF. The only study that comes close to this approach is the one developed by Mendoza et al. (2022), who characterized three circular BMs for HWF: (1) photovoltaic panels, WT and batteries, (2) Power-to-gas, and (3) Power-to-Liquid. However, the authors did not exhaustively discuss the possible combinations between technologies and circular economy strategies in the context of HFW.

In response, this paper aims to systematically identify and categorize technology pathways, BM solutions and CE strategies that can potentially drive HWF. To this end, three research questions (RQ) were defined:

RQ1: What are the main technological pathways and BM solutions in HWF?
RQ2: What are the main CE strategies addressed in HWF?
RQ3: How are BM solutions and CE strategies related in HWF?

A methodology comprising a systematic literature review (SLR) based on bibliometric analysis and content analysis was applied to answer these research questions. The following lines detail the methodology applied and describe the results and conclusions of the study.

4.2 Methodology

A SLR is a structured method for identifying, evaluating and interpreting available evidence relevant to a particular research domain in a rigorous, transparent and reproducible manner (Tranfield et al. 2003). SLR involves a series of steps, including defining the topic area, the inclusion criteria and the search keywords and collecting, analysing and synthesizing the literature (Chakraborty et al. 2021). Supporting SLR analysis and synthesis procedures with bibliometric analysis and content analysis can improve the rigour of the review and enable systematic evaluation of the main research topics (Chakraborty et al. 2021; Koberg and Longoni 2019; Lode et al. 2022). The bibliometric analysis allows for systematically evaluating scientific data using statistical methods to gain an overview of selected publications' main research themes and trends (Lode et al. 2022). Content analysis, in turn, supports the classification of large amounts of textual data into content categories for subsequent quantification and

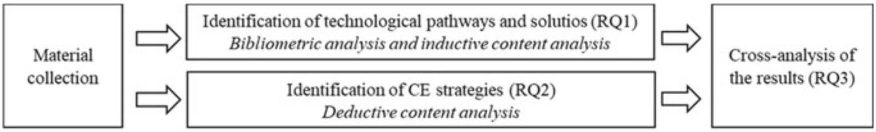

Fig. 4.1 Methodological steps followed in the present research

qualitative description (Bryant et al. 2018; Downe-Wamboldt 1992; Weber 1990). Content analysis can be deductive, using theoretical concepts to define the data coding system before the literature review, inductive, codes are developed from data and refined throughout the process during the review, or both (Elo and Kyngäs 2008; Horne et al. 2020; Hsieh and Shannon 2005). As Koberg and Longoni (2019) and Seuring and Gold (2012) recommended, the present study follows an iterative process combining deductive and inductive approaches. Figure 4.1 shows the applied methodology.

First, the material to be evaluated was searched, selected and collected. Then, a bibliometric analysis (deductive approach) combined with inductive content analysis was applied to identify the main technological pathways and solutions in HFW (RQ1). Next, a deductive content analysis identified CE strategies addressed in HWF (RQ2). Finally, the bibliometric analysis and content analysis results were cross-checked to explore the relationships between technological solutions and CE strategies in HWF (RQ3).

4.2.1 Material Collection

In March 2022, English articles and review papers on business models for HWF were located using the SCOPUS database. The following search string combining keywords on (1) wind energy, (2) business models and (3) hybrid energy systems was used in titles, keywords and abstract:

(1) TITLE-ABS-KEY ("wind technology*" OR "wind turbine*" OR "wind farm*" OR "wind park*" OR "wind energy*" OR "wind power" OR "wind energy technology*" OR "wind power technology" OR "wind sector" OR "wind energy sector") AND
(2) TITLE-ABS-KEY("business" OR "business model*" OR "value proposition" OR "value creation" OR "value delivery" OR "value capture" OR "value recovery" OR "value opportunit*" OR "value offering*" OR "value generation" OR "value configuration*" OR "value network*" OR "value chain*" OR "supply chain management" OR "revenue model*" OR "revenue stream*" OR "financial model" OR "customer relationship*" OR "distribution channel*" OR "customer segment*" OR "cost structure*" OR "revenue stream*" OR "revenue

model" OR "revenue mechanism*" OR "financial architecture*" OR "partnership*" OR "partner network" OR "infrastructure management" OR "financial mechanism*") AND

(3) TITLE-ABS-KEY (hybrid* OR "hybrid wind farm*" OR "hybrid wind park" OR "wind farm hybridization" OR "wind farm hybridization" OR "wind park hybridization" OR "wind park hybridization" OR "renewable hybrid power plant*" OR "renewable hybrid wind power plant*" OR "renewable hybrid wind farm*" OR "hybrid renewable energy" OR "hybrid renewable*" OR "power to" OR "power-to*").

Eighty-one articles were collected, and after a first quick content check of titles and abstracts, 35 were removed as out-of-scope. The remaining 46 articles were carefully read. 13 articles that did not explicitly focus on hybridization or business models were excluded. And 11 papers focused on remote communities, islands, residential buildings and microgrids rather than wind farms were discarded. As a result of this process, 22 potential studies and paper gathered through snowballing (Mourão et al. 2020) remained, resulting in a final sample of 23 academic papers.

In line with prior research (Bocken et al. 2014; Kristoffersen et al. 2020), the analysis was extended with a grey literature review to complement and enrich scientific data with additional real-life business cases. Industrial practices in HFW were analyzed by exploring the websites of 2 European wind original equipment manufacturers (OEM) and 6 International renewable energy associations:

- Vestas (https://www.vestas.com/): 9 documents
- Siemens Gamesa Renewable Energy (https://www.siemensgamesa.com/): 12 documents Wind Europe (https://windeurope.org/): 4 documents
- The European Technology Platform on Wind Energy (https://etipwind.eu/): 2 documents
- The Global Wind Energy Council (https://gwec.net/): 3 documents
- The International Renewable Energy Agency (https://www.irena.org/): 4 documents
- The International Energy Agency (https://www.iea.org/): 6 documents
- Hydrogen Europe (https://hydrogeneurope.eu/): 5 documents.

Thus, the final sample of documents to be analyzed consisted of 23 academic articles and 45 grey documents.

4.2.2 Identification of Technological Pathways and Solutions in HWF

A bibliometric analysis was conducted to evaluate the characteristics of the published scientific articles and provide some background for the subsequent evaluation of the content of each article. The bibliometric analysis involved examining authors' keywords in the 23 papers reviewed. Three different analyses were conducted using the R-package Bibliometrix v. 3.1.4, operated under the Biblioshiny web interface (Aria and Cuccurullo 2017): (1) most frequent words (to identify the most usually addressed topics), (2) word dynamics (applied to explore the evolution of keywords over time to identify main research trends), and (3) co-occurrence analysis (used to map and cluster related keywords together to identify main research themes).

The results of the analyses identified three main categories describing technological pathways and two sub-categories suggesting potential technological solutions for HFW. These initial categories and sub-categories were refined inductively throughout the academic and grey literature content analysis. The results are presented in Sect. 4.3.1.

4.2.3 Identification of CE Strategies in HWF

To identify potential CE strategies in HWF, predefined keywords drawn from the Circular Strategies Scanner developed by Blomsma et al. (2019) were defined. This scanner presents 30 CE strategies organized into four main categories that support CE innovations within manufacturing firms: (1) Recirculate, (2) Reinvent, (3) Rethink and Reconfigure and (4) Restore, Reduce and Avoid. The analysis was performed using the qualitative data analysis software QDA Miner Lite v2.0.9 (Lewis and Maas 2007). Table 4.1 shows the nomenclature and descriptions of the CE strategies (divided into categories and subcategories) adapted from Blomsma et al. (2019) and 33 related keywords used in the present study. The quantitative analysis of the results is presented in Sect. 4.3.2.

4.2.4 Cross-Analysis of the Results

In the last step, text was extracted from academic and grey literature and classified into technological pathways and CE strategies based on the results achieved in prior steps. The data was then cross-checked to explore the relationships between technological solutions and their circularity potential. The results are collected in a conceptual framework and discussed in Sect. 4.3.3.

Table 4.1 Categorization and definition of CE strategies adapted from Blomsma et al. (2019)

Category	Sub-categories/definitions		Keywords
Circular economy	An economic system that targets zero waste and pollution generation by using resources efficiently while relying on clean and renewable energy sources		*circular economy; circularity*
Recirculate	Extending use cycles of parts and products and managing end-of-life of materials to capture (residual) value or to reduce value loss from continued use of parts, products and materials		*recirculat**
	Upgrade	Extend existing use cycle by adding value or enhancing the function of a product in respect to previous versions	*upgrad**
	Repair and maintenance	Extend existing use cycle by countering wear and tear and correcting faulty components of a defective product/part to return it to its original functionality	*repair*; reparation; maintenance*
	Reuse	Extend the new use cycle by reusing a part/product (discarded/not in use) that is still in good condition and can fulfil its original function in a different context (new customer/user)	*reus**
	Refurbish and retrofit	Extend to new use cycles by returning a part/product (discarded/not in use) to a satisfactory working condition that may be inferior to the original specification	*refurbish*; retrofit**
	Remanufacture	Extend to new use cycles by returning a product (discarded/not used) to at least original equipment manufacturer (OEM) performance specification and quality	*remanufactur**
	Repurpose	Extend to new use cycles by using a product (discarded/not in use) or its parts for different functions	*repurpos**
	Recycle	Extend material lifespan by processing them in order to obtain the same or comparable quality	*recycl**
	Cascade	A subsequent use that significantly transforms the chemical or physical nature of the material	*cascad**
	Recover	Recover energy or nutrients from composting or processing materials	*recover**
Reinvent	Enable smarter business concepts through striving for full decoupling		*reinvent**

(continued)

Table 4.1 (continued)

Category	Sub-categories/definitions		Keywords
Rethink and reconfigure	Enable smarter business concepts through business model innovation for circularity. Products tend to not radically change, although the technology can evolve		*rethink*; reconfigur**
	Multi-flow offering	Extend the life of materials or products in a manner that exploits their residual value and becomes a significant part of the offering of the business. May involve providing new forms of value	*"multi-flow"*
	Long life products	Extend the life of products through offering support during their lifetime	*"long life"*
	Access or availability	Satisfying user needs without transferring ownership of physical products. Instead, user or consumer pays for access to the product for a certain period of time	*Sharing; "product share"*
Restore, reduce and avoid	Improve circularity potential and efficiency, prevent excess and aim for "gentani" (i.e., the absolute minimum input required to run a process)		*restor**
	Raw and materials sourcing	In the sourcing process	*"restorative sourcing"; "secondary sources"; "secondary materials"*
	Manufacturing	In product manufacture through consuming fewer natural resources or energy, aim for 'gentani'	*rework*; cascad*; recycle*; "lean manufacturing"; "cleaner production"*
	Product use and operation	In product use and operation through wiser use and operation of products (e.g., using digital technologies) and aim for 'gentani'	*"product longevity"; Longevity*

4.3 Results

4.3.1 Technological Pathways and Solutions in HWF

The bibliometric analysis was exploratory and aimed to provide an overview of the main research themes and trends based on the keywords most frequently used by the researchers in the 23 papers reviewed. Authors' keywords were analyzed by exploring keywords' frequency, dynamics and co-occurrence. Before the analyses, keywords were manually scanned to avoid typos and to homogenize spelling (Henry et al. 2021). Table 4.2 shows the 23 original keywords manually replaced by eight generic ones.

Table 4.3 presents the top-10 most frequent keywords out of the total of 79 authors' keywords comprised in the 23 articles. In line with the central theme of the study, the Keyword with the highest number of occurrences per article is "wind energy" (39,1% occurrences per article). The next most frequent keywords are "power-to-gas", "hydrogen", and "electrolysis", with 34,8%, 26,1% and 21,7% of the articles targeting these solutions, respectively. "Hybrid system", "solar energy", "energy storage", and "power-to-liquid" follow the ranking with the representativeness of 17,14%, 17,14%, 13% and 13% per article, respectively. Among the less frequent keywords are "methanol" and "offshore wind", each with 8,7% occurrences per article.

Exploring the dynamics of the top-10 keywords over time (Fig. 4.2), it can be observed that until 2015, "wind energy" research was closely aligned with research

Table 4.2 Manually corrected keywords

No	Authors' original keyword	Revised keyword
1	Hydrogen	Hydrogen
2	Cost of hydrogen	
3	Power-to-gas	Power-to-gas
4	Power-to-gas (ptg)	
5	Power to gas	
6	Power-to-gas technologies	
7	Power-to-liquids (ptl)	Power-to-liquid
8	Power-to-liquid	
9	Electrolysis	Electrolysis
10	Electrolyzer	
11	Pem electrolysis	
12	Wind energy	Wind energy
13	Wind power	
14	Wind farm	
15	Wind turbine	
16	Wind power cooperatives	
17	Hybrid energy systems	Hybrid system
18	Hybrid renewable energy	
19	Hybrid pv-wind	
20	Solar energy	Solar energy
21	Pv park	
22	Methanol	Methanol
23	Methanol production	

Table 4.3 Top-10 most frequent authors' keywords

Author's keywords	Occurrences	% Occurrences	% Per article
Wind energy	9	11,4	39,1
Power-to-gas	8	10,1	34,8
Hydrogen	6	7,6	26,1
Electrolysis	5	6,3	21,7
Hybrid system	4	5,1	17,4
Solar energy	4	5,1	17,4
Energy storage	3	3,8	13,0
Power-to-liquid	3	3,8	13,0
Methanol	2	2,5	8,7
Offshore wind	2	2,5	8,7

on "hydrogen" and "electrolysis" solutions, while the remaining keywords started to be used from 2015 onwards. Thus, the keywords "power-to-gas", "hybrid system", "solar energy", "energy storage", power-to-liquid", and "methanol" are gaining relevance; moreover, since 2020, the frequency of these keywords has doubled, suggesting a growing interest in hybrid solutions for wind farms in academia. On the other hand, "offshore wind" keyword seems to start to be used from 2020 onwards, which could indicate a recent interest for the hybridization of offshore wind farms. These results are consistent with the first circular economy action plan adopted by the European Commission in 2015 and the introduction of the first climate action initiatives under the European Green Deal in 2020.

For keywords' co-occurrence analysis, the Louvain clustering algorithm and association normalization were used (Bretas and Alon 2021). Co-occurrence analysis allows keywords used together by the authors to be clustered, suggesting key topics

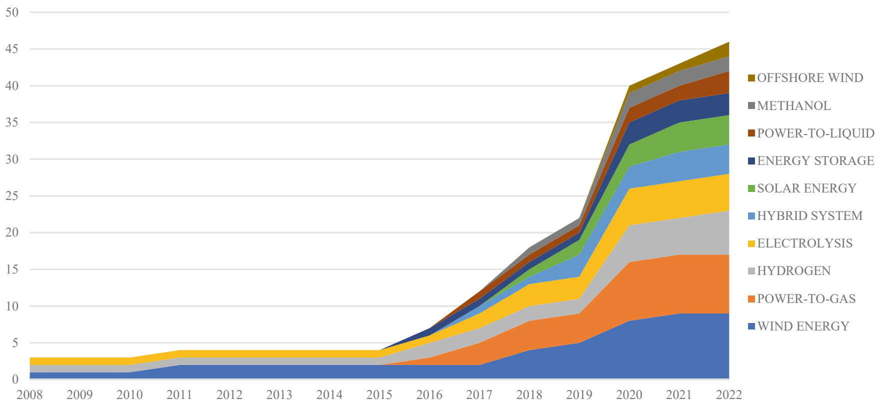

Fig. 4.2 Evolution of authors' keywords over time

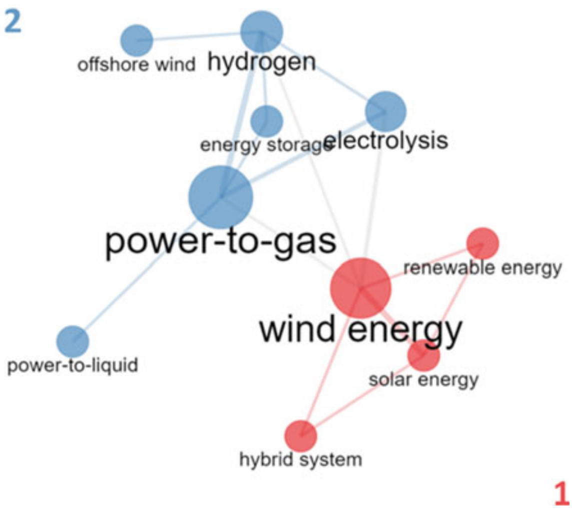

Fig. 4.3 Keyword co-occurrence analysis. Cluster 1 (red): wind and solar energy systems, Cluster 2 (blue): power-to-X solutions

within a research area (Aria et al. 2022). Figure 4.3 shows the keywords network indicating two main clusters: Cluster 1 (Wind and Solar Energy Systems) and Cluster 2 (Power-to-X solutions). Keywords are represented in nodes, where the size of the circle and text indicate the relevance of the Keyword in the network. The nodes are linked by ties, the thickness of the tie representing the closeness between keywords.

In cluster 1, "wind energy" is the most representative Keyword, having the closest link to "solar energy". Both keywords also bridge the keywords "hybrid systems" and "renewable energy". These results are consistent with the trend observed in the academic literature, where the concept of hybrid systems is often used to refer to the integration of PV in wind farms (Carvalho et al. 2019; Diemuodeke et al. 2019; Fasihi et al. 2017; Xu et al. 2021).

In cluster 2, the keywords "Power-to-Gas", "Hydrogen", and "Electrolysis" are the most representative of the cluster, being the links between "Power-to-Gas" and both "Hydrogen" and "Electrolysis" are the closest ones. Moreover, these three keywords link the blue cluster to the red cluster by linking to the keyword "wind energy". Therefore, cluster 2 seems to be related to the so-called Power-to-X technologies, which extend the value chain of wind farms by converting renewable energy into gaseous or liquid energy carriers. In line with the results, hydrogen is obtained via water electrolysis at the core of Power-to-Gas technologies (Lux and Pfluger 2020). Hydrogen can be further synthesized into liquid energy carriers such as methanol (González-Aparicio et al. 2018), usually known as Power-to-Liquid (linked to Power-to-Gas in the network). "Energy storage", linked in the network with both "Hydrogen" and "Power-to-Gas", may stress the potential of Power-to-Hydrogen solutions to facilitate the storage and transport of intermittent energy sources such as wind and solar (Balan et al. 2016). Finally, the tie between offshore wind and hydrogen could represent a research stream in the field of Power-to-Hydrogen solutions in the marine domain (McDonagh et al. 2020).

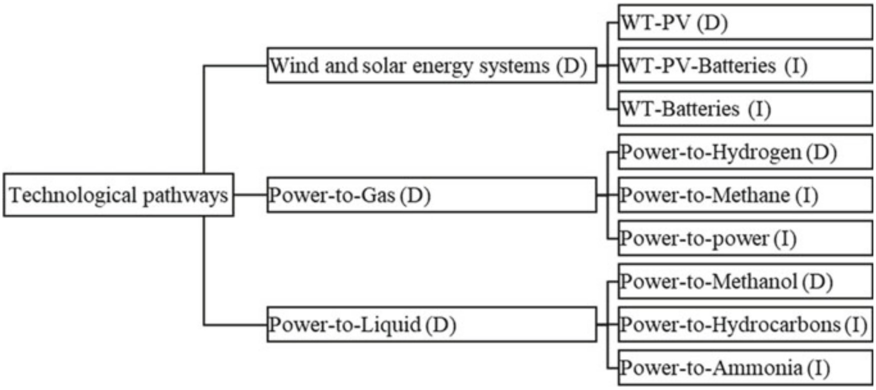

Fig. 4.4 Technological pathways and BM solutions in HWF. *WT* wind turbine, *PV* photovoltaics, *D* deductive, *I* inductive

Figure 4.4 presents the three technological pathways and two BM solutions for HWF deductively derived from the bibliometric analyses (indicated by a D in the figure). These preliminary categories were validated by further reviewing the academic and grey literature. Moreover, six new BM solutions were inductively identified, two for each technological pathway (indicated by a I in the figure). Therefore, the final framework consists of three technological pathways and nine BM solutions (three for each pathway) for HWF.

The simplest form of HWF (Wind and Solar Energy Systems, Fig. 4.2) is the integration of photovoltaics (PV) and/or batteries at the wind farm site. PVs produce more electricity during daytime/summer, while WTs produce more electricity during night-time/winter (Buonomano et al. 2018). Thus, the daily and seasonal complementarity of the two technologies can reduce intermittency impacts and produce power constantly (Carvalho et al. 2019). By adding batteries to WT or WT-PV solutions, energy can be stored and shifted to another time of the day or year, adding flexibility and efficiency to the energy system, improving the balance between energy demand and production and increasing asset revenues (Buonomano et al. 2018).

In Power-to-Gas technological pathway, renewable energy is used to power an electrolyzer and produce green hydrogen (Power-to-Hydrogen). Hydrogen can be stored, traded (e.g., industrial or transport sector) or converted into methane (Power-to-Methane) through CO_2 capture and a methanation process (Balan et al. 2016). Moreover, the stored hydrogen can be reconverted into electricity (Power-to-Power) using fuel cells (Scolaro and Kittner 2022) and gas turbines (Fasihi et al. 2017). Power-to-gas are potential solutions for long-term energy storage and transportation (Dieterich et al. 2020). The sale of hydrogen and methane allows market diversification of wind farms to sectors such as mobility, industry (e.g., chemical, fertilizer production), or heating (Balan et al. 2016; Schnuelle et al. 2020a, b).

In Power-to-Liquid technological pathway, hydrogen can be synthesized into liquid energy carriers such as methanol (Power-to-Methanol) and Fischer–Tropsch-fuels (e.g., diesel, kerosene and olefins) (Power-to-FT fuels). Two additional processes are required: gas-to-liquid synthesis (based on CO_2 capture) and product upgrading (Dieterich et al. 2020). Power-to-Liquid is a promising pathway to substitute fossil-based fuels in the chemical industry and hard-to-electrify sectors, e.g., aviation, shipping, and heavy transportation (Fasihi et al., 2017). Hydrogen can also be converted into ammonia as a feedstock in industrial processes (Power-to-Ammonia).

For a more detailed description of the technological pathways and BM solutions in HWF presented in this paper, see Mendoza and Ibarra (2022).

4.3.2 Deductive Content Analysis of CE Strategies

Of the 33 keywords defined to analyze the textual content of the 23 academic articles and 45 grey documents (i.e., company websites, industrial reports and business cases), a total of 13 CE strategies (39,4%) were recorded (Table 4.4).

Table 4.4 CE strategies reported in academic and grey literature

Category/Sub-category	Keywords defined	Academic literature	Grey literature	% Academic literature	% Grey literature
CIRCULAR ECONOMY	circular economy	0	2	0,0%	4,4%
	circularity	0	3	0,0%	6,7%
RECIRCULATE	recirculat*	0	1	0,0%	2,2%
- Upgrade	upgrad*	6	11	26,1%	24,4%
- Repair & maintenance	repair*	1	1	4,3%	2,2%
	reparation	0	0	0,0%	0,0%
	maintenance	14	13	60,9%	28,9%
- Reuse	reus*	1	4	4,3%	8,9%
- Refurbish & retrofit	refurbish*	1	2	4,3%	4,4%
	retrofit*	1	7	4,3%	15,6%
- Remanufacture	remanufactur*	0	0	0,0%	0,0%
- Repurpose	repurpos*	0	7	0,0%	15,6%
- Recycle	recycl*	0	4	0,0%	8,9%
- Cascade	cascad*	0	0	0,0%	0,0%
- Recover	recover*	4	9	17,4%	20,0%
REINVENT	reinvent*	0	0	0,0%	0,0%
RETHINK AND RECONFIGURE	rethink*	1	0	4,3%	0,0%
	reconfigur*	0	0	0,0%	0,0%
- Multi-flow offering	"multi-flow"	0	0	0,0%	0,0%
- Long life products	"long life"	0	0	0,0%	0,0%
- Access or availability	Sharing	0	0	0,0%	0,0%
	"product share"	0	0	0,0%	0,0%
RESTORE, REDUCE & AVOID	restor*	0	1	0,0%	2,2%
- Raw & materials sourcing	"restorative sourcing"	0	0	0,0%	0,0%
	"secondary sources"	0	0	0,0%	0,0%
	"secondary materials"	0	0	0,0%	0,0%
- Manufacturing	rework*	0	0	0,0%	0,0%
	cascad*	0	0	0,0%	0,0%
	recycl*	5	3	21,7%	6,7%
	"lean manufacturing"	0	0	0,0%	0,0%
	"cleaner production"	0	1	0,0%	2,2%
- Product use & operation	"product longevity"	0	0	0,0%	0,0%
	Longevity	0	0	0,0%	0,0%

The percentages have been calculated based on the total number of publications in the academic and grey literature (23 and 45 documents, respectively)

The most frequently addressed CE strategies in the HWF correspond to the RECIRCULATE category. Extending the existing use cycle of parts and products through *maintenance* and *upgrading* strategies and end-of-life material *recovery* represent 60,9%, 26,1% and 17,4% of academic literature and 28,9%, 24,4% and 20% of grey literature, respectively. In addition, the grey literature also emphasizes the extension of parts and products to new use cycles through *retrofitting* (15,6%) and *repurposing* (15,6%).

The second category that encompasses the most referenced CE strategies is RESTORE, REDUCE and AVOID; being *recycling* of materials (e.g., CO_2 or water) during the production processes of Power-to-Gas, and Power-to-Liquid solutions is the most relevant approach (21,7% of the academic literature and 6,7% of the grey literature). Additionally, one industrial report refers to the generic term *restore* (2,2%), highlighting the use of grid converters and batteries in offshore wind farms to reduce the restoration time of power plants and potentially avoid blackouts. Another report mentions a *clean production* strategy (2,2%) to refer to power-to-gas solutions, which involve cleaner production methods for hydrogen generation.

The following most used keywords fall under the general category of CIRCULAR ECONOMY. Interestingly, only the grey literature refers to a *circular economy* (4,4% of the documents) and *circularity* (6,7% of the documents).

The categories REINVENT and RETHINK AND RECONFIGURE are barely addressed. There were no results for the search of "reinvent", while in the RETHINK AND RECONFIGURE category, none of the keywords was found, except for the generic term "rethink", which appears only once in the academic article referring to the hybridization of wind farms to integrate Power-to-Gas solutions (Rasmussen et al. 2020).

4.3.3 Cross-Analysis of the Results

The cross-analysis analysis of the results allowed us to explore the relationship between the technological pathways and the CE strategies as summarised in Fig. 4.5. In terms of recirculating products, parts and materials, five CE strategies appear to cut across all technology pathways: Upgrade, Repair and Maintenance, Repurpose, Recycling and Recover.

As HWF is based on integrating new assets and technologies in new or existing plants, all BM solutions require infrastructure, equipment, and grid connection upgrades (Papadopoulos et al. 2018; Rasmussen et al. 2020). Similarly, these new BMs require skills and training to repurpose the workforce (GWEC 2022).

Maintenance of installations and equipment is also a key activity in all BM solutions. One of the challenges related to this CE strategy is optimising maintenance costs, as the new assets needed for converting energy into gas and liquids entail higher maintenance costs (Balan et al. 2016). In response, digitalization and artificial intelligence can help reduce costs through predictive maintenance, which allows optimization of the detection of possible failures before they occur (GWEC 2022). In

	Technologycal pathways	WSES			Power-to-Gas			Power-to-Liquid		
		WT-PV	WT-PV-Battery	WT-Battery	Power-to-Hydrogen	Power-to-Methane	Power-to-power	Power-to-Methanol	Power-to-FT fuels	Power-to-Ammonia
RECIRCULATE parts & products	Upgrade	Infrastructure & equipment upgrades. Grid upgrades								
					Product upgrading					
	Repair & maintenance	Facilities & equipment maintenance								
	Reuse							Reuse of chemicals		
	Refurbish				Plant refurbishment. Retrofitting pipelines					
	Repurpose	Skills and training repurpose. Repurposing wind blades. Repurposing grids.								
					Repurpose of infrastructure and pipelines					
RECIRCULATE materials	Recycle	Wind blades recycling								
	Recover	Recovery of composite materials								
			Energy recovery		Heat and CO_2 recovery					
RESTORE, REDUCE, AVOID	Clean production				Replacement of fossil fuel-powered processes with clean production methods to create clean gas and fuels					
	Recycling (pre-user)				Recycling of CO_2 and water					
RETHINK & RECONFIGURE	Multi-offering	New value propositions and revenue streams (ancillary services, electricity, gas and fuels)								

Fig. 4.5 Framework of technological pathways, BM solutions and CE strategies for HFW

offshore farms, applying remote sensing, robotic inspection and repair methods could increase the availability of wind turbines and reduce risk and human interventions (Fraile et al. 2021).

Moreover, recycling wind blades and the recovery of composite material used in their production (glass or carbon fibres and a polymer matrix) is another major challenge for the circularity of wind energy and, consequently, HWF. Approximately 90% of wind turbine materials and components can be commercially recycled (GWEC 2022). Advancing recycling technologies for composite materials (the remaining 10%) would further reduce wind technology's ecological footprint and the sector's dependence on critical raw materials. They would promote new business opportunities, such as secondary materials markets (Fraile et al. 2021).

Focusing on the Wind and Solar Energy Systems pathway, in WT-battery and WT-PV-Battery solutions, energy recovery is the main CE strategy, as batteries allow the storage of energy that would otherwise be lost (Malakar et al. 2014).

Power-to-Gas solutions require refurbishment and retrofit of existing gas pipelines and infrastructures for hydrogen and methane injection (Balan et al. 2016). Compatibility with repurposed pipelines and existing sites is already facilitating the establishment of green hydrogen as a mainstream energy source (Gamesa 2021).

In both, Power-to-Gas and Power-to-Liquid, various CE strategies such as the reuse of chemicals (Bos et al. 2020), heat (Balan et al. 2016) and CO_2 recovery (Wassermann et al. 2022) and CO_2 and water recycling (Bos et al. 2020; Fasihi et al. 2017) can lead to the optimization and efficiency of hybrid plants. For instance, since the production of methane or methanol requires CO_2 capture, locating hybrid plants close to high CO_2 emitters (e.g., power plants, cement or steel industries, and refineries) can facilitate recovering CO_2 while generating environmental benefits (Balan et al. 2016). Furthermore, the heat output from conversion processes, such as electrolysis and methanation, can be recovered and used in subsequent processes (e.g., Capture of CO_2). In addition, surplus water from methane or methanol could be recycled and reused in the electrolysis process electrolyzer (Bos et al. 2020; Fasihi et al. 2017).

Finally, the nine BM solutions represent circular business model strategies (multi-flow offering typology) since they involve new value creation, delivery, and capture (Blomsma et al. 2019). By adding new assets and technologies, they extend the life of wind farms by creating multiple energy products (electricity, ancillary services, hydrogen, methane, methanol, fuels, etc.), which in turn generate new revenue streams for wind farm owners.

4.4 Conclusions

This chapter provides an overview of all the potential technological pathways, business model solutions and circular economy strategies for the hybridization of wind farms based on a systematic literature review combined with a bibliometric analysis and content analysis of 23 academic articles and 45 grey papers.

The results of the bibliometric analysis showed a growing interest in the academic field in technological approaches to HFW, specifically in Wind and Solar hybrid systems, Power-to-Gas and Power-to-Hydrogen, Hydrogen storage and Power-to-liquid solutions, such as Power-to-Methanol. The detailed analysis of technological pathways and BM solutions resulted in 3 pathways (wind and solar energy systems, Power-to-Gas and Power-to Liquid) and 9 BM solutions (3 for each technological pathway) that support the technical and economic optimization and efficiency of wind energy systems, and the decarbonization of high energy- and carbon-intensive sectors (e.g., heavy transportation, aviation, steel, cement, plastic or chemical industry).

The quantitative content analysis on CE strategies addressed in both academic and grey literature shows that the main circular approaches adopted in HFW relate to extending the existing use of hybrid plants through recirculating strategies such as maintenance, upgrading, retrofitting, repurposing and material recovery. However, there is a gap in research and practice on strategies to reinvent, rethink and reconfigure current business strategies and business models for HWF. Moreover, only a few industry reports address concepts relating to a circular economy with HWF. Thus, more research is needed to understand what circular business model typologies can contribute to hybrid energy systems' economic viability and sustainability.

The cross-analysis of BM solutions and CE strategies for HWF resulted in a conceptual framework that serves as a professional guide and a basis for future research. The framework suggests that recirculate strategies (Upgrade, Repair and Maintenance, Repurpose, Recycling, and Recover) span all BM solutions. At the same time, Power-to-Gas and Power-to-Liquid pathways promote recycling and material recovery of heat, water and $CO_{2,}$ leading to the optimization and efficiency of hybrid plants.

The nine BM solutions represent potential BMs aiming to extend the life of wind farms by increasing the efficiency of their assets, diversifying their value propositions, and creating new revenue streams. However, the identified CE strategies should be complemented with appropriate approaches for cost-effective decommissioning, disassembly and recovery of components and materials at the end-of-life of hybrid plants.

In addition, further research should address the impact of digitalization and related technological developments such as artificial intelligence or robotics on HWF since they can bring new opportunities to increase the efficiency of hybrid plants and create new business opportunities (e.g., servitization capabilities and product-service system BMs).

Finally, progress towards circularity solutions for the HWF will require public–private partnerships (aligning innovation programmes with industry investments) and cross-sectoral collaborations to address common challenges such as composite material recycling (GWEC 2022). To make Power-to-Gas and -Liquid BMs economically viable, further technological development and reduction of investment costs are still needed regarding electrolyzer efficiency, "low carbon" CO_2 procurement and synthetic fuels production.

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Chapter 5
Circular Economy to Decarbonize Electricity

Fayaz Ahmad Malla, Tuan Dung, Suhaib A. Bandh, Afaan Ahmad Malla, and Shahid A. Wani

Abstract The term "circular economy" is being used more and more frequently within industries. In a circular economy, the value of products and materials is maintained for as long as possible. Resource usage and waste are minimized and when a product reaches the end of its life, it is reused to create the next value. Conservation and enhancement of natural capital, optimizing resource productivity and optimizing system-wide efficiency are some of the main principles of circular economy (CE). The Hannover Principles listed the following concepts/rules of the circular economy, which include: Use products as a service, sharing the platform, extended service life and extended lifecycle. Circular economy concept brings multiple benefits to industries and society. In traditional linear economy, producers exploit natural resources to make, produce or create products and services, which are then dumped from the production and consumption line. Circular economy manufacturers focus on extending life and making the most of the value of resources, then managing and recreating these products and resources at the end of their useful life. The prevailing economic model in construction sector in developing countries is linear which use

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raw materials to manufacture components that are subsequently used and ultimately end as waste at the end of their lifecycle. The demand for raw materials is predicted to double by 2050. It is therefore necessary to transition from a linear economy to a circular economy.

Keywords Decarbonisation · Linear economy · Circular economy · Wastes · Energy

5.1 Circular Economy (CE)

The “linear” economy, or the so-called “take-make-waste” approach of production and consumption as we used to observe it around us every day is linear economy. In the linear economic system, all the products we need are produced, used, and commonly disposed of, contributing to material resource depletion of the Earth and the accumulation of wastes (Haberl et al. 2019). The circular economy (CE) in contrast to the linear economy. CE is a systematic solution that tackles global challenges such as climate change, biodiversity loss, waste, and pollution and the definition is usually reduced to the 3Rs—Reduce—Reuse—Recycle. In fact, the concept is much more complex, presenting multiple ramifications that involve paradigm shifts in how manufacturing processes, technologies are designed with concerns to environments and sustainability.

5.1.1 Some Definitions of CE

The term “circular economy” is being used more and more frequently within industries as well as various other business sectors. In a circular economy, the value of products and materials is maintained for as long as possible. Resource usage and waste are minimized and when a product reaches the end of its life, it is reused to create the next value.

The EU has adopted a Circular Economy Action Plan (CEAP) in 2015, which is comprehensive, legislative and non-legislative actions aiming to transition the European economy from a linear to a circular model and to have huge economic benefits, contributing to innovation, growth and job creation EU (EC 2016). Ellen MacArthur Foundation (2013) defined the circular economy as based on designed principles that eliminate waste and pollution, keep products and materials in use, and regenerate natural systems.

China Circular Economy Law in China (FDI Gov China 2020) defined circular economy is a general term for activities of reducing, recycling and recovering resources in production.

Minimization means reducing resource consumption and waste generation in production, circulation and consumption. Recycling means the direct use of waste as a product, or the use of waste as a product after repair, rehabilitation or remanufacturing, or the use of all or part of the waste as part of other products. Resource recovery means direct use of waste as raw materials or recycling of waste.

5.1.2 Principles and Pillars of CE

Andrew Morlet (2015) listed three main principles of circular economy, which are:

(a) Conservation and enhancement of natural capital; (b) Optimizing resource productivity at the highest benefit at all times in both engineering and biological cycles; and (c) Drive system-wide efficiency by minimizing and designing to eliminate negative externalities.

The Hannover Principles listed the following concepts/rules of the circular economy:

(a) Insist on the right of humanity and nature to coexist in a healthy, supportive, diverse and sustainable condition.
(b) Recognize interdependence.
(c) Respect relationships between spirit and matter.
(d) Accept responsibility for the consequences of design decisions upon human well-being, the viability of natural systems and their right to co-exist.
(e) Create safe objects of long-term value.
(f) Eliminate the concept of waste.
(g) Rely on natural energy flows.
(h) Understand the limitations of design.
(i) Seek constant improvement by sharing knowledge.

Some pillars of CE include: Sustainable resources, use products as a service, sharing the platform, extended service life and new lifecycle.

How to implement CE or turning waste into resources and benefits of CE

In those above-mentioned principles of CE, materials can be recovered using the engineering cycle through different iterations: maintenance and repair, reuse and redistribution, refurbishment and remanufacturing, and finally recycling; a biologically derived resource goes a different way of recovery, which cycles back to the biological cycle after the end of its life cycle so that it can be reused as nutrients in the new cycle.

Circular economy concept brings multiple benefits to industries and society. In a traditional linear economy, producers exploit natural resources to make, produce or create products and services, which are then dumped from the production and consumption line, or buried, or even discharged into the environment. In contrast, the circular economy is a sustainable alternative to the aforementioned model. In a circular economy, manufacturers focus on extending life and making the most of the value of resources, then managing and recreating these products and resources at the end of their useful life. As such, the application of a circulating economic model will help reduce waste, emissions, promote the efficient use of resources, and contribute to solving scarcity of natural resources. On the other hand, circularity helps conserve, and support advanced competitiveness for the economy.

In particular, practices of the circular economy and regulations on each sector should be written and implemented. The transition to a CE, a resource-efficient and effective economy, requires the active engagement of all stakeholders such as societal and economic actors, including business, civic society, and political actors.

Moving towards a fully circular economy is a multi-step, complex processes that is mostly policy-driven but require multiple stakeholders' involvement. The government of Vietnam in principle through the Ministry of Natural resources and Environment and ISPONRE should implement laws on these new but multi-benefit areas in general.

In construction and urban development sectors, cities are resource consumption centers and significant producers of greenhouse gas emissions. The prevailing economic model in construction sector in developing countries is linear which use raw materials to manufacture components that are subsequently used and ultimately end as waste at the end of their lifecycle. The demand for raw materials is predicted to double by 2050. Urban communities are central to developing circular economy models. It is essential to analyze the urban structure as a whole.

A systematic review on the criteria and indicators (e.g., circularity, waste volumes) to evaluate and potentially monitor the implementation of circular economy in emerging economies and identify and align these indicators with the interest of nations and advise the CE experts accordingly. To guarantee that the future generations will have sufficient resources like food, water and prosperity, it is therefore necessary to transition from a linear economy to a circular economy (Halog 2021).

5.2 Circular Economy Boundaries

Proof of CE's capacity to meet human needs within planetary boundaries (PBs) is still needed. Circular economy is an umbrella concept that encapsulates and connects separate knowledge areas and experiences in terms of resource efficiency and reduced environmental impacts. Proof of CE's capacity to create the conditions required for meeting human needs within planetary boundaries (PBs) is still lacking.

PBs encompass nine key earth-system processes that define a safe operating space for humanity for maintaining the stability of the earth's life-supporting systems. Due to the extremely general and scientific evidence-based nature of the PB concept and the global and interactive nature of the boundaries, the PBs are not applied regionally and locally (Raufflet et al. 2021).

Vadoudi (2022) proposes a circular indicator adapted from the Material Circularity Indicator for the plastic industry. The circular economy is among the most efficient solutions to guarantee and achieve the sustainable development targets.

5.3 Renewable Energies (RE)

Renewable energies spans from wind, solar, geothermal to tide energy, etc. RE is the energy from a source that is not depleted when used, such as wind or solar power. How to enhance the electricity grid to absorb additional RE? Here are some suggestions for enhancing the electricity grid to absorb additional RE:

- One-stop service for RE
- Enhancing energy efficiency
- Promoting demand management
- Incorporating the Carbon Price such as more stringent Emissions Trading Scheme and increased electricity price
- Increasing in R&D to enhance the efficiency of RE including hydrogen.

5.4 Renewable Energy Trends in Coming Years

According to GECF (GECF…), the trend of growth of renewable energy will continue to grow, as pictured in Fig. 5.1.

5.4.1 Some International Experiences and Examples

Framework act on carbon neutrality and green growth of Korea

Korea has its national carbon neutrality master plan with a planning period of 20 years. The government will adopt “climate-responsive budgeting” and “climate change impact assessments” in major national plans, large-scale development projects, and

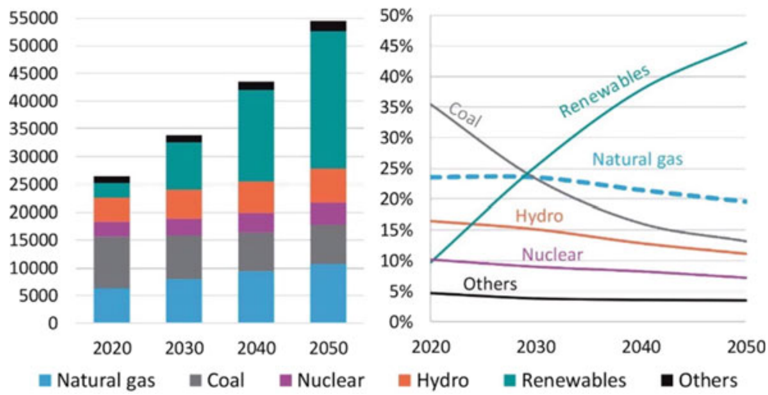

Fig. 5.1 Renewable development in recent and coming years (GECF 2021)

national finance to reduce greenhouse gas emissions. The Act sets the legal basis for GHG reduction policies of each ministry, such as carbon–neutral cities, green transport, and carbon sink expansion. The Act sets the legal basis for Article 6 carbon credit transactions. The South Korean government set up the Korean Climate Action Fund to effectively implement policies towards carbon neutrality and necessary reorganization of industrial structure.

Techno-Industrial transformation strategy—green new deal of Korea announced in 2020

- Solar and wind turbine capacity to 42.7 GW by 2025, up from 12.7 GW in 2019
- Install solar panels on 225,000 public buildings
- Rapidly roll out "smart grids" including "smart meters" in five million more apartments, to help consumers reduce their electricity use
- Invest heavily in the creation of microgrid communities in regional areas and on Korea's many islands. The vision is to create decentralized, low carbon energy systems
- 1.13 million electric vehicles (EVs) and 200,000 hydrogen-powered fuel-cell EVs
- Roll out 45,000 electric vehicle recharging stations (15,000 rapid and 30,000 standard) and 450 hydrogen refueling units
- Implement circular economy initiatives such as reducing and recycling energy using advanced computerized power grids in factories. The plan also involves technology to capture and store carbon emitted from industrial processes and re-using industrial materials.

5.4.2 Renewable Development in Vietnam

Vietnam is fortunate to have a vast potential for renewable energy development. In addition to solar, and onshore wind, Vietnam is endowed with some of the best offshore wind potential globally. The WB analysis shows that about 370 GW of renewable energy generation capacity could be added by 2040 to reduce reliance on fossil fuels. As Vietnam's recent experience shows, this can be achieved largely through private investment. To continue this growth in renewable energy would require improvements in the power system expansion planning and the procurement and regulatory framework to secure the least-cost renewable power sources.

Specifically, the current feed-in tariff policy, which contributed to a rapid growth of renewable energy development, should be replaced by a well-structured, planned and most importantly transparent competitive auction-based scheme to bring in the most efficient and lowest cost privately financed renewable energy projects to meet Vietnam's energy needs sustainably.

Viet Nam will stop building new coal-fired power plants from 2030 as part of its roadmap to realize commitments at the COP26. Viet Nam also aims to reduce the capacity of coal-fired power plants to 13.2% of the country's total power capacity by 2045 from the current 32%.

By the end of last year, the nation's total installed capacity of power plants reached over 78,120 MW, the highest among ASEAN Member States.

5.4.3 US and EU Proposals

US—Inflation Reduction Act set USD 370 billion dedicated to climate change in terms of investment; Reduce 40% of GHG emissions compared 2005 and create 1.5 million jobs, in terms of its impact. EU—Green Deal set EUR 1 trillion in 7 years in terms of investment in wind energy (Fig. 5.2).

With a rising focus on the effective integration of renewable energy, the importance of electric vehicles and reliable, resilient energy supply, energy storage is becoming an increasingly important tool in the electricity ecosystem.

- Energy storage is a critical hub for the entire grid, augmenting resources from wind, solar and hydro, to nuclear and fossil fuels, to demand side resources and system efficiency assets. It can act as a generation, transmission or distribution asset—sometimes in a single asset.
- Asia Pacific region is expected to account for 68% of the $10.84 billion global energy storage market in 2026 and Vietnam is heading in the race. Clime Capital Management is excited to provide critical capital at a key stage in the development of clean energy projects.

5.5 Renewable Energy in CE

One of the key pillars of CE is sustainable resources where renewable energy sources and biodegradable, recyclable or renewable materials are used. The use of renewable energy is a key aspect of producing and achieving circular products and resources. This include the way in which the components of renewable plants or factories are designed, manufactured, built and managed, as well as how their new life is handled.

Some products in renewable energies such as solar panels should be made from sustainable resources to extend its service life and recycled after its service life. In sustainable construction model, measures for integrating waste recycling or reuse of wastewater can be studied, while waste materials can be reused to create roads or embankments. In solar power of renewable energies sector, the electric vehicle batteries can be given a second chance by providing services to the grid or integrating them into storage plants (Enel 2022). In biomass sector, ethanol produced from agriculture by products or waste are also a good example of creating a new Lifecyle of agriculture products and how sustainable resources are used (Hoang and Nghiem 2021). Application of AI can help to obtain the CE targets in renewable energies sector (Hoang et al. 2022).

The circular economy has potential to generate competitiveness in conjunction with innovation and sustainability. In this model, the traditional approach to the

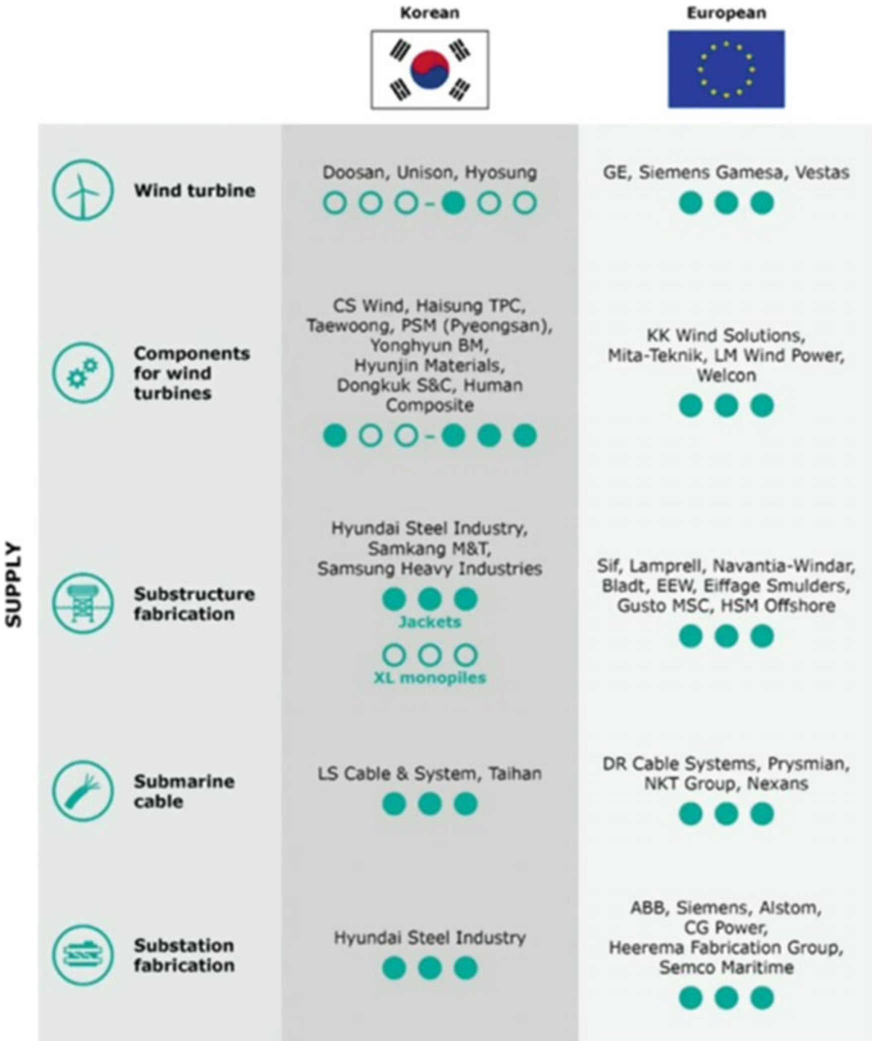

Fig. 5.2 Selected major suppliers for fabrication in the Korean offshore wind market

market, customers and natural resources will change. This allows companies to gain notable competitive advantages such as reduced costs, efficiently use of energy, decreased CO_2 emissions and optimized safer supply chains.

5.6 Decarbonisation of Electricity by Green Hydrogen

Achieving the Paris Agreement's decarbonization targets will depend heavily on the use of green hydrogen. Nearly everyone wants to do better for the planet, but keeping global warming below 2 °C by 2050 would be difficult without a diverse array of zero-carbon energy sources.

Intermittency—environmental, seasonal, and daily cycles that might restrict its usage or efficiency—has slowed the rapid expansion of renewable energy use. These renewable energy sources require a backup when the sun isn't shining and the wind isn't blowing in order to complete the last stretch of decarbonization.

Transportation, electricity generation, and industry are the three largest contributors to global warming in the United States. It's challenging to completely reduce emissions from certain sectors of the economy. Green hydrogen is the only carbon-free alternative that Plug Power believes can decarbonize the aviation, shipping, long-distance haulage, and concrete/steel production industries.

Hydrogen is readily available, and there appears to be no end in sight to the supply. Green hydrogen, which is produced by electrolyzing water to separate the hydrogen and oxygen, is a zero-emissions, "always on" energy source that potentially reverse the tide against resource depletion. Pipeline, over-the-road in cryogenic liquid tanker trucks, or over the road in gaseous tube trailers can get it from the place of production to wherever it's needed. Hydrogen can be created from excess renewable energy and stored in tanks in enormous volumes for longer periods of time, unlike batteries used for electric cars and stationary power, which are unable to store big quantities of electricity for extended periods of time.

Hydrogen has about three times as much energy per unit weight as fossil fuels, therefore less of it is required to have the same effect. Green hydrogen also has the benefit of being able to be created wherever there is water and power, allowing for the creation of other forms of energy such as electricity and heat. Electrolysis of water produces usable quantities of hydrogen (H_2) and oxygen (O_2), which may then be put to use.

For residential usage, green hydrogen may be stored in the same gas pipelines that are currently in place. When processed into a carrier like ammonia, which may be used as a zero-carbon fuel for transportation, it can also serve as a renewable energy source. Electric automobiles and other electronic gadgets may be powered by combining it with fuel cells. In addition, hydrogen fuel cells may be used indefinitely without being refilled or depleted, provided that a source of liquid hydrogen is nearby.

Green hydrogen is now available, despite the fact that its mainstream acceptance may not occur for another decade, according to some specialists in the field. Green hydrogen is used to power Walmart's forklifts in distribution and fulfilment centres, while Edison Motors' municipal bus fleets run on green hydrogen fuel cells. Toyota and other automakers have known for years about the advantages of hydrogen fuel. The Hydrogen Council predicts that hydrogen will make up 18% of the global energy market by 2050, and a recent McKinsey research predicted that the hydrogen economy in the United States could create $140 billion and sustain 700,000 jobs by 2030.

Although green hydrogen on its own won't solve global warming, it's essential to achieving complete economic decarbonization and solving the world's emissions crisis. Rather of relying solely on green hydrogen, Plug Power proposes integrating renewable energy sources including solar panels, wind turbines, battery storage, and hydrogen fuel cells into a single system. It is impossible to realise this future energy infrastructure without utilising green hydrogen.

Without renewable hydrogen, the decarbonization goals of the Paris Agreement cannot be met. Although most people desire to improve environmental conditions, doing so without a wide variety of zero-carbon energy sources might make it impossible to keep global warming below 2 °C by 2050.

Slowing the rapid increase of renewable energy consumption is intermittency, or environmental, seasonal, and daily cycles that may limit its utilisation or efficiency. To get through the last stages of decarbonization, these renewable energy sources need a backup when the sun isn't shining and the wind isn't blowing.

Emissions from transportation, electrical generation, and industry account for the bulk of America's contribution to climate change. Reducing emissions entirely from some economic areas may be difficult. Plug Power maintains that the only viable strategy for decarbonizing industries including aviation, shipping, long-distance transportation, and the manufacturing of concrete and steel is to transition to green hydrogen.

The availability of hydrogen is practically limitless, and it is also quite cheap. Electrolysis of water into its component hydrogen and oxygen atoms yields green hydrogen, a zero-emissions, "always on" energy source with the potential to turn the tide in the fight against resource depletion. From the site of production to its eventual destination, it can be transported via pipeline, over the road in cryogenic liquid tanker trucks, or over the road in gaseous tube trailers. While batteries used in electric vehicles and stationary power cannot store large amounts of electricity for lengthy periods of time, hydrogen may be produced from excess renewable energy and stored in tanks in massive quantities for longer periods of time.

Green hydrogen in the nation's gas pipelines may be used to power homes. As an ammonia-based renewable energy source, it has the potential to be used as a zero-carbon transportation fuel. Therefore, everything that needs energy, including electric automobiles and gadgets, may be powered by fuel cells. In addition, hydrogen fuel cells never run out of energy and don't need to be recharged so long as a supply of liquid hydrogen is readily available.

Green hydrogen cannot solve emissions concerns on its own, but it is necessary for decarbonizing the economy. Plug Power suggests that we build a sustainable energy infrastructure that combines solar panels, wind turbines, battery storage, and green hydrogen. Hydrogen fuel cells that run on green hydrogen are a key component of this planned energy network of the future.

5.7 Decarbonisation of Electricity by Solar on Grid Technology

There is a worldwide energy revolution happening right now. Solar power has seen an 80% drop in price while wind power has seen a 40% drop in price over the previous decade, making them competitive with traditional fuels like coal and natural gas in most global markets. The use of renewable energy sources is growing quickly, and in 2018, they accounted for the great majority of newly installed electrical generation capacity. To expand marginal capacity has become cheaper in most markets thanks to them. Even more importantly, renewables are an integral element of any country's plan to cut greenhouse gas emissions.

But you have no control over Mother Nature's whims. Wind and solar electricity cannot, therefore, offer continuous, 24/7 matching of supply to demand, in contrast to baseload producing facilities powered by coal, natural gas, or nuclear power. We have reached a point of crisis. Cost-effective and reliable electricity is a necessity for cities, states, and nations. Power plant carbon dioxide (CO_2) emission reduction targets have been set by a number of nations. It seems impossible to me that they could handle both tasks simultaneously.

Flexibility, or the ability to deal with the intermittent nature of no dispatchable power sources like wind and solar, is necessary for the successful integration of significant volumes of renewable electricity. Supply and demand can be balanced through a variety of possible approaches. In order to compensate for fluctuations in wind and solar power generation, for example, natural gas and coal plants may increase or reduce output. Using transmission lines, it is possible to standardize output across geographic areas. "Demand side management" programmes aim to reduce consumption by offering financial incentives to customers. As a generator during discharge and a consumer during charge, battery storage might make two types of contributions to the power system. There are solutions like these out there, and their efficacy has been well-documented. Still, few utilities or governments have developed a comprehensive, quantified strategy for decarbonizing the electrical sector.

There is nothing like the current market environment in terms of dynamism. In spite of this, there are commonalities amongst many decarbonization strategies. Decarbonization strategies will depend critically on the capacity to manage the intermittent nature of renewable energy sources like wind and solar. Using integrated bulk-generation, transmission and distribution, and direct consumer offers, this article presents a high-level overview of the technologies and expected costs for achieving full decarbonization of power networks by 2040. Next, we examine the future of four diverse industries. At last, we speculate on how potential changes in technology could affect these paths in the future.

Decarbonization rate of 50–60% is not only theoretically possible, but also the most cost-effective option in many scenarios. After that point, 90% decarbonization is theoretically conceivable but may require extra costs depending on the specifics of the situation. Additionally, both technically and monetarily, providing comprehensive coverage will be difficult.

A decarbonization rate of between 50 and 60% is achievable in most markets with minimal to no out-of-pocket expense beyond what would be expected from purely prudent economic activity. Due to the rapidly decreasing cost of solar, wind, and storage technologies—all of which are essential to any deep-decarbonization scenario—decarbonizing is typically the least priced solution.

Four- to eight-hour intervals of storage are about in sync with the sun's daily cycle. Unlike wind-plus-storage, which cannot provide a constant supply of power owing to wind's unpredictability, "solar-plus-storage" may release the energy it has stored at night. Since the wind usually picks up at night and in the winter, when the sun isn't as powerful, wind and solar power make a great pair. Markets that have access to both solar and wind resources are better able to handle intermittency as a result.

If we are able to decarbonize the energy industry to this degree, it is unlikely that the power grid's efficiency would suffer much. We estimate that 2–5% of the produced power will be lost as a result of curtailment. Individual fossil fuel plant utilisation rates (the proportion of time a plant provides power) also wouldn't deviate very much from their existing levels of approximately 50–60%. Some of these assets, however, would be abandoned when more affordable renewable energy sources entered the market. Almost no additional transmission would be required. Achieving a decarbonization rate of 50–60% would not call for significant changes to the power system, to sum up.

Reducing carbon emissions by 80–90% will be more challenging, expensive, and reliant on market-specific policies. It is possible that increasing storage utilization over longer time periods and tighter demand management will be required, but no unique technologies are required. This might entail redistributing industrial loads or actively controlling HVAC systems in buildings. Sharing baseload resources and consolidating renewable energy supply across a greater region may need additional transmission links in some markets.

At this point in the process of decarbonization, the system's appearance would undergo a radical transformation. We anticipate a curtailment of 7–10% due to the abundance of renewable power output to meet demand during periods of lower production. The utilization of fossil fuel facilities has declined from 65 to 20% as a result of the proliferation of renewable energy sources, however many are kept online as a backup in case renewables are insufficient.

Decarbonization costs are most unpredictable between the 80–90% range. In places where power is more expensive than usual, total system costs might drop by one to two percent per year. There's a chance expansion will happen in cheaper areas.

The path toward total decarbonization is already convoluted, and the cheapest options are subject to alter as the market evolves. Most regions will have to rely on more advanced technology to satisfy energy demands when wind and solar power output are low. While technically feasible, the extra 25% in cost might make it less attractive than other options. The most crucial action toward decarbonizing the power sector is filling up the gaps over the long run. As a result, decarbonizing the remaining 10% of a power infrastructure may be prohibitively costly.

Here are some examples of current technology that might bridge the gap and enable the construction of a fully decarbonized power grid on the global market:

Biofuels. In terms of greenhouse gas emissions, biofuels such as landfill gas and biomethane are completely carbon neutral. However, due to their high price and restricted availability, they are typically only effective when used in addition to other measures.

Carbon dioxide emissions sequestration (CCUS). CCS refers to the process of capturing, using, and storing carbon dioxide (CO_2) from the burning of fossil fuels (CCUS). It has been proven that CCUS is a cost-effective option. Technological progress and scale economies can both contribute to a decrease in cost. Further, CCUS has a finite capacity for carbon capture, thus other technologies will be needed for full decarbonization. CCUS is most likely to be effective in highly interconnected markets where land is scarce for renewables, clean power is valuable across a greater region, and CCUS facilities can be run at or near full utilisation.

Capturing and storing carbon dioxide emissions from the burning of biofuels (BECCS). The BECCS method is based on the burning of carbon–neutral biomass, such as wood pellets and agricultural waste, while collecting or storing the resulting CO_2 emissions. In sum, this results in "negative emissions," in which greenhouse gases are actually removed from the atmosphere. Potential for increasing biomass usage is obscure, and the technology supporting it is in its infancy. Repurposing idled coal power stations into BECCS facilities allows them to take advantage of existing connections while reducing upfront investment costs.

Conversion of natural gas to electricity and back to natural gas (P2G2P). P2G2P technology allows for the storage of excess electricity in the form of hydrogen, which can subsequently be utilised to fuel power plants at peak demand. We can produce "clean gas" that can be stored for several weeks or months using P2G2P technology. It's pricey and ineffective, though. Ten megawatt-hours of generated power only yield around three megawatt-hours of usable power after being converted back to electricity for usage. The flexibility of P2G2P technology, however, may substantially facilitate the adoption of intermittent renewables if there is demand for clean gas in sectors other than the power sector.

Inhaling and exhaling normally (DAC). DAC is capable of capturing carbon dioxide from the atmosphere. Here we have another another negative-emissions technology that might one day replace the electricity sector's residual reliance on carbon-intensive sources. While it is possible and has been demonstrated that CO_2 may be captured, isolated, and sequestered, doing so requires vast amounts of energy. However, there is a steep price to pay for this action. Based on our findings, this strategy is not practical for attaining full decarbonization.

Complete decarbonization in the electrical sector will necessitate a large reduction in fossil-fuel plant utilisation (to roughly 4–6%) compared to the scenario for 80–90% decarbonization. In addition, biofuels, P2G2P technology, or the discovery of novel offsets would likely be required to “net” the carbon emissions of each market. Just as much chopping would go place, approximately.

There will need to be a variety of strategies for decarbonizing power systems across markets because of climate, natural resource, and infrastructure differences (exhibit). Our investigation has led us to identify four separate markets. These markets were chosen to illustrate a range of global features, such as initial carbon intensity, transmission capacity, the quality of clean resources (including both intermittent solar and wind energy and dispatchable hydro and nuclear energy), and the potential for the distributed network to provide flexibility.

5.8 Carbon Foot Prints, Circular Economy and Smart Cities

CE is a regenerative system in which energy and material loops are slowed, closed, and narrowed to reduce resource input and waste, emission, and energy leakage. Longevity in design, maintenance, repairs, reuse, remanufacturing, refurbishment, and recycling are all viable options for reaching this goal. Contrast this with the linear economy (LE). The “Lean Green” (LG) concept is applicable here since it provides a framework for quantifying the environmental advantages of these. Its goal is to bring about the alterations that will cut down on consumption of raw materials, power, water, and other essentials, as well as create resource-saving buildings and implement cutting-edge machinery. Businesses in today’s fast-paced, cutthroat market under intense pressure to embrace sustainable practises that strike a good balance between their financial, environmental, and social impacts. The LG manufacturing method has become well-liked (Abualfaraa et al. 2020) because to its integration of lean techniques centred on satisfying customer needs with green practises aimed at lessening the negative effect of the company’s operations on the environment. Research studies generally agree that LG and CE may complement one another very well in the industrial industry. The key to efficient results may be found in the common goal of minimising inefficiencies and maximising value. As a result, it makes sense to put them together (Bhattacharya et al. 2019; Silva et al. 2019; Nadeem et al. 2019). In order to accomplish the SDGs, it will be necessary to optimise the use of primary resources in order to prevent or decrease waste and encourage re-use, which is exactly what the CE and the green economy propose to do. They advocate for more than just waste management, however, and instead incorporate the concept of resource loop closure whenever possible. The primary goal is to lessen the amount of garbage sent to landfills and incinerators, hence reducing the loss of resources that could be recycled back into the economy. To encourage ecologically responsible actions, society as a whole will need to shift its perspective.

Reducing environmental consequences such as greenhouse gas emissions and deforestation may be accomplished by reusing and recycling things rather than producing new ones from scratch. Fourteen percent of world emissions come from

EU member states, the USA, Japan, Argentina, and the other Shift nations combined (Teixeira et al. 2021).

Cities play a crucial role in circular economies since they are the primary sites of product consumption and utilisation. Consequently, the role of municipalities in fostering the development of circular, intelligent economies lies largely in the forms of regulation and promotion of consumption. For instance, consider the topic of food. Although urban areas may not have much influence on rural issues such as the renewal of soils and the expansion of agricultural biodiversity, they do play a crucial role in the consumption and, unfortunately, waste of the vast majority of the world's food supply. This is both a massive challenge and a massive opportunity. This trash has to be reduced and redistributed so that cities may become more appealing places to live while also improving environmental health and creating jobs.

Much of the innovation required to restructure our economy will naturally live in, and can be promoted in, cities since they are centres of creativity. When it comes to environmental pollution and health, access to outdoors, and the negative consequences of climate change, cities bear a disproportionate share of the cost. The Ellen MacArthur Foundation predicts that "two-thirds of us" will reside in cities by the year 2050. Our metropolitan centres, which account for only 2% of the Earth's surface area, are responsible for 75% of the world's resource consumption, 50% of its solid waste production, and 60% of its greenhouse gas emissions, all of which contribute to pollution, climate change, and biodiversity loss.

To execute a vision for circularity, promote circular thinking, manage urban space, purchase goods and services that are consistent with the circular economy, and influence markets and habits through legislation, cities are in a prime position to engage with a wide range of stakeholders. To ensure that this new economic system benefits not just our common environment and economy, but also individuals, families, and citizens, it is crucial to promote a civic culture of innovation and experimentation, to align various interests and stakeholders, and to involve inhabitants on deep levels. When viewed as a chance to strategically grow an economy, this economic shift doesn't have to be traumatic for communities. Jobs can be made, residents' quality of life can be enhanced, the economy can become more competitive and attractive, and innovation can be fueled if circular economies are established.

5.9 Conclusion

Circular economy concept brings multiple benefits to industries and society. In traditional linear economy, producers exploit natural resources to make, produce or create products and services. Circular economy manufacturers focus on extending life and making the most of the value of resources before managing and recreating them. The prevailing economic model in construction sector in developing countries is linear which use raw materials to manufacture components that are subsequently used and ultimately end as waste.

Circular economy is an umbrella concept that encapsulates and connects separate knowledge areas and experiences in terms of resource efficiency and reduced environmental impacts. Renewable energies spans from wind, solar, geothermal to tide energy, etc. How to enhance the electricity grid to absorb additional RE? Suggestions include enhancing energy efficiency, demand management, increased electricity price and more stringent Emissions Trading Scheme (ETS) pricing. Vietnam is fortunate to have a vast potential for renewable energy development.

About 370 GW of renewable energy generation capacity could be added by 2040. This can be achieved largely through private investment, writes World Bank's (WB) Vietnam Project Director, Nguyen Phu Trong. Energy storage is a critical hub for the entire grid, augmenting resources from wind, solar and hydro, to nuclear and fossil fuels. Asia Pacific is expected to account for 68% of the $10.84 billion global energy storage market in 2026. Clime Capital Management is excited to provide critical capital at a key stage in the development of clean energy projects.

Keeping global warming below 2 °C by 2050 would be difficult without a diverse array of zero-carbon energy sources. Green hydrogen is the only carbon-free alternative that Plug Power believes can decarbonize the aviation, shipping, long-distance haulage, and concrete/steel production industries. Green hydrogen is now available, but mainstream adoption may not occur for another decade. Hydrogen Council predicts hydrogen will make up 18% of the global energy market by 2050. Plug Power proposes integrating solar panels, wind turbines, battery storage, and hydrogen fuel cells into a single system.

Hydrogen is a renewable energy source with the potential to turn the tide in the fight against resource depletion. Hydrogen fuel cells never run out of energy and don't need to be recharged so long as a supply of liquid hydrogen is readily available, according to Plug Power. Decarbonization strategies will depend critically on the capacity to manage the intermittent nature of renewable energy sources like wind and solar. This article presents a high-level overview of the technologies and expected costs for achieving full decarbonization of power networks by 2040. It examines integrated bulk-generation, transmission, distribution, and direct consumer offers.

"Solar-plus-storage" may release energy it has stored at night. Since the wind usually picks up at night and in the winter, wind and solar power make a great pair. It is possible that increasing storage utilization over longer time periods will be required. Decarbonizing the remaining 10% of a power infrastructure may be prohibitively costly. Here are some examples of technologies that might bridge the gap and enable the construction of a fully decarbonized power grid on the global market (BECCS, CCUS, P2G2P).

The "Lean Green" concept is applicable here since it provides a framework for quantifying environmental advantages. In order to accomplish the SDGs, it will be necessary to optimise the use of primary resources in order to prevent or decrease waste and encourage re-use. The CE and the green economy advocate for more than just waste management but incorporate the concept of resource loop closure whenever possible.

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Chapter 6
Circular Economy in Materials to Decarbonize Mobility

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Abstract Numerous countries have adopted the circular economy concept in their industrial and commercial sectors in order to reduce waste generation. Economic and social development on a sustainable basis requires a focus on material selection during product design and continuous integration of innovation and technology throughout the product's lifecycle. Speaking of our case study, Thailand has shifted its economic and social development model to one that is based on the country's biodiversity and natural resources. Utilizing current technology and innovation will aid in dismantling barriers and propelling forward in order to generate sustainable economic growth. By implementing the Bio-Economy, Circular Economy, Circular Green Economy, And Green Economy (BCG) economic model and achieving zero waste, we can ensure that everyone has a say in how money, opportunity, and wealth are distributed. We can also maintain a balanced resource base and biodiversity by utilizing an integrated circular economy model. This chapter focuses on the circular economy and green economy in an integrated form, in accordance with the United Nations Sustainable Development Goals for sustainable development and the Sufficiency Economy Philosophy's principles of economic development. Thailand's government and society seek to mainstream the circular economy. This report is an integration case study in which, from start to finish, waste, scrap, garbage, and repurposed resources are comprised by leveraging scientific knowledge, technological improvement, and innovation to create added value. Scholars can use a

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wide range of resources to help solve environmental problems in a different way that can also be good for the economy. This report is an integration case study from start to finish, waste, scrap, garbage, and recycled materials comprised by leveraging scientific knowledge, technological advancement, and innovation to create added value.

Keywords Mobility · Decarbonize · Green economy · Sustainable development

6.1 Introduction

The world's population growth is unabated, as is economic growth. As a result, the world's population continues to grow, necessitating the use of natural resources to manufacture consumer goods. Consumption demand increases proportionately. However, due to the natural resources that are primarily utilized, this is a finite resource that is rapidly depleting, both in production and consumption, resulting in significant waste or garbage. Globally, business organizations are aware of the situation and issues at hand and understand the critical nature of utilizing available resources in the most cost-effective and efficient manner possible. Additionally, the waste generated by a portion of consumer waste can still be recycled. As a result, the world's ecosystems continue to degrade. The efficiency with which basic resources such as biomass, metal, non-metal, and fossil energy are used remains low in Thailand's economic development. Numerous resources, including low productivity, soil, water, degradation, and quality degradation, are impacted by waste management efficiency. The social cost of addressing pollution and its consequences continue to rise, and there are few innovations and technologies to support the transition to a circular economy or existing technology (e.g., environmental insights, material flow analysis, life cycle assessment, and indicators of energy efficiency). Attitude and behavioral changes on the part of producers and consumers recognize that garbage or waste is still a renewable resource if it is separated, stored, rotated, and used properly. The benefits include increasing manufacturers' and consumers' acceptance of circular economy-related products. It will contribute to the development of a circular economy and the reduction of market volatility. Thailand has a total of 29 million tons of solid waste generated by its communities. In addition to recycling, which generates greenhouse gases and contributes to climate change, smoke, hazards, marine debris, and improper waste disposal, open-air burning, particularly of rice fields, has a detrimental effect on the environment and human health. Contribute to the ecosystem's health (Information on Waste Management in Thailand [Online] Wikipedia. https://en.wikipedia.org/wiki/WastemanagementinThailand. Accessed 25 May 2021). Thailand's economy is transitioning to a circular economy model by creating value worth less than three billion USD in 2017 (Information on Waste Management in Thailand [Online] Wikipedia. https://en.wikipedia.org/wiki/WastemanagementinThailand. Accessed 25 May 2021). Pressure or constraint acts as a catalyst for the development of recovery capacity, resulting in resource conservation, restoration, development, and enhancement, including resolving pollution and environmental issues through an emphasis on resource management and manufacturing factors.

An economic system that is circular is an economic system in which the production system's resources can be planned, restored, and reused. To address future resource shortages, resource recovery can take the form of utilization in a variety of fields, including adding value to the material (Information on Waste Management in Thailand [Online] Wikipedia. https://en.wikipedia.org/wiki/WastemanagementinThailand. Accessed 25 May 2021). The European Union recently announced the "2018 Circular Economy Action Package," which includes objectives and policies aimed at reducing plastic waste, reducing landfills, and increasing recycling. This demonstrates that governments and businesses around the world are actively promoting the circular economy. Thailand places a premium on the country's development toward sustainability and the transition to a circular economy. People in the government want businesses to use the "circular economy" concept in their work, and they want them to do that by setting up a "Strategic Plan for Building Growth with an Environmentally Friendly Quality of Life" in the 20-year National Strategic Plan (2017–2036).

Thailand has shifted its economic and social development model to one that is based on countries' biodiversity and natural resources. Contributing to the enhancement of value throughout the chain of goods and services production. Utilize modern technology and innovation to assist in breaking down barriers and taking a leap forward in order to generate sustainable economic growth. We can achieve clear participation, universal distribution of income, opportunity, and wealth, and the maintenance of a balanced resource base and biodiversity by implementing the BCG economic model and zero waste production. It is a development that is environmentally friendly and sustainable. "B" stands for "bio-economy," and "C" stands for "circular economy." "G" stands for "Green Economy." Thailand is trying to promote the BCG Model as a global climate change agenda in the spirit of one world, one destiny. A Single World, a Single Common Vision Thailand can then respond to the global community.

This report focuses on the circular economy and green economy, in accordance with the United Nations Sustainable Development Goals for sustainable development and the Sufficiency Economy Philosophy's principles of economic development. Thailand's government and society intend to mainstream the circular economy.

Adopting a circular economy as a "New Economy Model" or BCG Economy (Bio-Circular Green Economy), a sustainable development economic model, is a holistic economic development strategy that will simultaneously create a 3D economy composed of three distinct economies: B stands for Bio-Economy, which is a bioeconomy system centred on cost-effective bioresource utilization. The government has designated the BCG Economy as the country's driving strategy for the years 2021–2026 in order to lift Thailand out of poverty. The circular economy is also recognized as a means of economic recovery following the outbreak of COVID-19, as it contributes to the creation of products and materials with value.

6.2 Intelligent Product Design

It consumes fewer resources (Smart Design: Fewer Resources) and has a longer useful life (Extended Product Life), thereby reducing global waste. Used products must be repurposed, as well as the sharing system promoted (the sharing economy). With an increasing reliance on domestic production and consumption (local consumption), recycling is a critical industry for Thailand because it is interconnected with the production of other industrial sectors. Although the market is worth more than four trillion baht, it must be adjusted to meet the needs of lower production costs, energy savings, and minimal environmental impact. This is a critical industry that we must advance. As a result, the indicators are highly valued and in constant demand by the market. The government has pushed for a circular economy in the industrial sector. The Ministry of Industry has placed a premium on the government's development policy. Simultaneously, the BCG economy encourages private sector investment. Also, the industry of scrap recycling is being promoted. This results in a reduction of long-lasting pollutant emissions and reduces industrial waste generation by repurposing it in a way that adds economic value. Collaborate with relevant agencies, such as the United Nations Industrial Development Organization (UNIDO), Pollution Control Department, the Department of Environmental Quality Promotion, the National Research Office of the Ministry of Higher Education, Science, Research, and Innovation, and the National Science and Technology Development Agency, as well as scrap recycling entrepreneurs.

Since the Industrial Revolution, the waste of wealth has been a major global driver. Even now, there is a greater variety of raw materials available. However, renewable resource use remains an indispensable raw material. It is the fundamental raw material used in the manufacture of a large number of series products, such as automobiles. Industries include construction, agriculture, energy, services, and packaging. It is a vital sector of the Thai economy. Additionally, the industry is critical because it produces and exports to a large number of countries. There is tremendous potential for a circular economy all around us. It is a critical mechanism for Thailand to develop and improve its national, regional, and global competitiveness. The BCG model plan for a National Agenda for Sustainable Economic Development aims to propel the country forward by increasing the value added along the production chain through the application of modern technology and innovation. The BCG economic model is the engine that propels inclusive growth in the country. Concurrently developing the economy with social development and environmental preservation in a balanced manner in order to achieve stability and sustainability is economic development throughout the value chain. This is accomplished by transforming the advantages Thailand has derived from biodiversity and culture in order to compete with innovation on a global scale. This includes the application of creativity to enhance the value of products made from recycled materials, as well as the application of knowledge to increase production efficiency. It is important to pay close attention to an environmentally friendly production system and production measures that adhere to international standards. Upgrading products through innovation and transforming them into high-value products can result in a price increase of up to doubling. This lengthens the supply chain, resulting in increased income distribution to the community to alleviate inequity and build community and growth that evenly distributes income, opportunity, and wealth.

Forces both within and without the nation Several disciplines' technologies are merged. This led to further development to create a structure for collaboration between communities, the governmental sector, the corporate sector, and financial institutions. Educational institutions are beginning to give easy-to-use technologies for occupations and enterprises, as well as the utilization of resources and waste materials for manufacturing and usage, leading to increased income while conserving ecosystems and the environment.

Individual research project funding should be supported. Improve industrial sector human knowledge and skills to enable global technological progress Creating and linking cluster networks of professionals and firms in the manufacturing and processing industries. Continuous product development research Various agencies are tied to standardized factory selection prototypes.

It is necessary to provide research assistance, raw material production, and acquisition for educational institutions and the private sector to enhance the industry's growth to ensure its long-term competitiveness. When building a new strategic industry, it is best to stick to the current industry.

Relationships of Thailand with the International Community Adopt foreign technologies, sustain dual circulation, and grow domestically. Promote originality while fostering self-reliance and discipline. Entrepreneurs in the group are involved in innovation and originality. Developing a new economic system Create a new market through privatization and Increase producer and consumer adoption of circular economy products, hence mainstreaming the circular economy in society. The BCG Economic Corridor must be distributed among all regions.

Developing and improving products is derived from a variety of resources by enhancing their quality and creating solutions that provide discarded materials with extra value. Developing standards for recycled materials or products from the application of waste to fulfil the requirements of the new market in terms of quality and safety in order to assist in analyzing, testing, and certifying quality product performance and registering and promoting products. To facilitate the expansion of both domestic and foreign markets, we must provide an ecosystem that encourages private sector investment in supranational development.

For the operation to have a chance of commercial success, private sector participation is essential. Advancing Thailand's progress toward the Sustainable Development Goals by establishing a brand with added value needs to:

- Utilize Insufficient resources for a country's development. Adopting the economic idea to attain objectives.
- Utilize resources to generate economic value.
- Connect products made from recycled materials to new alternative resources.
- Improves existing skills, upskills, reskills, or acquires a new skill.

- Necessitate supporting the reorientation of the Thai economy toward the production of innovative goods and services by encouraging the emergence of entrepreneurs, particularly in innovation-and creativity-related organizations.
- Promote access to funds and markets for items made from recycled materials, as well as product registration, product performance studies, and market introduction.
- To achieve user acceptance and compete with imported products in order to increase the likelihood of entering the international market, it is necessary to create an ecosystem to support the development of new industries in terms of infrastructure promotion measures and to remove obstacles to the expansion of the recycling industry.
- Constructing a production platform on an industrial scale is important.
- Unlock restrictions on investment by utilizing fewer resources and fostering a sustainable society; the circular economy contributes roughly $4.4 million to world economic growth.

Thailand is in the midst of shifting to a value-centred circular economy. It affords the nation a cost advantage and permits humans to coexist with nature. Promoting sustainable manufacturing and consumption increases profits and creates jobs. In the next ten years, it will contribute at least 200 billion THB, or 1% of GDP, to the country's economy.

6.3 Concepts, Theories and Related Research

A Circular Economy (CE) is an economy that is circular by design. To address the situation, it is possible to restore and reuse all production resources. Future resource scarcity will necessitate an increase in production resources as the economy grows and consumer demand for goods and services rises. As a result, the circular economy prioritizes maximizing the duration of the product value. Encourage reuse and prioritize the management of production and consumption waste by reusing previously produced raw materials in a new manufacturing process. In contrast to the linear economy, in which large quantities of natural resources are extracted before being used in the manufacturing process and sold to customers, the circular economy involves the extraction of natural resources, their use in the manufacturing process, and their sale to customers. When a product has outlived its usefulness, it is discarded as garbage.

6.4 Definition

Scrap Chain

"Product scrap" refers to a product that has been damaged or degraded to the point where it can no longer be used or desired. A business that is registered with the Pollution Control Department or a local government agency is referred to as a "residue collection facility." collect product remains from consumers or those in possession of scrap products, or a collection network for the product remains. A "products disassembly facility" is defined as a factory that has been granted a license to operate a sorting business under factory law or a sorting business establishment that has been authorized under the public health law and registered with the Pollution Control Department. Soil or rubbish.

The term "importer" refers to the owner or possessor of electrical and electronic equipment products from the time they are brought into the Kingdom; "manufacturer" refers to the owner of a brand or trademark on electrical products and electronic equipment. If no brand or trademark is present, the manufacturer is assumed to be the person listed on the label or the name on the label, and it is assumed that the inventor assembles or acquires the product.

The term "product collection network" refers to an individual or organization. Corporations, foundations, non-governmental organizations (NGOs), and other organizations (provide services for the return of product remains to a scrap collection site from consumers or those in possession of waste products). The circular economy focuses on waste management and waste resulting from the consumption of goods. It is a system that utilizes resources in the most effective manner possible. Return used goods to the manufacturing process (Make-Use Return) for balanced business growth, improved quality of life, and a sustainable global future. The concept of the circular economy is founded on nature-inspired innovation. Environmental design concepts are based on a process-based approach that follows the product's life cycle (Bio-mimicry). From the pre-production to the post-production stages, As a "natural" model or Cradle to Cradle design, the circular economy is a waste-free production system based on natural principles (C2C). Due to the fact that one company's waste will always serve as a source of raw materials for another, reuse and recycling will be the most crucial aspects of this economic system (Özkan and Yücel 2020).

6.5 Circular Economy and Scrap Metal Recycling Industry

There is research on the factors that affect circular economics and environmentally responsible behaviour. The environment of scrap metal recycling companies in Thailand is analyzed using a structural equation model (SEM) to determine the causal relationship between variables from previously studied studies (Akkalatham and Taghipour 2021). The variables used in this study to analyze the behaviour of the study targets, namely foundry parts, were selected based on the responses of stakeholders in the manufacturing and management industry chain (Taghipour et al. 2022). It was found that respondents valued long-term relationships with product manufacturers (suppliers) and business partners and that quality control had a substantial impact (Taghipour et al. 2022). The ability to meet customer needs while using the fewest resources possible in production can be produced in accordance with the number of customers' required time frame as well as the best quality and price. The cost of recycling and the cost of recycling was discovered to be comparable. Environment awareness has the desired effect on perception and behaviour regulation. As a result, it is essential to educate the public on the circular economy and its principles. The study also demonstrates that the intention of a society to recycle has the greatest impact on the circular economy's implementation and outcomes. The confidence of all sectors is the most influential variable in a circular economy. Encouraging collaboration in the implementation of the circular economy concept. Numerous factors are required in order for the steel industry to successfully implement a circular economy. The most obvious is society's willingness to recycle and adopt lean production systems, protection of behaviour, and environmental stewardship. via convictions and attitudes (Akkalatham and Taghipour 2021). Additionally, it increases production capacity to aid in the growth of the nation's economy, and the circular economy concept must be aggressively promoted. The circular economy is a future business model because there are environmental and economic benefits to doing so, as it is depicted in Fig. 6.1 (Akkalatham and Taghipour 2021).

According to Donati et al. (2020), the addition of steel and aluminium to the production of parts would result in a 28% reduction in raw materials. It is believed

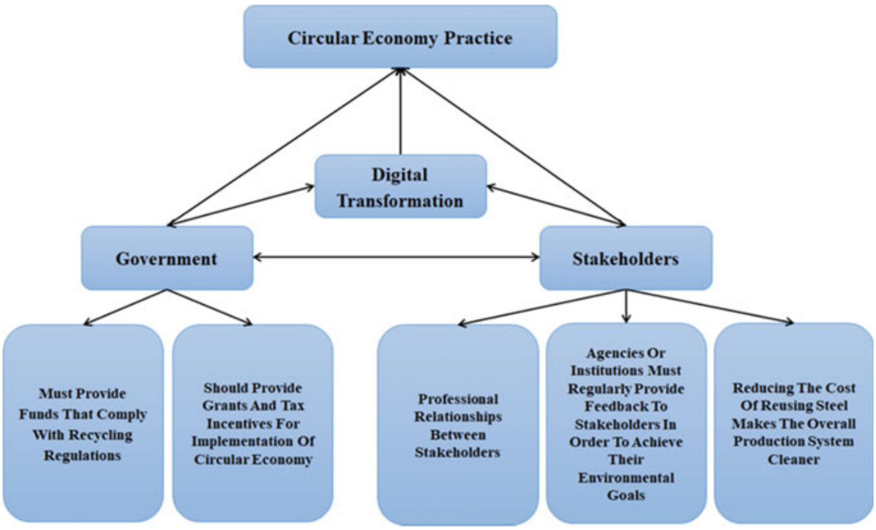

Fig. 6.1 Circular economy practice (Akkalatham and Taghipour 2021)

that the use of instruments, machinery, and electrical equipment enhances all production (Mahapornprajak 2019). Doubling from the industrial revolution due to mechanization, mechanical engineering is the most diverse of the engineering sciences (Schwab 2017). The indicators demonstrate that reducing manufacturing waste has a positive effect on the environment. This approach is based on the assumption that 35% of steel and aluminium products from semi-finished products is transferred to other uses, despite the fact that the socioeconomic analysis yields negative results (Tsai et al. 2019). Fewer scrap metals remain, and as a result, machine knowledge is being transferred across industries (Maloutas 2015). For example, in the construction industry, up to 90% of steel and aluminium scrap can be recycled (Allwood and Cullen 2015), leaving only 7% in production lines and industrial plants. Therefore, we believe that promoting recycled materials is the correct action to take.

In 2018, production costs increased globally, comprising 66% of total production costs (Donati et al. 2020). Both scrap metal prices and imports of raw materials have recovered. Products made of steel that have reached the end of their useful lives will be recycled and reused. In the new melting technique, the chemistry has changed. Superior to metal in distinction, Magnets contribute to the recycling process by removing contaminants such as plastic, brick, stone, mortar, sand, and metal from steel, among others. Consistent with the circular economy principle of zero waste, the reusability of the properties has a significant environmental impact. These guidelines will help you reduce waste at its origin (Japan Iron and Steel Federation 2019).

6.6 Guidelines for the Circular Economy in Thailand

Responsibilities for Solid Waste Management in Thailand, the local government's waste management system oversees all aspects of waste management, including raw materials, production, storage, transportation, use, and disposal. According to Parinda and Sirawan, the amount of recyclable waste generated in 2018 was approximately 27.8 million tons. 8–9.5 million tons of benefits, 10.8 million tons of properly managed waste, and 7.36 million tons of improper solid waste disposal resulting in environmental and public health problems. In addition, there is currently no production control system for waste disposal processes or waste management. The production line is neither the responsibility of the user nor the importer. Consequently, recyclable trash is discarded. It is combined with domestic garbage and discarded without classification (Sakolnakorn et al. 2016; Ghosh 2020). Large heaps of trash (gravel) with no way to return to the original site. Along the way, it releases a great deal of pollution into the water, soil, air, and living things. When more raw materials are needed, we must continue to extract new resources from nature until our current resources are nearly depleted. Approximately 57% of municipal solid waste collection and disposal is only 7.88 million tons, including incinerators with air pollution control and the construction of a waste disposal centre, or 53% of the total waste collected. An estimated 47% of collected waste, or 6.93 million tons, was disposed of at landfills. Eliminate everything in mass. The remaining 43% of waste is not collected by the local government (Toomwongsa 2017). 6.53 million tons of waste per year or 13.5 million tons of waste dumped illegally (Somboonwiwat et al. 2018). There are still no waste management regulations in place. As well as participants' long-term planning for the start of the waste management procedure (Tangwanichagapong et al. 2020). Environmental Control and Pollution Control Plan for 2012–2016 outlines the nation's waste management objectives (Ghosh 2020). A study of waste management methods and policies reveals that consumption and production patterns are not used creatively, which can be quantified as a company's ineffective use of waste and resource management methods. Initial policy and administration are required. In addition to behavioural modification, Initially identified and modelled as an "industrial system of awareness and creatively designed for revitalization" (Lewandowski 2016), the circular economy entails exploring and creating opportunities for change in accordance with the Cradle-to-Cradle methodology. The circular economy will prioritize waste-free product design, the use of renewable energy, and respect for local communities and ecosystems in order to promote recovery. Toxic substances must be disposed of properly, and waste must be recycled, which must end to a better design of materials, products, systems, and business models (Özkan and Yücel 2020). Emerging as a new paradigm for resource management, energy generation, and value creation is a circular economy. Creating Employment to Develop a Business Explain why it is necessary to utilize multiple business structures in order to maximize overlap and benefit. Linder and Williander (2017) define a circular business model as one in which the principles of value creation are integrated throughout the business sector's product lifecycle. From the manufacturing process to the consumption of new raw materials, this new cyclical pattern has been transformed into Make-Use-Return, which aims to produce (make) products utilizing as few resources as possible through innovation and design (Pongpiachan and Apiratikul 2021). Then, utilize the product to its maximum capacity and dispose of it properly so that the materials can be reused in the new manufacturing process. Mentink (2014) defines CE as a "closed-cycle economy of materials" and "the impetus for its development." procurement and measurement within the closed material circuit.

6.7 Strategies or Strategies for Decarbonizing Solving Problems or Development Guidelines

Innovativeness and technological progress improve our world by fostering collaboration in multiple areas through agency or hyper-collaboration (public–private people partnership) that spans the dimensions of space, people, and products, utilizing innovative technology to aid in the manufacturing, processing, distribution, and product management processes along the supply chain. The ability to strike a balance between production and marketing creates value. Both productivity and product quality are increasing. Developing and Integrating Expert Clusters Entrepreneurs and networks shift from operating independently to cooperating and joining forces. The industrial sector and the nation's economy are expanding in a sustainable manner, and the government plays a crucial role in assisting the industrial sector in recycling raw materials. The COVID crisis serves as a significant global catalyst for the "Management of production of zero waste.". The desire to utilize unlimited resources is the result of economic and social growth (van Eijck et al. 2014). How to achieve zero waste through recycling materials Modern education, incorporating science and innovation, has been transformed into an economic system. The creative economy and the new value creation economy emphasize both quantitative and value-added productivity in order to recycle value. A diverse range of goods It is used in conjunction with technology and innovation to fit the modern world economy and society, with the goal of creating both short-term and long-term benefits; the short-term goal is to reduce costs and increase profits, while the long-term goal is to enhance community and environmental well-being and safety. Environmental innovation is the extension of the four innovations and the implementation of original concepts (Wang et al. 2020). These types include products, processes, services, and business models designed to develop and enhance management. Manage the corporate environment by engaging in activities such as product development, recycling, and product enhancement.

6.8 Decarbonization Strategies

- Efficiency (efficiency) outcomes that are in line with the productivity target the same employee is more productive or produces superior results.
- Making the most of limited time and financial resources. Taking "value for money" into account.
- Low cost, no leakage, less yield loss, and lower maintenance costs.
- Engage in a variety of activities by converting scraps into valuable raw materials, "zero waste" means there is no waste wasted or waste that causes pollution and danger.
- Wastes can be converted to new alternative materials, thereby increasing efficiency, decreasing costs, reducing pollution, enhancing sustainability, and preparing individuals for the future.
- Empowering human resource development is the most valuable asset, transferring knowledge from each entrepreneur's direct experience in that field, combined with research studies, technology, and innovation trips from abroad, in order to reduce skill gaps.
- Information on the skills, competencies, and knowledge required of personnel for operation, as well as information shared with partners. Hence, the best way to learn is by doing.
- Utilizing the resources of each individual, conducting value analysis and value engineering, and creating new innovations.

These strategies can be used together, which is important for the success and growth of knowledge exchange over time because it lets people meet each other's needs and help each other.

6.9 Enhance Competitiveness

- Instead of strengthening the internal economy and integrating it into the global economy, the country's growth should be influenced by external influences.
- Establishing guidelines for recycled materials based on their environmental impact. Reduce product registration procedures to enhance consumer confidence (recycled content of secondary materials). EPR specializing (Extended Producer Responsibility). The foremost authority on the formation of a circular economy in the United States.

From the shelf to the shopping mall, Integrating research and development with business (Research to Industry Convergence) In accordance with the government's aim to promote research and innovation through collaboration, we are supporting collaboration. The government has built an ecosystem that encourages the private sector to invest in the development of a higher quality than the state, so encouraging the private sector to become the principal investor in the private sector. To construct a new strategic industry, the economic development of the old sector must be modified. Modifying grant money for particular research projects to research funding From research and development through production and distribution, the sector is at the forefront of technological and intellectual innovation. Developing and adding to product and service value Increasing receptivity to world-changing currents and rising technological autonomy Government, commercial sector, community, society, universities, research institutes, and worldwide networks share four features. Transform Thailand's diverse advantage into a competitive edge. Initially, the research effort failed to match entrepreneurs' actual requirements. Consequently, the project was concluded. To develop implementation recommendations for linking research results that meet requirements. Increased investment or joint ventures can also benefit entrepreneurs or industries. In practical initiatives, academics, researchers, and faculty members leverage private-sector research. Entrepreneurs and students from across the nation engaged in the project coordinated by the research office. NATIONAL and the Department of Industrial Promotion collaborate on research with the commercial sector to increase public understanding and address societal concerns. Increase Thailand's competitiveness by increasing its waste disposal capacity. By allowing entrepreneurs with superior expertise and technology to invest in waste management enterprises, we are fostering innovation and entrepreneurship. Increased interchange, learning, and network building in the field of research boost competitiveness. Increase the likelihood of expansion. This enables the production of more diverse or creative goods and services, hence enhancing sustainability (Lunkham 2019). Natural resources and environmental development. It assists in behavioural change. Reduce waste at the household, office, and community levels and separate trash. Education is essential for promoting and enhancing the quality of life of a country's population in order to keep up with changes in society and the global community; it is a vital component of the nation's development. The laboratory research is ready for pilot production, factory production, prototype production, and industrial production. The recycled products contribute to the economy by meeting market demands and boosting national competitiveness. The university will successfully employ its knowledge, skills, and potential within strategic groups in which it possesses the expertise on an international scale. University competition is a critical growth engine for the nation; thus, it should be encouraged. The objective of training a new generation of BCG and circular economy researchers is to improve the community and future generations' resource management.

6.10 Guidelines for Driving into Action

Through innovation and creativity, BCG Economic Policy and Sargent's Project Action Plan provide examples of waste materials and waste that add value to the manufacturing and service sectors. By separating contaminants, this novel process improves the quality of scrap and waste. In short, it can transform the conventional business model. However, it must also be used in conjunction with a variety of business models to achieve long-term efficiency. The business model of the circular economy is based on the principle of "creating value" by radically altering the traditional economy. Change the structure of the economy from a labour-intensive nation to one that produces goods and manages innovations, becomes self-reliant, and transforms into a developed nation. To reduce the cost of imported technology, the factory produces innovative products while taking environmental costs into consideration. This report is a pilot application of innovative technology as a model for increasing efficiency, decreasing pollution generation and emissions, and making the production process extremely environmentally friendly. Circular economy practices are more important than the 3Rs: Reduce, Reuse, and Recycle and zero waste, but at its core is a redesign, which is rooted in "design thinking" that comprehends the societal pain. According to the national development strategy, SMEs, startups, corporations, large publicly traded companies, the community, employees, educational institutions, and research and innovation personnel of all sizes, both public and private, are encouraged to participate. Recycled materials are a renewable resource. Creating a new generation of society with knowledge, attitudes, and conscience that takes into account the efficient use of resources, value for the quality of life, and a good environment requires the separation of storage, circulation, and use, as well as the acceptance of circular economy-related products by manufacturers and consumers. Establish and utilize a second round of raw material collection or exchange centres. The secondary raw materials hub creates an infrastructure for the disposal, sorting, and recycling of biodegradable waste into secondary raw materials. Create a learning centre and a database of flow information. Both waste and raw materials are included in recycled materials. Develop market mechanisms that are suitable and incentivized to induce change and reduce the type, type, and diversity of recycled materials. The design and development of products derived from waste or byproducts. With certification labels for the circular economy, waste can be linked to capital market instruments and financing to facilitate entrepreneurs' access to capital for business transformation. To construct a platform Services for online sharing and exchange of knowledge, The national and international public and private sectors should collaborate on circular economy news. Enter the recycling business with the policy framework, the control of in-situ pollution in the recycling industry, and the provision of subsidies for innovation-related businesses in the scrap metal industry are all interconnected. 89.5% of governments or institutions conclude that professional relationships between stakeholders are essential and should encourage their development. To achieve these goals, implement environmentally responsible production. As part of its efforts to protect the environment, the government should educate the public on the significance of recycling. Environmentally responsible sorting procedures Both the public and private sectors contribute to the cause's support. A comprehensive examination of 89.6% environmental friendliness Reducing environmental impact through recycling clean scrap separation from other materials prior to melting the product that generated the least amount of production waste, 93.9%, clarified that the decreased cost of recycling strengthens the overall production environment. Increased by 91.1% it was discovered that the use of the green branding environmental protection seal was associated with a These products are brought to life with the aid of environmentally friendly goods and services. Reducing environmental impact is the objective of creating a green society in the future. 84.8% of steel importers and exporters stated that globalization increased the complexity of small-scale industries, and 89.6% agreed that implementing circular economy principles would increase product efficiency. 95.5% of respondents agreed that an online marketplace should exist. On websites where interested individuals can access information, users are interested in the information. Recycle rapidly. The Internet will become the hub of commerce that can be reached rapidly and fulfil the purpose of promoting trade and waste disposal to truly aid in the elimination of waste.

6.11 Summary and Recommendations

The recycling industry contributes over four trillion Thai Baht to the national economy and continues to grow. It creates enormous career opportunities for Thais. Creating Creative ecosystem businesses is the engine that propels economic growth. Since the Industrial Revolution, it has been the world's primary driving force. Nevertheless, despite the fact that there are more raw materials available today, it is still an indispensable raw material that cannot be eliminated. However, production costs must be reduced to meet demand. Technological progress is a catalyst for the formation of adaptable new businesses and returning to the original challenge of creating new opportunities and alternatives to change. Transforming problems into business intelligence, having the foresight to deal with the future, maintaining an open mind, and being creative are characteristics of business intelligence. The learning exchange enters the industrial revival period. Natural degradation and more severe environmental issues, such as the problem of solid waste management, environmental pollution, contamination, improper sorting, and recycling, are largely caused by unclean leftovers. It will lead to polluted combustion, which will negatively impact the environment and public health. As a result, a sustainable recycling enterprise is being established, which can help reduce the amount of trash that must be destroyed. Recycling reduces waste production, and this also requires less energy than the production of new raw materials due to the lower melting point of waste materials. Recycling can also help reduce water and air pollution and aid in reducing water pollution, which consequently contributes to small business owners' income generation. Moreover, health concerns necessitate environmental remediation, which in turn necessitates modification. There is social pressure to adopt greener production methods (Suksabai and Tuprakai 2020). To bring Thai industry standards up to international standards, waste needs to be managed in a safe and efficient way. To make the factory eco-friendlier, materials need to be used more efficiently, and waste needs to be cut down. A healthy society cannot be purchased. Want to assist? Environmental innovation consists of the application of novel concepts and the development of new products. Products, services, processes, and business models are the four major classes. The creation of green products with added value and recycled products is a component of management enhancement and corporate environment enhancement from the design phase through purchasing, hiring, and production of technology applications with added value. Under current regulations, comprehensive waste management is required to prevent the release of pollutant-causing substances. The international standard recognizes innovation and the application of systems and tools for quality management. Environmental security is improved by investments in pollution-reduction technology innovation. By replicating the success factors, the overall profitability of the chain is increased. This contributes to the improvement of the quality of the production line. The emphasis should therefore be placed on innovation by modifying the innovation production procedure. So, new processes designed to maximize benefits in the BCG Model Recycling Industry's Supply Chain Raw Material Preparation prioritize the use of materials that are clean, safe, and less wasteful. Adding value distinguishes products and is not constrained by differentiation, operation speed, or adaptability, which means that the invention of new alternative industrial materials results in a product that cannot be replicated, even if it is technically feasible to do so. Furthermore, the consciousness of the significance of environmental management alongside business expansion, fortifying factories to save the world, minimizing dust, and continuously conserving energy. Also, employees must be educated on the significance of innovation and technology. Promoting the efficient use of resources and a positive image creates an advantage for the organization in terms of reducing costs associated with raw materials, energy, and pollution treatment. Additionally, the organization and surrounding communities benefit from conservation efforts.

The recycling industry implements "best environmental practices." Measures must be implemented throughout the supply chain to reduce emissions. Inadvertent emissions of persistent pollutants from waste recycling centres and businesses reduce industrial waste generation by reintroducing production in a manner that adds value. Sustainable development goals (SDGs) The Sustainable Development Goals are a comprehensive set of development objectives established by the United Nations and encompass nearly all aspects related to the quality of human life. Greenhouses from waste recycling centres and businesses by the issue of SDGs related indicators. The recycling industry is characterized by inclusiveness, full employment, and sustainable economic growth while building infrastructure to support change, promoting sustainable patterns of production and consumption and accelerating action on climate change and its consequences. The creation of a policy framework, guidelines, and instruments must include regulatory and control measures that lead to pollution remediation. Regional information linking and development province by province Utilizing incentives and economic measures as opposed to legal and awareness-raising measures, there exists a structure that can be scaled up by industrial plants based on their power output. By establishing a budget-supported development fund for entrepreneurs with limited income and expenditures, the government can support a sustainable green industry. The government can consider tax deduction incentives for entrepreneurs willing to invest in pollution reduction. In addition, the government may offer low-interest loans for the development of technology and assist companies in securing financing from the World Environment Agency.

To inform the public, stakeholders, and operators, the government should collect and disseminate reliable, consistent, and accurate data in accordance with applicable laws and disseminate information to the public via its website and various social media platforms. The government must incubate and seek out innovative technology in Thailand's recycling industry, compile a list of Thai inventions, and fund research to add items to the list. Aside from that, they must increase quality, the capacity to list innovations and funding for constructing a networked BCG technology enterprise. Opportunities for promoting sustainability must be generated through business ventures and innovation subsidies that allow entrepreneurs to reduce fuel costs. In addition, these practices reduce the release of toxic substances into the environment and contribute to the enhancement of BCG's image in the country, which is an additional factor in attracting investment. Consequently, the economic growth of medium-sized cities within the metropolitan area is of greater significance. It is a significant force in the development of sustainable cities and human settlements and plays a vital role in urbanization. The sustainable business model can create a system for managing air quality that is efficient and effective.

Building infrastructure and utilities in accordance with the plan to increase a country's competitiveness stimulates production and strengthens its ability to carry out missions effectively. Its purpose is to enhance production, service, and asset management by applying technology and innovation. For urban and economic development, the region must diversify its investments. To increase competitiveness, international cooperation must be promoted. To facilitate cooperation between polluters and communities, participation from multiple sectors, the development of network partners, and the empowerment of entrepreneur projects are required. In order to provide change incentives, the organization must establish a sustainable development working group comprised of public, private, and local stakeholders in the region where it operates. Similarly, academic collaboration with colleges, universities and government agencies is required to create a database to store placement data and training and evaluation plans. There is a quantifiable number of pilot area projects, pilot activities, and demonstration activities at the circular economy factory waste management centre entities with the motivation and readiness to act. The government coordinates factory operations in accordance with the standard for the green industry. By providing a training course, a discussion forum, and technical support, we can help reduce the linear economy practices.

6.12 Case Study

Innovative building materials It engages in product life extension, green cement production, and circular supply. The government recognizes the significance of government market innovation growth. The objective is to achieve supply and demand equilibrium (Egbaria et al. 2020; Fan and Fang 2020). A report on Thai innovation has been compiled as a result. Innovative reverse engineering mechanisms and functional structure discovery techniques enable the commercial production of goods and services with internationally comparable specifications and standards. Before constructing a new device or system, it is necessary to analyze the operation of an existing device or system. A new device that functions identically without copying the prototype results in a product that is superior to the original by avoiding flaws and enhancing the strengths of the original product. New businesses generate marketing opportunities and stimulate economic growth (Liang et al. 2020; Mahattanalai 2019; Wijayasundara 2020). The country's circulation increases the likelihood that people in the region and rural areas will have access to technology. Enhancing stability and self-reliance and fostering the growth of human capital that generates employment. A nation's economy is sustainable when it is able to export products that are competitive on the international market. The new economy promotes economic growth.

With a business, This facilitates the production and addition of value to waste materials. The National Science and Technology Development Agency Ministry of Higher Education, the Science Research and Innovation Office Ministry of Industry, and the Thailand Industry Council are among our collaborators. The Department of Industrial Promotion Office of the Board of Investment Budget Office of Industrial Product Standards Department of the Comptroller General Concrete is used in the construction industry where reinforcing steel is used (reinforcement) of a log, grate, or is embedded within. It possesses a remarkable compressive strength. However, it is delicate when tense. Therefore, steel, which has a high compressive and tensile strength and the same coefficients of stretch and shrinkage as concrete, is employed so that the two materials can provide mutual support. The iron will act as a tensile load, while the concrete is compressible; this material is commonly referred to as reinforced concrete (reinforced concrete). In addition, the use of reinforcing steel is permitted can also help reduce the size of a column or beam without diminishing its strength. Round bars, steel re-rolled round bars, deformed bars, steel wire strands, and high tensile steel wire for pre-stressed concrete are the five most common types of reinforcing steel. Strong Tensile is to create a prototype of social innovation and technology for waste reduction, and a paradigm shift is used to analyze the transfer of new knowledge and technology in order to locate a prototype.

Sustainable waste management is integrated by Utilizing information from other fields in the industrial sector Absorption of foreign technology, also referred to as interdisciplinary cross-species knowledge, amplified the impact of material innovation until the emergence of a new body of knowledge integrating interdisciplinary technologies. Reduce the use of minerals in material science (Economic and Social Commission for Asia and the Pacific (ESCAP) 2021). Combine virgin and recycled materials to create secondary raw materials. The technologies of robotics, energy storage, and modular design reduce expenses, resources, and environmental impact. Contributing high-quality research to the body of national knowledge. Utilize design to increase the value of the product. Slowing the generation of waste by increasing the value of leftovers extends their lifespan and transforms them into something other than waste, such as reducing their use in the creation of new products in accordance with green industry and zero emission standards or business continuity models. Using circular economy and intelligent networking, an integrated model for waste management will be created.

This social and urban development included the emergence of special economic zones to develop new industries to meet future needs, which led to a substantial increase in construction. Due to the high proportion of steel fibre usage, developing a model for using recycled steel fibre to replace steel fibres is an intriguing aspect of the commercial development process. Bio-Economic Development-Circular Economy-Green Economy (Bio-Circular Green Economy—BCG Model) has as one of its tenets the reduction of natural resource consumption and greenhouse gas emissions (Apisitniran 2020). The concept of reusing waste materials to reduce iron ore imports and the consumption of new resources is known as recycling. In addition, it adds value to scrap materials to reduce costs. The BCG Model is reflected in the guidelines for construction. By giving it a new purpose, reusing steel fibre in reinforced concrete will benefit both the economy and the environment. If it can be used commercially, it must conduct an experiment to compare the properties of various types of reinforced concrete and document the results as a guideline for the creation of a standard for the use of recycled steel fibre in reinforced concrete in order to achieve the set objectives.

Better load-bearing capabilities. Steel fibres with a higher utilization rate aid in extracting maximum efficiency. Utilizing the floor increases its capacity to withstand greater loads. Utilize the optimal area thickness. Steel fibre contributes to the suitable and durable thickness of the area.

Reduce the construction duration. The use of steel fibre for reinforcement shortens construction time and reduces construction expenses.

It requires less density than flooring reinforced with rebar.

Wire derived from worn tires The bead wire and plied cord extends from the tire's rim surface to support enormous loads, allowing the vehicle to travel at high speeds without the tire exploding. It is resistant to abrasion, which is the process of reducing it to wire size with steel round bars. Through the cold-drawing process, a thin line becomes dense and brittle, gaining mass and tensile strength (Cisa Pushes Tax Changes to Boost China Steel Scrap Use 2021). The wire is not curved, cannot be briquettes, and cannot break, as depicted in the image. Thailand is the origin of these imports of raw materials. Majority of worn-out tires In Thailand, more than 30 million vehicles are registered, including 800,000 10-wheelers, 18-wheelers, and 8-wheeler buses. Each line of old truck tires weighs 40 kg, totalling over 300,000 tons per year. Nakhon Pathom Suphan, Korat, and Surat Rong Lim are locations where used tires can be purchased. The pyrolysis plant can produce fuel oil, while used tires can be burned directly. The purchase price ranges between fifty and three hundred Thai Baht. If you can still cast flowers, deduct between 500 and 700 baht per line. At this location, one can purchase a service.

To replace the steel grating, bonding before pouring the floor, such as deformed wire mesh pre-cast that is not received as it is depicted in Fig. 6.2.

Advantages:

1. Pressure-bearing, bearing forces give concrete much more strength.
2. Controls cracking, increases tensile strength, and increases strength.
3. The anti-crack concrete cast floor will experience fatigue.
4. Increase impact resistance and durability.
5. Reduce concrete density and risk.
6. Reduce the quantity of excess iron. Avoid wasting time by adding iron.
7. Reduce construction duration by more than 70%.
8. Reduce labour costs for steel tying.
9. Place the supporting steel for the cement ball.
10. Can be poured on top of the existing floor.
11. Prevent penetration.
12. Seamless floor.
13. Transportable and packaged in sacks or crates.
14. If a wall lacks a solid window, the glass may cause signal loss.

Appropriate for particular types of labour. Reduce costs by at least 30% based on the value of material investments and energy savings.

Old tires are omnipresent waste products that are rapidly increasing in quantity. Due to the rapid increase in the number of passenger cars and transport trucks, hydrocarbons, which are also used as fuel for the combustion system, are the primary component of tires. Production process the pyrolysis process (pyrolysis) is widely used because it converts tires into gas, solid, and liquid fuel (oil). The tire's composition is composed of 85% rubber, 12% reinforcing steel, and 3% fibre by weight. From a chemical standpoint, they are 51% hydrocarbons, 26% carbon black, 13% oil, 2% zinc oxide, and 1% sulfur from a chemical standpoint. The allure of the steel bar made of high-carbon steel that is encased in rubber is determined by its proximity to

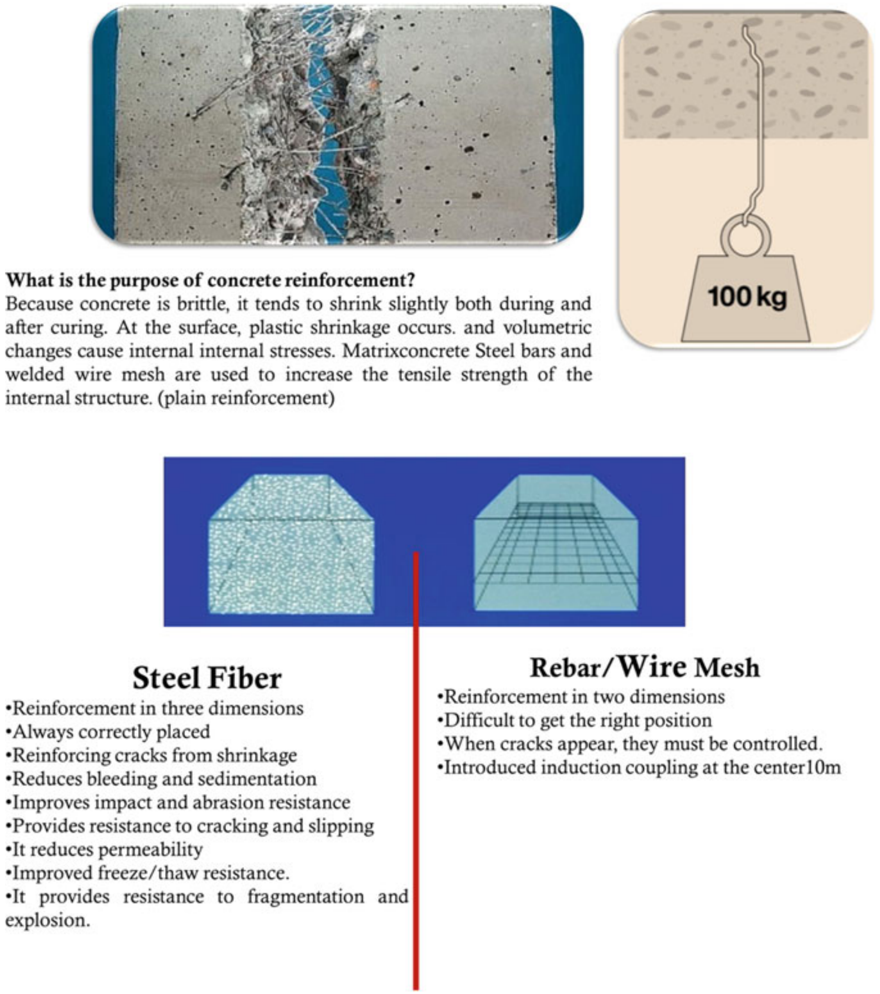

Fig. 6.2 Recycled fibre steel for reinforced concrete features and comparison with other existing products (RSFRC). *Source* Authors

the rubber. Copper or brass, which have high strength, may be used to coat the exterior. Excellent flexibility and fatigue resistance, as it is depicted in Fig. 6.4. Bringing steel bars to a blast furnace to melt It is not widely used because the rebar is small and thin, causing it to burn quickly in the furnace rather than rust the iron. Mixing it with cement is yet another method of application (Fig. 6.3). Polyester, nylon, polyamide, and rayon are the most common high-strength fibres used to reinforce the shape of tires.

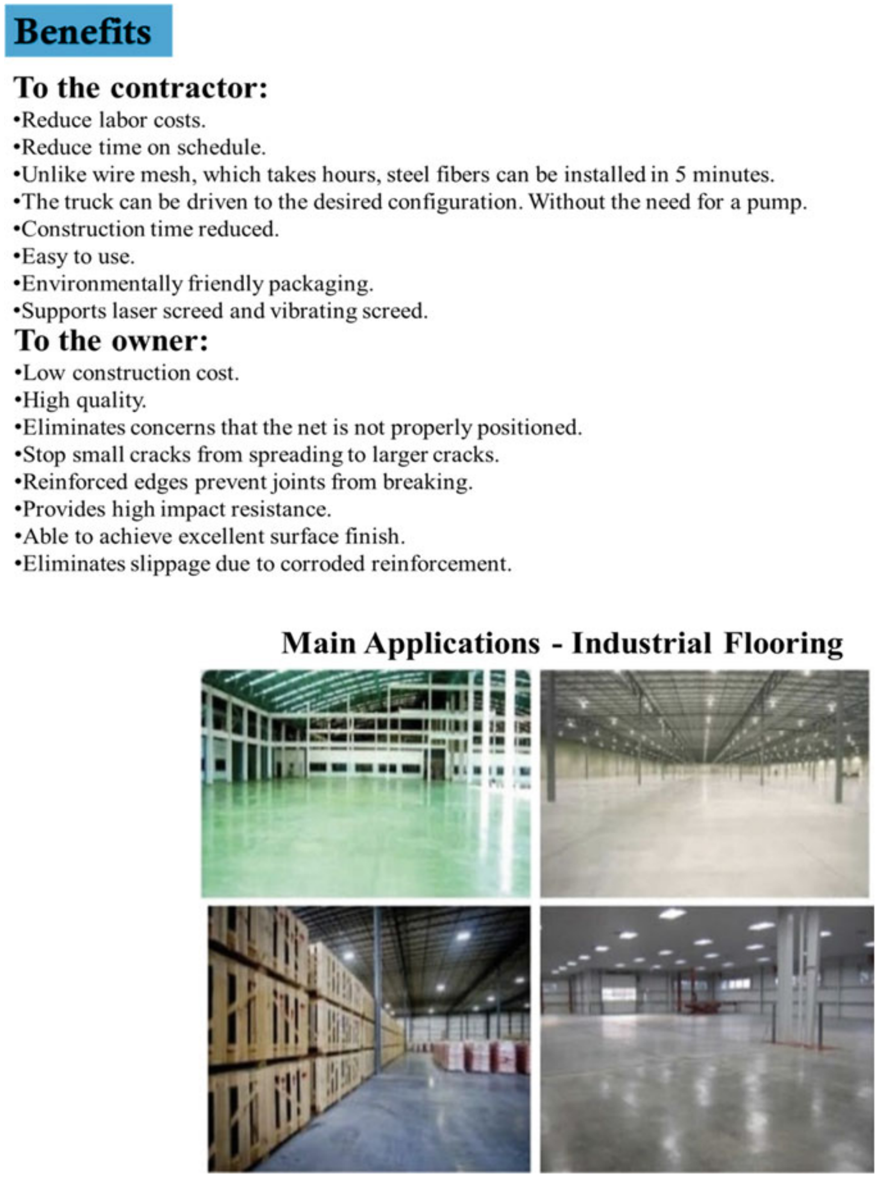

Fig. 6.3 Recycled fibre steel for reinforced concrete benefits for the shareholders (RSFRC). *Source* Authors

Specifications	Steel Bar	Steel Fiber	Recycled Steel Fiber	Polypropylene Fiber
Picture				
Tensile Strength	420-1400 MPa	1000-2900 MPa	1000-2,500 MPa	50–600 MPa
Additional Rate Range	.....	1-3% of mass UHPC	1-3% of mass UHPC	1-3% of mass UHPC
Toughness/Elongation At Break	6-14%	more than 6%	more than 6%	more than 7%
Elastic Modulus	200 GPa	more than 30 GPa	more than 30 GPa	more than 6.6 GPa
Price	600$- ... /ton	300$ - ... /ton	....$ - ... /ton	1000$ - ... /ton
Standard	ISO/TC 17/SC 3 ISO/TC 17/SC 17 ISO/TC 82 ISO/TC 17/SC 4	ISO 13270:2013 ASTM C 1399 ASTM C 1581 ACI 544.1R	ASTM C 1399 ASTM C 1581 UNE EN 14845-1 UNE EN 12390-3 UNE EN 4651 ACI 544.1R	

Fig. 6.4 Compares the properties of steel fiber in the market. *Source* Authors

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Chapter 7
Waste to Energy in Circular Economy

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Abstract Humans are producing ever-increasing volumes of waste and contaminants, and it is not difficult to understand that resource exploitation is increasing in tandem with resource depletion. When compared to the previous century, today's global resource utilization, economic activity, and population are all considerably larger. Devastating environmental degradation, contamination, and climate change are the results of unprecedented levels of resource utilization to satisfy human needs.

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Recent global energy consumption levels, as well as an over-reliance on waste disposal and emissions rather than reusing and recycling, are clearly unsustainable. Thus, it is challenging to maintain the conditions for long-term socio-economic and environmental stability, indicating that fundamental changes in the organization of energy resources and waste flows, namely the resource economy, are critical. In addition, the waste-to-energy approach has been offered as a viable solution for decarbonizing the transportation and energy sectors; its primary goal is to recover waste energy in the circular economy. The purpose of this chapter is to examine the role and principles of the circular economy in the design of waste treatment facilities.

Keywords Waste-to-energy · Circular economy · Barriers · Policy and technologies

7.1 Introduction

The worldwide population has been expanding at an alarming rate, with the world population estimated to reach 9.7 billion in the year 2050 and 11 billion by the end of the century (Sharma et al. 2020b). Industrialization, urbanization, and overpopulation are viewed as the underlying causes of the issues mentioned above. Huge growth in energy use and the generation of solid waste are the two main concerns facing the globe. Fossil fuels (such as coal, natural gas, and petroleum) are extensively utilized in order to fulfill the continuous energy demands (Mishra et al. 2019; Mehta et al. 2019). However, the non-renewable nature of fossil fuels is alarming since they produce significant problems such as increased fuel consumption, economic concerns, and climate change. Overuse of fossil fuels has led to the discharge of harmful gases such as NOx, CO_2, SO_x, CH_4 and others, which have noticeably contributed to climate change, global warming, biodiversity loss, and acid rain, all of which have serious consequences for living things and endanger the environment (Malla et al. 2022; Sharma et al. 2020a). Moreover, a shortage of energy supplies could result in considerable increases in fuel prices, causing budgetary issues. Besides, energy consumption was determined by population, which was expected to increase by 50% by the year 2035 (UNDESA 2018). Apart from hazardous emissions discharged from transportation, the growing population also led to an increase in waste generation. It was anticipated that waste created each day in the world has increased to 3.5 million tons/year and by 2025, it could reach 6.1 million tons/year, as shown in Fig. 7.1 (Makarichi et al. 2018).

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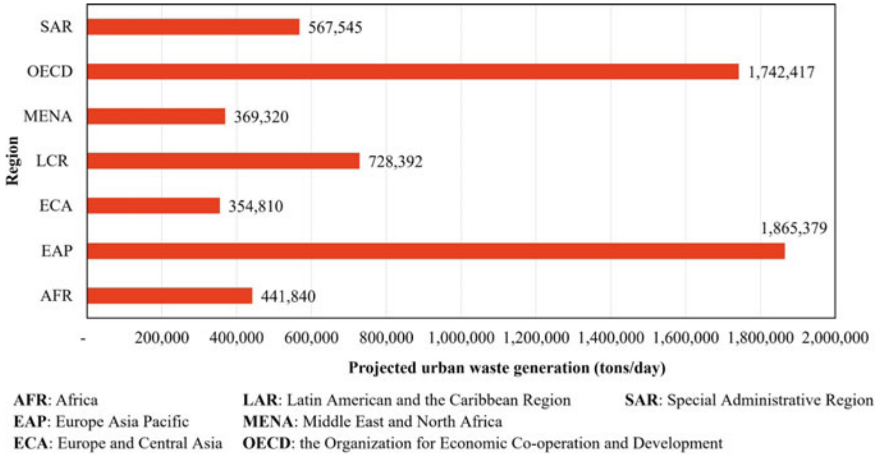

Fig. 7.1 Estimated waste generation by region in the world by 2050 (Makarichi et al. 2018)

It is clearly stated that uncontrolled carbon dioxide (CO_2) emissions released into the atmosphere are considered to be a threat to the natural habitat; therefore finding alternate energy solutions is critical for the world's future stability. In addition, the waste poses a threat to both environmental quality and human health, hindering the development of the economy and society. If municipal solid waste is not effectively handled, it would consume vast amounts of land as well as impede national development. Hence, it is critical to foster the building of a waste-to-energy (WtE) system in a circular economy for sustainable development.

WtE plays an essential part in facing rising waste generation. WtE is considered an appealing way for recovering energy and usable materials as a result of depleting fossil fuel supplies and the production of sustainable energy (Dong et al. 2019). Since last century, generating and employing energy from solid waste combustion is a notion that has been applied in Europe. However, concerns over the quality of groundwater and a lack of space for landfilling prompted Japan and several European nations to begin huge building projects for WtE strategies in the 1960s. Predictions for the number of new, cutting-edge WtE facilities developed by 2020 ranged from 60 to 80, depending on how many are needed to meet EU WtE requirements. The reported percentage of EU energy consumption met by WtE is 1.5% (Mayer et al. 2019). Scandinavian countries have supported the WtE for a long time, and some Asian nations including China, Japan, Singapore and Taiwan have the most WtE facilities in the world. Japan, for instance, has solved its solid waste problem by handling approximately 70% of waste in WtE plants. In addition, China is among the biggest markets for the construction of WtE plants. Indeed, by 2020, the capacity of Chinese WtE was 193 million tons, with about 510 WtE factories, in comparison with the EU WtE capacity which was 96 million tons, and the US WtE capacity is approximately 27 million tons (Themelis and Ma 2021). In this context, the future aim of modern WtE has shifted from "waste treatment field" to "energy and resource generator" (Arena 2015). The construction of WtE as district energy system for the society supported the "win–win" mentality circular economy concept, indicating a prosperous economy and a clean environment could coexist (Balaman et al. 2018). WtE offered a circular relationship between economic growth and greening in order to address existing environmental issues as well as resource limitations by enhancing the efficiency of resource usage in terms of energy generation and the utilization of renewable kinds of energy. In this chapter, WtE would be assessed from the perspective of the circular economy. The techno-economic feasibility of waste-to-energy facilities will also be examined.

7.2 Role of Waste-to-Energy in the Circular Economy

Material flows and their roles (as shown in Fig. 7.2) that waste recycling and WtE can play in a circular economy. The circle illustrates activities in various areas, such as agriculture, services, industry, residences, and waste generation. Recycling is thought to be the most sustainable option for waste treatment for the vast majority of waste. The most appropriate treatment strategy for the many kinds of waste created in a sustainable circular economy is evaluated by economic, social, environmental, and health factors (Van Caneghem et al. 2019).

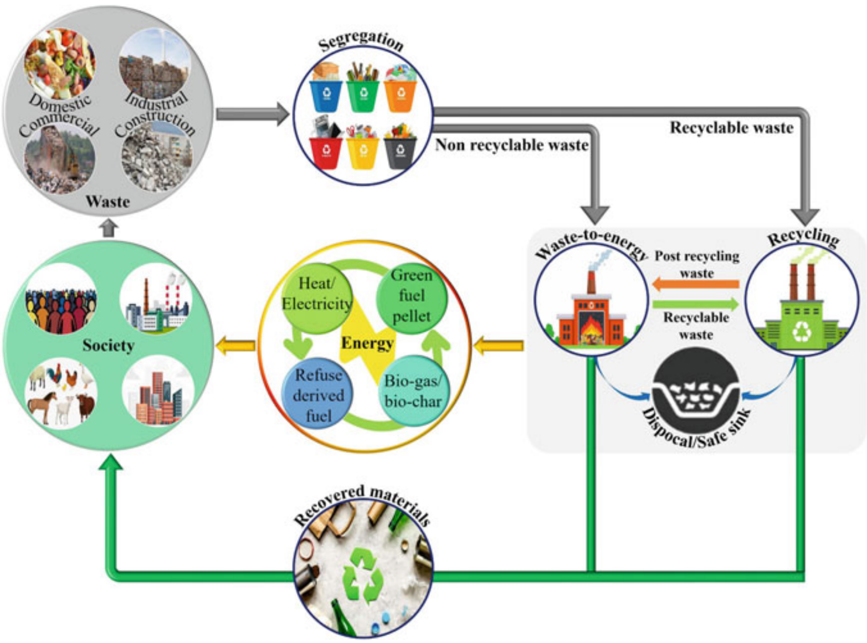

Fig. 7.2 WtE scheme and role of waste in the circular economy

The conventional economic chain is characterized by a one-way flow of "crude materials and energy collected from the environment as well as manufacturing activities and home consumption and contaminants." Besides, traditional economies are known for high emissions, high energy use, and limited resource employment. On the contrary, the energy and material's circular flow provided by a CE is characterized by minimal emissions, low consumption of energy, and high resource use level (Xiao et al. 2020). In the traditional economy, humans utilized natural resources from the ecosystem in order to fulfill the demands of their products as well as living activities. As a result, waste and contaminants are continuously released into the soil, water, air, and the environment during the manufacturing process. Reusable waste, on the other hand, can be recycled or converted into energy in a circular economy, including charcoal, green fuel pellets, biogas, electricity, heat, and refuse-originated fuel. The circular economy is fundamentally a financial framework that substitutes the traditional linear economy by reducing, recovering, recycling and reusing resources in order to achieve sustainable development as well as obtain economic prosperity, environmental quality, and social equality (Kirchherr et al. 2017). Constructing a WtE supply chain is structurally crucial for achieving circular economy goals by ensuring sustainability in the plan and operation of transportation systems and energy via material recovery to produce bioenergy (Boloy et al. 2021). Energy is transformed from waste via WtE and it would be returned to society which includes the recycling industry. In the last few decades, a steam boiler was often used in a WtE plant to recover energy from hot combustion gases aiming to produce power generation, resulting in a maximum total energy efficacy of up to 80% (De Greef et al. 2018). Besides, some solid materials recovered after the WtE process could be used for subsequent recycling. For example, bottom ash, known as the most significant WtE's residue, was a heterogeneous substance composed primarily of metals, ash, and stones. The bottom ash treatment during the WtE process was greatly enhanced over the previous decade aiming to boost the rate of recovery and promote the separated materials' purity, allowing the recycling of nearly the whole bottom ash portion (Kahle et al. 2015). Bottom ash from the WtE process could be used as an uncontained building material, as a substitute for cement, sand, or gravel in construction activities, as a feedstock in the generation of ceramic material, and as raw materials in manufacturing cement (Verbinnen et al. 2017). Aside from heavy metals, chlorides may restrict the utilization of bottom ash in concrete and cement applications (Van Caneghem et al. 2016). In this approach, WtE served as a gatekeeper for the circular economy, allowing materials to be recovered from non-recyclable waste while ensuring that recovered materials were free of harmful chemicals (Van Caneghem et al. 2019).

WtE is universally recognized as an effective strategy for limiting the production of greenhouse gas emissions and mitigating climate change. In addition, WtE is identified as a critical technique to alleviate greenhouse gas emissions. WtE is also important for biodegradable waste since removing it from landfill decrease methane emissions, as reported by Jeswani and Azapagic (2016). It was demonstrated that one ton of biodegradable waste being shifted from a landfill to anaerobic digestion for the production of fertilizer and biogas could prevent up to two tons of CO_2

equivalent emissions (Bernstad et al. 2012). Regarding the organic part of the separately collected waste, like garden garbage and kitchen waste, anaerobic digestion with fertilizer recycling may be a viable management alternative (Malinauskaite et al. 2017). Owing to its potential for greenhouse gas reduction, WtE facilities in the EU are unnecessary to have credits or a permit for CO_2 emissions. In the EU, waste-derived energy carriers were used in urban energy systems such as electricity, transportation and natural gas. They replaced the primary energy carriers, which led to a decrease in the consumption of fossil fuels and non-renewable energy. Owing to the connection between waste and energy, waste planning required coordination with the urban planning and energy system. Generated energy carriers could be utilized to power waste management systems on a local or larger scale, advancing the Circular Economy's "closing the loop" notion. As a result, it was necessary to integrate the development of an energy system (Persson and Münster 2016), management of resources, as well as an energy system and urban waste coupling (Tomić et al. 2017; Tomić and Schneider 2018). Even though this technique ensures high recycling rates for waste, it must also take into account the quality issue of recyclables, the consequences on human health and the environmental issues associated with recycling at the destination. Therefore, the critical and core goal for the recycling sector is not to increase recycling rates, but rather to produce recyclables of higher quality (ISWA 2018).

7.3 Waste-to-Energy Technologies

7.3.1 Thermal Technologies

Thermal WtE conversion methods typically include all thermal processing approaches to produce heat, gas, and oil from waste. Figure 7.3 shows the standard parameters as well as synthesized products of several thermal WtE methods (Tsui and Wong 2019).

As reported by Suthar et al. (2016), the most extensively used technology is waste-to-energy incineration, which is essentially the burning of waste materials operated under high temperatures, with electricity and heat as its principal outputs. Previously, incineration was thought to be primarily employed aiming to minimize the volume of waste (land conservation) and to eliminate toxic materials. Because of the lengthy history, incineration was commonly paired with heat and energy recovery units, so significantly enhancing their application values and performance. In comparison with other thermal WtE methods, waste-to-energy incineration was conducted under the conditions of substantially lower temperatures and in an environment with reduced oxygen, which was related to distinct product yields and reactions. Systems of WtE incineration offered various benefits, including recovery of energy, the reduction of GHG emissions, and savings of resources (Cui et al. 2020). An incineration factory with a working life of 30 years required less than 100,000 m^2 of land to treat one

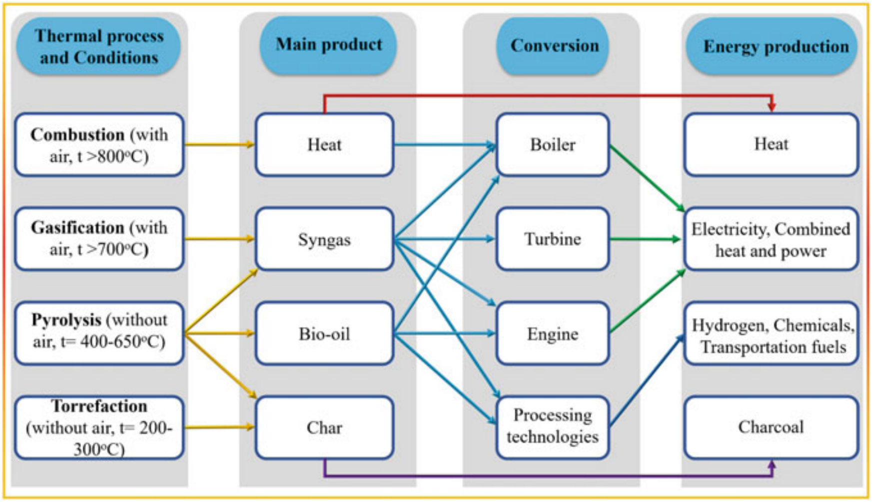

Fig. 7.3 Thermal methods for WtE processes (Makarichi et al. 2018; Sanlisoy and Carpinlioglu 2017; Chen et al. 2018; Tsui and Wong 2019)

million tons of waste each year, but landfilling required 300,000 m^2. Sweden and Denmark were the pioneers in applying incineration, with incineration generating about 5% of Denmark's energy consumption and 14% of total domestic heat usage in their national systems of energy in 2005 (Bosmans et al. 2013). When one ton of garbage is utilized to produce energy, about 1.3 tons of carbon dioxide might be removed from the atmosphere if the same amount of energy were produced by fossil fuel-powered power plants. According to the combustion methods and composition of waste, the final mass conversion proportions of waste to fly ash and ultimate bottom ash were approximately 10:1 and 10:2.5, respectively, with 75% of the total waste mass being released as of gas (Malindzakova et al. 2015). Moreover, waste incineration has a somewhat narrower range of carbon emission factors (corresponding to 0.04–0.14 kg-CO_2/MJ) for producing electricity compared to fossil-fuel power plants (Astrup et al. 2015). By 2015, there were 1179 waste incineration plants operating globally, with a total capacity of approximately 700,000 t/d (Lu et al. 2017). China, the European Union, Japan, and the United States ranked first through fourth, with anticipated capacity of 255,850 t/d for China, 207,104 t/d for the EU, 92,203 t/d for Japan, and 88,765 t/d for the United States (Cui et al. 2020; Lu et al. 2017; Michaels 2014). Notably, the robustness of incineration in the handling of diverse waste was its distinctive characteristic. Given its maturity, incineration was likely the most effective solution to the problem of rapidly expanding populations producing waste at the present time. Although the convenience of WtE incineration was normally preferred, it led to severe consequences including depleting the natural ecosystem of material reserves as well as pure air. WtE incinerators were also designed to dispose of waste safely and effectively in addition to generating usable energy. Therefore, they were regarded as the most advantageous solution for sanitary landfills, particularly in big and medium-sized communities where landfill space might be restricted.

In addition to WtE incineration, gasification is a process that is intermediate between combustion and pyrolysis process in which it is related to material's partial oxidation. In other words, oxygen is introduced, yet not in sufficient quantity for complete combustion to occur. Temperatures typically range between 650 and 800 °C. Even though it was predominantly exothermic, it was noted that this process could be required to initiate and sustain the gasification process (Seo et al. 2018). In comparison to waste incineration, waste gasification was observed to be favored over incineration since it produced a syngas product which could be utilized in a variety of ways. Furthermore, gasification produced uniformly high-quality syngas from diverse and complicated residual waste. Only gasification could offer multimodal products like heat, liquid fuels, power, chemicals, cooling, and gaseous fuels (Rauch et al. 2018). Gasification also allowed for efficient power generation with excellent integration with existing power generation equipment including gas engines, steam cycles, and gas turbines. Apart from that, the gasification of wastes was a prelude to biomass gasification on a large scale and would enable carbon capture and storage, which would otherwise result in detrimental greenhouse gas emissions (Saghir et al. 2018). It was noticeable that gasification was known as incomplete oxidation in which the amount of oxygen was less than required for full stoichiometric combustion. Actually, partial oxidation was accomplished with the use of gasifier agents like CO_2, in comparison with WtE incineration. The generation of SO_2, dioxins, and NO_x was thus better regulated, and the overall flue gas volume was reduced, resulting in less costly gas treatment devices. Because of the minimum volume of flue gas, pollutants became more concentrated, allowing for more effective physicochemical treatment in which tiny particle matter was collected. Actually, the employment of air as an oxidant was considered a less expensive choice in terms of capital investment; however, it might not provide syngas with high calorific value, so a compromise had to be struck throughout the selection process (Gañan et al. 2005). Since the range of syngas heating values was from 4 to 40 MJ/kg (McKendry 2002), they had a significant impact when choosing a gasifier. Certain waste types, such as plastic waste, biomass-originated material, and paper waste and packaging were already gasified (Win et al. 2019). Nevertheless, pre-treatment was often required regarding mixed waste, and the mechanical biological treatment's additional energy consumption should be considered in the total energy balance (Deng et al. 2017). Three main system devices used in this process were: fuel bed (including rotating, fixed, and moving), entrained flow, and fluidized bed (Qi et al. 2019). Some factors such as the process magnitude, as well as the requirements of upstream and downstream processing all, had an effect on the choice of gasifier system. In addition, capital costs, the application and quality of syngas products all impacted the choice of oxidant kinds like air, O_2, CO_2, or steam. In order to recover extra energy, the majority of commercial gasification units that handled waste-originated feedstock used a secondary combustion chamber for syngas burning as well as energy recovery from a steam circuit. Moreover, at different phases of the gasification process, plasma gasification techniques with high temperature could also be in use. This plasma technology could produce tar-free clean syngas (Seo et al. 2018). In addition, there existed many thermal treatment factories relying on relatively modern processes like the Ebara fluidization process, direct smelting, and melting procedures including Thermoselect gasification (Suzuki 2007). The above-mentioned processes generated glass fibers which were not only less toxic compared to traditional WtE combustion processes but they could also be useful in exterior landfills.

Waste pyrolysis was used for alternative green energy production in the form of gaseous and liquid fuels (Chen et al. 2014a, b; Lam et al. 2016a). It was noted that pyrolysis was a thermal approach to treat solid waste without oxygen; however, it required higher working temperatures in the range of 300–650 °C, with the desired by-products being condensable gases and char. Furthermore, pyrolysis was carried out in an oxygen-free environment, and with inert gas purging (like nitrogen or others) used to maintain an inert atmosphere (Mahari et al. 2021). In addition, the liquid oil was improved via catalytic cracking, emulsification, deoxygenation, hydrocracking, and refinement or reforming so that it could be used as transportation fuel. Meanwhile, the gaseous products experienced reforming reactions for syngas production, and the solid product could be utilized as biochar or charcoal. During the pyrolysis process, the waste material was heated above its thermal stability threshold, causing the waste material components to break down and produce volatiles. The resulting volatile components were condensed into solid char, non-condensable gases, and liquid oil. Operating conditions and the feedstock had a considerable impact on the composition and production of gases or oils generated by the pyrolysis of waste. In most situations, the gas output for general waste increased along with working temperature but remained less than 1 Nm^3/kg waste (Chen et al. 2014a, b). Besides, the liquid products contained a large proportion of water with chemically complicated compounds. This necessitated sophisticated wastewater treatment processes prior to disposal, with insufficient outcomes in terms of energy or material cycling. Hence, plastic waste could be utilized in place of heterogeneous waste bulk if oil production was desired. Despite a high heating value and the promising resource for material or solid fuel of waste char (Sipra et al. 2018), it was polluted with harmful organic contaminants, and heavy metals needed more attention.

Typical pyrolysis methods which are heated by a furnace could yield potentially valuable liquid hydrocarbon fuels, but these approaches still have several drawbacks. In conventional pyrolysis, for example, uneven heat distribution has an impact on the heating process, extending the reaction time of pyrolysis. Furthermore, the resulting liquid oil possesses oxygen concentration, high acidity, and viscosity. As a result, the problem was in order to fulfill the demand for enhancing liquid oil for transporting grade fuel, which was driving research into the use of advanced pyrolysis techniques to enhance the conventional pyrolysis process (Mahari et al. 2021). Apart from that, the energy needed for the pyrolysis was provided by pyrolysis assisted with plasma; consequently, there was no requirement for energy from combustion to degrade waste materials. Syngas was created from the O, C, and H elements found in waste, obviating the requirement for utilizing oxidizing agents throughout the process (Muvhiiwa et al. 2018). There was a low tar content and high calorific value in the syngas created by plasma pyrolysis, making it suitable for use as a synthesis gas in order to produce hydrogen or in gas turbines to generate power (Punčochář et al. 2012). Additionally, vacuum pyrolysis was known as a novel method for transforming waste and biomass into liquid hydrocarbon fuels. The need for a carrier gas like argon or nitrogen to keep the atmosphere free of oxygen was removed in this method (Dewayanto et al. 2014; Fan et al. 2014). Besides, microwave pyrolysis was thought to be an exciting technology for energy recovery from hydrocarbon and biomass wastes (Lam et al. 2012; Abubakar et al. 2013). The temperature gradient inside the heated material between traditional heating and microwave made contributions to the distinct compositions and yields of products. This method of pyrolysis was observed to create a liquid oil free of sulfur with a calorific value of 46 MJ/kg which was comparable to 45 MJ/kg of diesel fuel as well as light C10–C15 hydrocarbons. Hence, pyrolysis of waste using a microwave could generate a high liquid oil output with desirable fuel properties (Lam et al. 2016b). In spite of the promising yield along with the fuel characteristics of the produced products, the thermochemical decomposition speed of this method was determined by the material's capability of absorbing microwave energy. As a result, microwave absorption enhancers were often used as supplementary supports during the microwave pyrolysis of materials with low absorption.

Torrefaction is a slower and milder kind of pyrolysis that has operating temperatures ranging between 200 and 350 °C with an overall focus on devolatilization and moisture evaporation. Normally, torrefaction produces char with a higher content of energy and enhanced stability (with no further degradation of microbes), in comparison with pyrolysis (Stępień and Białowiec 2018). Torrefaction is a more environmentally friendly and potential thermochemical technique that is commonly used by scientists to pre-treat various sorts of wastes. Torrefaction not only enhances thermochemical process performance (Abdulyekeen et al. 2021) but also promotes biomass hydrophobicity by decreasing moisture concentration, O/C and H/C proportions (Nhuchhen et al. 2021; Martinez et al. 2021), and enhancing fixed carbon. As a result, there was an increase in the energy density and calorific value of biomass (Sukiran et al. 2019; da Silva Ignacio et al. 2019). It was run in a nitrogen environment at a reaction temperature of 200–300 °C, a rate of heating of below 50 °C/min, and a residence period of 10–60 min (Zhang et al. 2020; Singh et al. 2020). Based on their room temperature condition, waste torrefaction products were classified into three types: solid, permanent or non-condensable gases, and liquid or condensable gases (Abdulyekeen et al. 2021). The solid contained char, significantly altered sugar structures, ash, newly produced polymer structures, as well as the original sugars' chaotic structure, and it was employed for the applications of bioenergy, adsorption, and soil amendment. Whereas, the liquid (unwanted product) containing lipids, organics, and reaction water, was utilized for (a) biogas generation through anaerobic digestion, (b) plant protection as herbicide, pesticide, and insecticide, and (c) phenol–formaldehyde adhesive synthesis in the plywood panel manufacturing process (Cahyanti et al. 2020). In addition, the gas was consisted of CO, CO_2, and traces of hydrogen and methane, which might be burned in the combustor for providing some of the energy needed for the torrefaction. Furthermore, char could be used as a high-quality fuel for remediating soil, co-firing in combustion, and adsorbing contaminants in water treatment (Nobre et al. 2019).

7.3.2 *Biological and Chemical Waste-to-Energy Technologies*

Waste valorization necessitates the integration of conversion methods in order to supply more opportunities for the generation of value-added products and power while lowering overall expenses. Hence, a number of the latest waste biorefinery technologies were attempted to combine with other approaches such as anaerobic digestion in order to provide parallel waste treatment as well as biotransformation to produce chemicals and biofuels (O'Callaghan 2016). Figure 7.4 described current methods of waste biorefinery.

Waste biorefinery processes rely mostly on single conversion technology, and they can be made from organic wastes with the use of rather simple biological methods. Multiple technologies are thus recommended to be combined for forming interconnected biorefinery process chains so that more commercial products can emerge. Furthermore, direct employment of heterogeneous waste is not only unusual but also unsuitable for biorefining, so according to the circular economy concept, it is evident that developing separate collecting systems along with recycling capacity should be a major priority. The reason is that separation technologies are necessary to remove antioxidants, cellulose, amino acids, and other undesirable compounds from

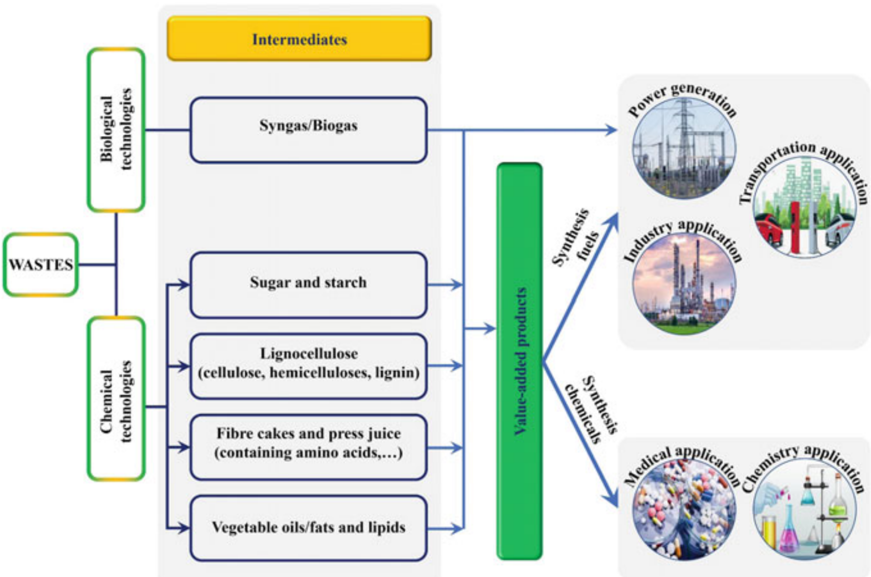

Fig. 7.4 Synthesis of platform chemicals from wastes (Fernando et al. 2006; Menon and Rao 2012)

the refinery process chain. While regular distillation can be employed in petroleum refineries to separate products, the chemical components that are recovered from biomass are observed to be less volatile. If waste is not effectively stored, the costs of substance separation could potentially exceed the value of the final bioproducts (Bastidas-Oyanedel and Schmidt 2018; Ashokkumar et al. 2019). Thus, in the bioeconomy, more intensive sorting of waste strategies as well as the development of appropriate procedures have to be prioritized.

The generation of bio-derived fuel from the use of waste material, among other WtE approaches, has the potential to be applied and constructed globally. For the creation of biofuel, various potential treatments were being investigated (Ali et al. 2020). Remarkably, in the United States, it was calculated to build a CHP facility aiming to process wastewater and produce bio-based fuel, thereby meeting the energy needs of more than 260,000 households. Biofuel was regarded as the most promising renewable energy source contender. It was expected to satisfy the aim of the Sustainable Development Goal in terms of renewable and eco-friendly sources of energy, as well as to help solve the global energy crisis (Acheampong et al. 2017; Bhan et al. 2020). There was a wide range of waste which could be used to generate bio-based fuel. The waste sources could be edible, like palm, corn, soya beans, or sugarcane; cellulosic biomass, including crop residue or wood sawdust, as well as waste from biological mass decomposition (Bilal and Iqbal 2020). Moreover, biomass could be utilized to produce a range of biofuels, including biohydrogen, biodiesel, biogas, and bioethanol (Pari et al. 2018). Biohydrogen, which could be produced both biologically and chemically, was another type of biofuel being studied as a possible replacement for fossil fuels. Attempts were being made to develop a promising bio-based process for biohydrogen production from waste contents rich in carbohydrates from the agriculture, food industries and timber (Gorazda et al. 2013). The chemical process by which lipids react with alcohol and a catalyst being present to form esters based on alkyl fatty acid is known as transesterification. The presence of fast and oil in sewage sludge made it more advantageous because they were a highly saturated lipids' excellent source such as triglycerides, monoglycerides, diglycerides, free fatty acids, and phospholipids (Kengpol et al. 2018; Jamal et al. 2022).

Anaerobic digestion was considered one of the least expensive means of energy production (Anukam et al. 2019). Biomethane or biogas generated through anaerobic digestion has been shown to be a renewable energy source (Materazzi and Foscolo 2019) that may be used not only to displace fossil fuels but also to produce energy (Hussain et al. 2020). In the anaerobic digestion process, organic components of waste such as crop residue, sewage sludge and garden waste were utilized as a substrate in anaerobic digestion, which was put in a closed reactor without oxygen, in which two important parameters in anaerobic digestion included temperature and pH (Li et al. 2015). Microbial activities predominated in the biogasification factory to break down organic waste and had four anaerobic digestion steps: acetogenesis, hydrolysis, methanogenesi, and sacidogenesis. Moreover, organic waste was broken down into protein, lipids and carbohydrates during the hydrolysis. Furthermore, they were transformed into sugars, monosaccharides, and amino acids during acidogenesis, which were further transformed into ammonia and volatile fatty acids during acetogenesis.

In the final stage of methanogenesis, it was observed that bacteria produced methane gas, which could be directly employed for fueling vehicles, cooking, or indirectly used for producing electricity (Pujara et al. 2020). After the biogasification process, the residual slurry could be utilized as manure to condition soil in activities related to agriculture. The microbial community responsible for generating biogas can be classed as thermophilic (50–65 °C) or mesophilic (25–37 °C), with higher operation temperatures generally increasing the speed of conversion in anaerobic digestion. The microbial decomposition processes in anaerobic digestion were quite similar to those in landfills; however, the anaerobic digestion system produced more biogas during a shorter reaction time. It was also demonstrated that anaerobic digestion is able to produce twice to four times the methane production per ton of waste just in three days compared to seven years in landfills (Gao et al. 2017). Furthermore, 1 m^3 of biogas was transformed into 6.7 kWh of energy with current technology (Hasan and Ammenberg 2019). Different process-engineering strategies such as pretreatment, additive dose, and process configuration could be in use depending on the kinds and quality of feedstock (for example, biodegradability, inhibitory components, nutritional content, and so on) (Safarudin et al. 2018; Meng et al. 2018). Anaerobic digestion was a critical process to activate a circular economy, which was especially true in the biological cycle, in which organic matter was treated in a sustainable manner and retained in a closed loop (Hussain et al. 2020). As a result, many problems including chemical fertilizers, waste in landfill, as well as nonrenewable energy could be handled. Actually, for decades, anaerobic digestion has been utilized, and technological advancements these days have resulted in its increasing applications in both developing and developed nations, on both large and small scales (Zhang et al. 2016). During the last twenty years, in Europe, the development of anaerobic digestion treatment capacity has been primarily affected by the policies of the EU, particularly the ones focusing on waste management and prevention, including biodegradable materials' disposal. Its goal was to alleviate climate change while also enriching deteriorated soil (Gregson et al. 2015).

Biogas produced by anaerobic digestion was frequently used to generate electricity or was directly flared in some cases while the value and extent of biogas applications could be greatly enhanced by the removal of CO_2 and other pollutant gases so as to supply biomethane with high quality as an alternative for natural gas in various domestic purposes and industrial uses (Sahota et al. 2018; Srinuanpan et al. 2019). However, biogas from anaerobic digestion cannot be considered as a sustainable energy source without the addition of solar energy or wind power. Anaerobic digestion possessed multi-functionality such as the most obvious strength, reinforcing sustainability principles with ties to numerous breakthrough waste refinery techniques and sustainable agriculture so that waste concerns could be alleviated and nutrient recycling worldwide could be handled. According to recent studies, the critical issue in anaerobic digestion and the bio-economy was to pave the way for the next wave of evolutions that might promote technology and bio-origin products for promoting more sustainable and transformative organic waste treatment.

7.3.3 *Refuse-Derived Fuel*

Refuse-derived fuel is the non-recyclable combustible part with a high calorific of treated waste that can be used as a fuel for producing electricity and steam or employed as an alternative fuel in boilers and industrial furnaces. As a result, particular industrial wastes including sewage sludge, textile waste, plastics, agriculture waste, spent oil, wood cuttings, and scrap papers can be employed in WtE facilities alongside refuse-derived fuel to improve the calorific value. Notably, the refuse-derived fuel process involves separating non-combustible wastes such as metals, glass, sand, stones, and so on, and then the remaining dried waste would be crushed to raise its surface area. Finally, the waste can be directly utilized as boiler feed or processed into pellets if necessary. In the last decade, the creation of fuel from waste in WtE facilities contributed to a 50% decrease in the waste that was transported to landfills (Brew 2020). Aside from wealthy nations, the concern about recovering refuse-derived fuel from waste has spread to some developing countries, including Indonesia, Thailand, and India. Furthermore, refuse-derived fuel is also gaining popularity in the Middle East. Despite being the world's second-biggest producer of gas, the Kingdom of Saudi Arabia initiated research into refuse-originated fuel from municipal solid waste as a promising renewable source of energy (Yang et al. 2021). Figure 7.5 depicted the refuse-derived fuel synthesis from waste. The physical characteristics of optimum refuse-derived fuel included particle size (ranging from 10 to 300 mm), moisture concentration (between 10 and 30%), and bulk density (120–300 kg/m^3). In addition, the ideal calorific value was more than 2,000 kcal/kg with a volatile matter of 75–80% and ash concentration of 10–20% (Akdağ et al. 2016). A lower concentration of moisture along with greater calorific values was desired for a cost-effective and beneficial WtE refuse-derived fuel factory (Vounatsos et al. 2015), while sulphur, heavy metals, and chlorine were not (Psomopoulos 2014).

In general, refuse-derived fuel is seen as a sustainable fuel that mitigates environmental impacts and supports natural resource conservation such as coal, natural gas, and petroleum. The refuse-originated fuel produced was often utilized as a coal alternative in the industry of cement to reduce CO_2 emissions by 40% (Rodrigues and Joekes 2011). Nonetheless, significant attempts should be made to develop novel technologies and enhance existing techniques in order to achieve higher fuel quality and profit margins.

7.4 Barriers to WtE Technologies

Barriers often prevent organizations from developing technologies and processes which are critical for green-supply chains in order to convert energy from waste. The key economic constraints, according to both intermediaries and developers, are related to economic viability, virgin material prices as well as the functionality of

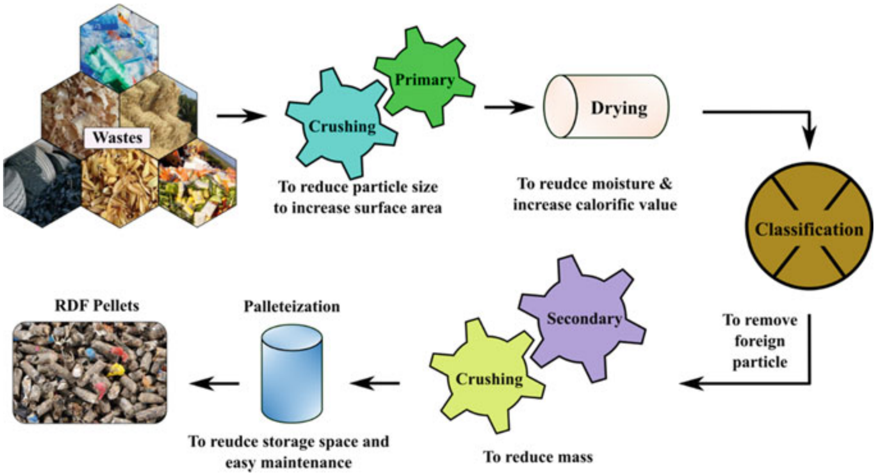

Fig. 7.5 Refuse-derived fuel preparation from waste (Pujara et al. 2020)

the recyclables market. Collection expenses are prohibitively expensive, the materials obtained are insufficiently useful, or their prices are excessively fluctuating. Furthermore, developing markets for secondary materials were shown to provide substantial challenges for biogas actors that used biodegradable waste. Besides, developers raised concerns about losing not only economic but also environmental advantages due to inefficient waste collection logistics. The difficulties associated with a shortage of regional or governmental support, like economic incentives to encourage secondary material markets or directly support funding for R&D activities, were highlighted by intermediaries. Moreover, policymakers faced challenges in developing or implementing green policy chains that could bring benefits to the whole society. Apart from that, the identified barriers differed significantly across intermediaries and developers. In comparison with intermediaries, developers assessed regulatory and institutional impediments as less important. In particular, many intermediaries showed concern about how various rules could restrain the circular economy. Nonetheless, the change of legislation, notably the divided obligations in waste management, was the primary concern of not only developers but also intermediaries. As a result of farmers' concerns about the economics and dependability of farm-scale biogas facilities, the use of waste-derived products as fertilizers has been restricted. Generally, outdated habits and thoughts were hindering the transition to circular processes in every sector. Apart from the aforementioned restrictions, there existed certain technological challenges. Some local industries and firms lacked access to green techniques and remained reliant on conformist methods, which was especially visible in developing countries. If the above-mentioned hurdles were not overcome, climate change, biodiversity loss, and other ecological problems would occur.

7.5 Conclusions

The precipitous rise in global population led to significant urbanization, and thus an unprecedented rise in waste material. Cities were unsustainable due to their abnormally high waste levels. These wastes, on the other hand, represented a rich supply of energy that could be regenerated as a renewable source of energy. Therefore, the supply chain of WtE for the energy system was considered a significant stage for the industrial circular economy in tackling the existing difficulties of energy demand, waste management for the communities in the world, and greenhouse gas emissions. Generally, if WtE technologies were implemented, waste could be regarded as one of the most promising renewable sources of energy as these methods would both alleviate reliance on traditional energy sources in order to meet the ever-increasing demand for energy, but they would also mitigate the waste problem. According to the available WtE techniques, the most viable waste resolutions in developing nations were anaerobic digestion for organic wastes, landfilling for inert wastes, incineration for the mixture of waste, gasification, and pyrolysis for certain waste types. On the other hand, regulations and rules of the governments, advanced technology as well as financial support could improve the future outlook for WtE facilities.

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Chapter 8
Biofuels in Circular Economy

Juliana Ferreira Soares, Jeane de Almeida do Rosário, Flávio José Simioni, and Róbson Ilha

Abstract This chapter presents a constructive analysis of forest biomass, bioethanol, biodiesel, and biogas in the circular economy. Initially, the chapter presents the main production sources of these fuels, conversion processes, and potential applications (thermal and electrical energy and vehicle fuel). Alternatives for the use of residues and byproducts of production processes are then discussed, promoting the circular economy approach in production chains.

Keywords Biofuels · Alternative energy · Biomass · Biodiesel · Bioethanol

8.1 Introduction

The depletion of non-renewable resources and the degradation of environmental quality are major problems associated with a linear economy based on fossil fuels. To circumvent this scenario, recent studies have focused on the circular economy based on biofuels, which can be produced from renewable sources, such as solid waste and effluents from industries, rural farms, and homes. In addition to increasing the supply of renewable energy and diversifying the energy matrix, this strategy contributes to the correct treatment of waste and effluents as well as a reduction in greenhouse gas emissions.

According to the International Energy Agency (2021), the world's total primary energy supply was 606.5 EJ in 2019, of which only 13.8% was produced from renewable energy sources. Biofuels and renewable municipal waste accounted for 9.1%, hydro 2.5%, and wind, solar photovoltaic, solar thermal, tidal, and geothermal 2.2%. Considering the high costs of producing biofuels and the limited supply of affordable, sustainable raw materials, the great challenge for the future is to mobilize

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investments to develop large-scale facilities and seek new sustainable biomass supply chains (IEA 2021). In this context, the circular economy based on biofuels can be considered an option for overcoming these limitations.

Traditional linear economy considers the approach by which resources are produced, used and discarded (Blades et al. 2017). In the circular economy, the concept of "end of life" is replaced with the reduction, reuse, recycling, and recovery of waste in the stages of production, distribution, and consumption, operating on the micro level (companies, products, consumers), meso level (industrial parks), and macro level (city, region, and nation) (Kirchherr et al. 2017). Therefore, the circular economy is based on the concept of zero waste; all waste generated in the production chain is used sustainably, enabling a balance between industrial/economic development and environmental conservation/protection (Kapoor et al. 2020).

The circular economy concept can be applied to the production chain of biofuels, such as forest biomass, bioethanol, biodiesel, and biogas. For instance, Blades et al. (2017) state that biogas production from anaerobic digestion (AD) could be at the heart of sustainable rural energy infrastructure. Farms can provide crop residues and animal waste and local industries can provide food waste as feedstock to generate biomethane and electricity. Biomethane can be returned to the local community, fueling agricultural vehicles and public transport, and electrical energy can be used on local farms as well as in homes and industries. AD digestate can also be used as fertilizer in agriculture and the cycle can continue.

This chapter presents the circular economy approach to the life cycle of forest biomass, bioethanol, biodiesel, and biogas. The analysis includes the raw materials and production process of each biofuel, the residues resulting from these processes, and how they can be inserted back into the production chain.

8.2 Biofuels

8.2.1 Forest Biomass

Biomass is characterized by its versatility of uses and the different conversion routes used to generate bioenergy. Despite the wide range of types of biomasses, this section focuses on the use of biomass of a forest origin, considering its different production chains that are part of the forest-based sector and fall within the perspective of a circular economy (Fig. 8.1).

Forest raw material can be grouped into two categories: primary origin and secondary origin. Considering the primary raw material, biomass is composed of natural materials from trees, such as stems (logs), branches, bark, and roots. This material can be obtained directly from forests planted for multiple uses or forest crops specifically intended for the supply of bioenergy, also known as "energy forestry". Trees are harvested and logs (with bark) are generally used for the production of firewood or transformed into chips. In some cases, residues from forest exploitation,

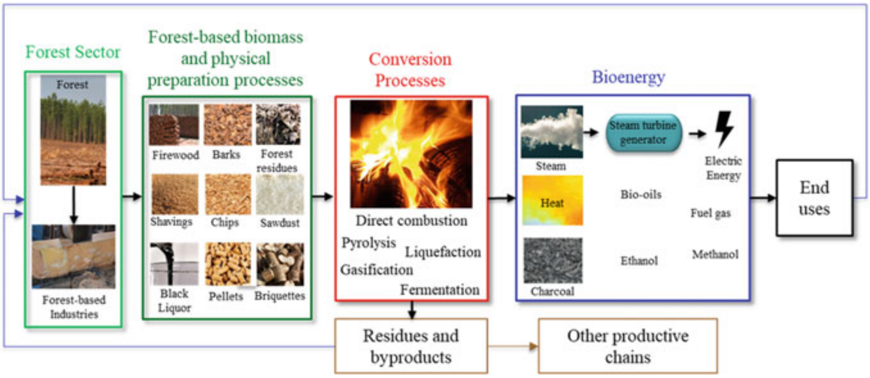

Fig. 8.1 Forest biomass, its energy conversion processes and types of bioenergy in the circular economy approach

such as stumps, small saw timber, branches, and other woody materials, are also used for energy purposes. Leaves and roots remain in the soil for nutrient cycling.

The second group is composed of residues generated in different processes of the industrial transformation of wood, such as sawmills, wood-based panel industry, pulp and paper industry, furniture factories, etc. The main residues generated are bark from the log debarking process, sawdust and chips from wood cutting processes, and black liquor from the pulp and paper industry. In general, the energy conversion routes of forest biomass can be classified in three ways: physical processes, thermochemical processes, and biological processes (Lora and Andrade 2009).

Regarding the physical processes of biomass preparation, it is common to chip whole wood logs, sideboards, or parts of wood from industrial processing for the production of smaller particles (chips). Wood waste from industrial production, especially that with smaller granulometry, may also receive pre-treatment, such as densification via pelletizing and briquetting processes. Combined with other forms of pre-treatment, such as drying and roasting, these processes give the biomass greater energy density (Phanphanich and Mani 2011; Shahrukh et al. 2016; Stolarski et al. 2013) and represent a potential market for forest biomass (Lestari et al. 2022).

The main thermochemical processes of transforming wood into energy are direct combustion, pyrolysis, liquefaction, gasification, and fermentation (Vidal and Hora 2011). Direct combustion is one of the oldest forms of heat generation used by humans. It can be used in wood stoves for cooking food and/or space heating or in industrial ovens for generating heat. It can also be burned in boilers, where thermal energy is generated in the form of steam. The steam produced in a boiler can be used directly in various industrial processes or to produce electrical energy by directing the steam to a turbine and generator system. It is also possible to combine a system that generates thermal and electrical energy at the same time, which is denominated cogeneration.

Pyrolysis is a carbonization process used to produce charcoal, with fuel gas, tar, and pyroligneous acid as byproducts. Charcoal has wide application in various domestic and industrial activities. For instance, it is used as a thermo-reducer in the iron and steel industry (Mousa et al. 2016; Pena-Vergara et al. 2022). Liquefaction consists of transforming biomass into liquid products under conditions of high temperature and pressure. The resulting products include bio-oils (crude), an aqueous fraction, solid residue, and a gaseous fraction (Peterson et al. 2008; Singh et al. 2015). With this process, lignin, tannins, and other products can be extracted from biomass and used for different purposes, such as to produce resins (Zhao and Yan 2014). Gasification, on the other hand, transforms biomass into gaseous products, while fermentation, which is a biological process, results in ethanol. Some of these technological processes have greater technological maturity and economic viability than others and their use depend on the scale of production (Lora and Andrade 2009) as well as the physicochemical characteristics of the forest biomass.

From a circular economy standpoint, the use of charcoal in the iron and steelmaking process rather than fossil fuels reduces the environmental impact by 14% (Liang et al. 2020) and is one of the options for reducing CO_2 emissions (Mousa et al. 2016; Pinto et al. 2018). Pyroligneous acid has antimicrobial, antioxidant, and pesticidal properties and also plays a role in plant growth, demonstrating potential application in agriculture (Grewal et al. 2018). Tar also has several uses, such as in veterinary and traditional medicine, the cosmetics industry, and other uses, including as insect and animal repellents (Ninich et al. 2022). The gases produced in charcoal production ovens can be used for different purposes either by combustion to produce heat (for drying wood, for example) or to generate electricity, contributing to a reduction of up to 90% of all categories of potential environmental impacts from this process (Miranda Santos et al. 2017).

Taking the offer of bioelectricity from forest biomass as an example, there are 121 plants in operation in Brazil (ANEEL 2021). The pulp and paper sector uses black liquor (21) for electricity generation, whereas steel mills use charcoal (7) and blast furnace gas (12). In regions where the wood processing industry of planted forests is concentrated, there are 10 energy units based on firewood, 69 based on forest residues and one on biogas. There are more than 4300 MW of power plants installed in regions with the highest concentration of forest production (Junior et al. 2020), demonstrating that energy recovery is one of the main ways of using wood waste for a circular economy (Silva et al. 2020). Furthermore, about 2/3 of companies in the Brazilian forest-based industry use energy from renewable sources as a circular economy practice (Tedesco et al. 2022).

From the standpoint of the transition to a sustainable economy, Braghiroli and Passarini (2020) carried out a review study and presented evidence of recent technological innovations that enable adding value to forest biomass residues through their conversion to biomaterials. Taking the use of forest biomass in Portugal as an example (Gonçalves et al. 2021), the circular flow was 49% for energy use and 51% for the production of other materials, with emphasis on paper and wood packaging as the most recycled products, while the panels' sector used the most industrial residues. Another example of circularity is the use of ash resulting from the burning of forest biomass, which has several applications, such as in soil for nutrient replacement, closing the production cycle (Symanowicz et al. 2018), and treating sewage sludge (Wójcik et al. 2020).

8.2.2 Bioethanol

Bioethanol is a fuel produced from the fermentation of sugar sources concentrated by distillation processes. Several biomasses are sources of sugar—from those most easily converted into alcohol (e.g., sugarcane and fruit juices, which provide simple carbohydrates, such as glycose) to intermediate sources (e.g., grains and roots, which provide starch) and the most complex (e.g., wood and plants, which are sources of cellulose). Simpler sources of sugar are easier to convert it into alcohol (Gonçalves et al. 2022; Zabed et al. 2016). Sugarcane juice, for instance, is obtained by crushing the sugarcane stalk. The juice is then subjected to a simple pre-treatment (sieving, pre-heating, decantation, and filtering) to make it suitable for the fermentation process. As starch is formed by long-branched glycose chains, it should be first hydrolyzed by malt enzymes. Cellulose, however, is much more difficult to convert into alcohol, since it is formed by a complex polymeric structure and is associated with lignin, which makes the vegetable components more adhered and therefore more difficult to break down and digest. Hence, cellulose requires thermochemical pretreatment, which involves a higher consumption of energy and chemicals (Zabed et al. 2016).

The type of sugar biomass depends on the suitability of the crop in a given region. Countries such as Brazil and Indonesia have a strong culture of sugarcane and fruit crops, mostly due to the availability of land and water as well as the favourable climate and soil (Paixão et al. 2020). European countries and the United States rely mainly on starch sources, such as corn (Li et al. 2022). Each crop results in different requirements of soil preparation, pesticide use, and irrigation as well as harvesting, which can be by hand or mechanized. This exerts an influence on the quality of the produced juice (sugar and dirt content and, consequently, the need for washing) and the environmental impacts. In Brazil, for instance, a common practice in the hand harvesting of sugarcane is the burning of the plantation to eliminate the straw and facilitate the collection of sugarcane stalks (Galdos et al. 2013).

The fermentation process occurs by reaction (8.1) and regards the digestion of sugar by yeasts (e.g., *Saccharomyces cerevisiae*). From 6 to 72 h (depending on the source), most sugars are transformed into very diluted ethanol (also known as wine) at a concentration of around only 9ºGL. This product must be distilled to concentrate the ethanol to a concentration of up to 96ºGL, providing the first commercial product: hydrated ethanol, which is frequently used as a direct fuel in Flex and alcohol-powered vehicles. Some of the hydrated ethanol is dehydrated in a distillation process with cycle-hexane or benzene, generating the second commercial product: anhydrous ethanol, with a concentration of up to 99ºGL, which is used as a gasoline additive (Boddey et al. 2008).

$$C_2H_{22}O_{11} + H_2O \xrightarrow{\text{yeast}} 4C_2H_5OH + 4CO_2 \quad (8.1)$$

Advantages:

- Cleaner burn and lower emissions of greenhouse gases, such as CO_2
- Extensive residue recycling
- Potential for energy sustainability of the process
- Use as gasoline substitute or additive
- In Brazil:
  - Availability of sugarcane crops (simple sugar)
  - Existing infrastructure and logistics of production, distribution, and commercialization since the 1980s.

Problems:

- Lower calorific value (in comparison to oil derivatives)
- Influence of climate and agriculture (precipitation, air temperature, soil condition)
- Seasonal labour (can lead to working in precarious conditions and slave/child labour)
- Use of pesticides (especially herbicides on sugarcane crops)
- Competition with food production (can lead to an increase in food prices).

There are several possible routes of the circular economy that can be associated with bioethanol production (Fig. 8.2). Most residues generated during the production of bioethanol can be used in other processes and feedback into the process itself. Most cellulosic residues obtained during the planting and harvesting of sugar sources and extraction of sugar juice have high calorific power and, therefore, have potential use as biomass fuels to generate electricity for the plant or heat, which is required in the fermentation, distillation, and other steps (Boddey et al. 2008).

The burning of sugarcane straw and bagasse in Brazilian alcohol plants, for instance, has increased the participation of biomasses for thermal purposes in the energy matrix of the country (REN21 2021). Recently, however, cellulosic residues have been gaining more importance for the obtainment of second-generation alcohol, which can lead to lower greenhouse gas emissions in comparison to direct burning. Corn cobs, corn stover, sugarcane bagasse, fruit peels and fibres, and seed husks have been studied and applied to produce ethanol through lignocellulosic routes (Akbas and Stark 2016; Carvalho et al. 2020; Freitas et al. 2021; Hofsetz and Silva 2012). These residues can be also destined for animal food.

Some residues can also be applied as biofertilizers and for soil amendment, such as the ash produced during residue burning, the filter cake generated during the filtration of the sugar juice, and the bottom products of the distillation operation, known as vinasse. Vinasse, particularly, is a subject of concern due to the high productivity (10–15 L of vinasse for each litre of alcohol produced from sugarcane) and high levels of oxygen biochemical demand and oxygen chemical demand (close to

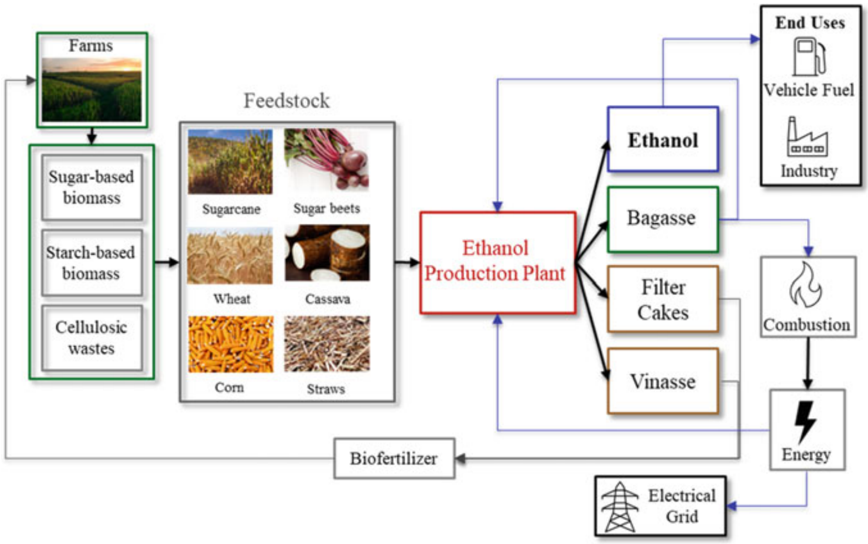

Fig. 8.2 Ethanol production chain in the circular economy approach

those of domestic sewage) (Cortes-rodríguez and Fukushima 2018). It is traditionally applied in fertigation due to its high potassium content, but unrestricted use can have serious environmental consequences, such as soil and water contamination (Nair and Taherzadeh 2016). In the search for other alternatives, some studies are evaluating the use of vinasse and filter cake as co-digestion substrates to produce biogas (Moraes et al. 2015) and the recycling of vinasse in fermentation, substituting part of the water used in the preparation of fermentation wort.

8.2.3 Biodiesel

The increase in fuel demands combined with environmental concerns has led to the investigation of fuel alternatives to petroleum and its derivatives. Diesel use is associated with a high level of carbon dioxide (CO_2), carbon monoxide (CO), sulfur dioxide (SO_2), and particulate matter emissions (Sanjid et al. 2014). Among the different renewable energy sources, biodiesel has received considerable attention in recent years. Biodiesel production was 41 billion L worldwide in 2019 and is projected to reach 46 billion L by 2025 (IEA 2020a). Biodiesel can currently be produced from vegetable oils (edible and non-edible), animal fats, microalgae, biomass waste, and waste cooking oil (WCO). Figure 8.3 illustrates biodiesel production in the circular economy approach.

Transesterification is the most widely used technique to produce biodiesel from various feedstocks to reduce the molecular weight of raw oil and viscosity (Zareh

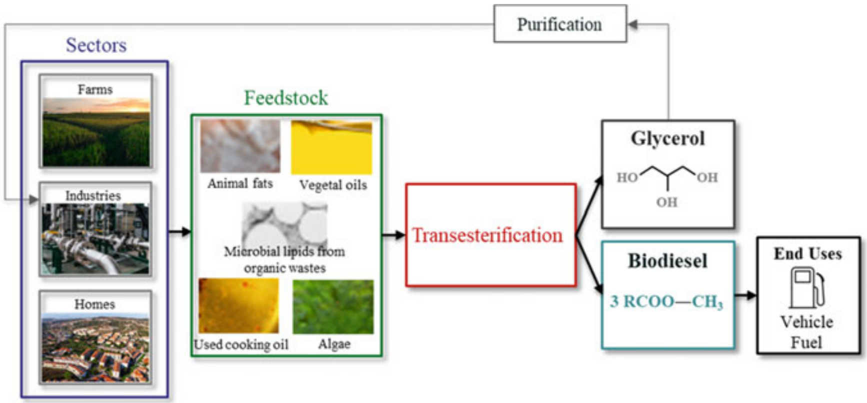

Fig. 8.3 Biodiesel production in the circular economy approach

et al. 2017). In the transesterification process, oil reacts with alcohol in the presence of strong catalysts, resulting in an alkyl ester (biodiesel) and a byproduct known as glycerol (Fadhil et al. 2018). Glycerol accounts for 10% (mass basis) of biodiesel production and has numerous applications in the personal care, pharmaceutical, food, and cosmetic industries and is also used as a lubricant and plasticizer (Kazmi and Clark 2012).

Edible plant oils (first-generation feedstock) are used in biodiesel production and the food industry. Thus, usage has increased for a few decades. Different edible oils (e.g., sunflower, palm, and soybean oil) produce approximately 95% of biodiesel globally (Nayab et al. 2022). As most biodiesel is made from edible oils, there is some concern that problems may arise. The risk of limitations in the food supply is the main disadvantage of using these feedstocks (Aransiola et al. 2014). By converting edible oils into biodiesel, food resources are being converted into automotive fuels, increasing the cost of food products. This major disadvantage underscores the need to study new sources of raw material.

The use of WCO and non-edible plant oils as feedstock in biodiesel production would eliminate competition with food consumption and decrease production costs. Non-edible oils (second-generation feedstock) are obtained from lignocellulosic biomass and wastes from different agricultural and forestry processes (Nayab et al. 2022). Studies (e.g., Silitonga et al. (2014)) have proven that biodiesel produced from non-edible oil is a promising option. Some examples of non-edible oilseed crops are *Calophyllum inophyllum*, *Hevea brasiliensis* (rubber seed), *Mahua indica*, *Pongamia pinnata* (Karanja), and *Pongamia glabra* (koroch seed). Non-edible plants are used for afforestation to reclaim wastelands (Yang et al. 2014), are well adapted to arid and semi-arid conditions, and require low fertility and moisture demand to grow (Atabani et al. 2013). As these plants do not compete with food, the seed cake after oil expelling may be used as organic matter for soil enrichment (Emmanuel et al. 2011).

The biodiesel produced from animal fat, WCO, microalgae, fish oil, and other products is denominated as third-generation biodiesel. The major benefits of this generation of biodiesel are the lower greenhouse effect, high growth rate and productivity, less competition for agricultural land, higher amount of oil percentage, and lower effect on the food supply (Singh et al. 2020). Every year, a large amount of WCO is generated throughout the world, such as in Europe (4 Mt) and the USA (0.75 Mt) (Sharma et al. 2020). WCO is two to three times cheaper than fresh vegetable oil, resulting in a significant reduction in processing costs (Said et al. 2015). The use of WCO as feedstock for biodiesel production also constitutes eco-friendly pollutant disposal for this residue and helps promote the circular economy.

Although WCO is available in abundance, the presence of water and impurities are among the major challenges in using WCO as feedstock (Kodgire et al. 2022). These undesirable properties result in low biodiesel productivity due to saponification during transesterification (Milano et al. 2018). To improve the physicochemical properties of WCO biodiesel, research is being carried out using mixtures of WCO with other types of oils (e.g., Martinez-Guerra and Gude 2014; Yunus Khan et al. 2015; Milano et al. 2018).

Minimal water requirement, high tolerance to carbon dioxide content, and no required herbicides or pesticides to grow are some of the multiple advantages of microalgal feedstocks for biodiesel production over conventional terrestrial feedstocks (Jacob et al. 2021). Microalgae can also be used for coupling biodiesel production and wastewater treatment. Therefore, various sources of wastewater from industry or sewage containing nutrients, such as phosphorus and nitrogen, can be exploited as a nutrient supply for the culture, contributing to the circular economy. Arif et al. (2020) showed that *Chlorella sorokiniana* is a viable option for use as feedstock in biofuel production and wastewater treatment.

Although third-generation biofuels are far more advantageous in comparison to the other generations, algal cultivation can only be achieved in expensive photobioreactors (Jacob et al. 2021). Thus, algal biodiesel is not considered economically viable in the current scenario (Brar et al. 2022). The production of microalgal biodiesel in the form of a hybrid refinery along with the production of conventional microalgal products can improve the marketability of microalgae and, consequently, economic viability (Goh et al. 2019).

Animal fat has recently drawn attention as a potential economically sustainable feedstock. Animal fat is mainly used as raw material in the cosmetics and soap industries. Waste animal fat (WAF) is an attractive biodiesel feedstock due to its lower cost in comparison to vegetable oils (Habib et al. 2020; Simsek and Uslu 2020). Another benefit is that the use of WAF in biofuel avoids the need for waste disposal. WAF obtained from meat processing industries and slaughterhouses seems to be a suitable feedstock for biofuel synthesis due to its renewable nature, good calorific value, chemical inertness, and zero corrosivity (Andreo-Martínez et al. 2022). Chicken fat, mutton fat, beef tallow, duck tallow, pork skin, and pork lard are some of the animal fats studied for biodiesel production. Compared to the traditional transesterification of vegetable oil (US$ 0.6–0.8 per litre), biodiesel production from WAF is currently cheaper (US$ 0.4–0.5 per litre) (Balat 2011). Although the use of WAF for biodiesel production is a promising option to help reduce the price of biodiesel, further investigation and technological development will be needed.

8.2.4 Biogas

Anaerobic digestion (AD) is a recognized process for converting organic waste into energy, which contributes to sustainability in the production chain. The great advantage of AD is the production of biogas, which is a potential alternative to fossil fuels. The use of biogas reduces the consumption of fossil fuels and the amount of organic waste sent to landfills, which consequently contributes to a reduction in greenhouse gas emissions (Abad et al. 2019). Biogas can be used as a source of thermal and electrical energy for homes, industries, and farms, and as a fuel for automotive vehicles and industries. AD also results in a digestate, which is rich in nutrients and can be used as organic fertilizer in crops. Thus, AD products may not only be an important source of energy and resource for farms, industries, and homes, but the organic waste generated in these sectors can also be important sources for AD plants, which is a clear demonstration of the circular economy approach (Fig. 8.4).

The AD process involves four steps in which different microorganisms degrade organic substrates in the absence of oxygen: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The operational conditions and the type of substrate exert an influence on the composition of the biogas. According to Ryckebosch et al. (2011), biogas is composed mainly of methane (40–75%) and carbon dioxide (15–60%). Small amounts of other components may be present and are inconvenient if not removed, such as water (5–10%), hydrogen sulfide (0.005–2%), nitrogen (0–2%), ammonia (<1%), oxygen (0–1%), halogenated hydrocarbons (<0.6%), carbon monoxide (<0.6%), and siloxanes (0–0.02%).

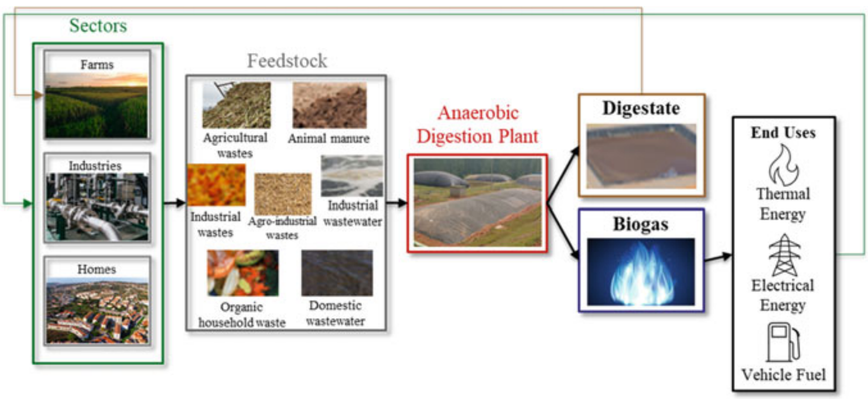

Fig. 8.4 Biogas production in the circular economy approach

Substrates for the production of biogas include agricultural and agro-industrial waste, animal manure, industrial organic waste and effluents, the organic fraction of municipal solid waste (MSW), and sanitary effluents. Mono-digestion is the term used when only one type of substrate is used for AD. According to Mata-Alvarez et al. (2014), however, this process has some disadvantages. For instance, animal manure and slaughterhouse waste have high concentrations of N, which can inhibit methanogenic activity. The organic fraction of MSW has a relatively high concentration of heavy metals and improper materials. Moreover, crops and agro-industrial waste are seasonal substrates.

To overcome the problems of mono-digestion, two or more substrates can be used in the process, which is denominated co-digestion (Mata-alvarez et al. 2014). The co-digestion strategy makes this process even more suitable for the circular economy concept, as different types of organic waste or effluents from a region can be used together in a plant. An example of this is the work being done by Blades et al. (2017), who investigated the application of a biogas-based circular economy in a rural agricultural environment in Northern Ireland. The feedstock used in the AD plant is a combination of grass silage, chicken litter, and cattle slurry obtained from the family dairy farm and other local farms. According to the authors, the AD plant analyzed has the potential to fuel 22 average-size dairy farms in N. Ireland. Moreover, the authors calculated that only five dairy farms would be needed for an annual supply of grass silage and cattle manure.

Abad et al. (2019) estimate the economic impact and biogas production in a real AD plant when changing from a mono-digestion scenario (organic fraction of MSW) to a co-digestion scenario (organic fraction of MSW with 13 types of industrial waste) in a circular economy framework. The characteristics of the waste exert a considerable influence on the cost of AD and the income of the plant. The biogas production potential, the presence of non-biodegradable materials that must be separated and correctly discarded, and the physical characteristics of each type of waste are the main variables to investigate. The results of the economic analysis demonstrated the feasibility of co-digestion, as the calculated costs of industrial waste treatment are lower than the organic fraction of MSW treatment. Moreover, the management costs of rejected materials (non-biodegradable materials) were the main factor that affected the cost of the AD plant.

The amount of waste currently used for biogas production is insignificant compared to the real potential of such waste in generating this biofuel. Kapoor et al. (2020) identified several barriers to the effective implementation of agricultural waste in a biogas-based circular economy, which can also be considered for other types of waste used in AD: (1) the lack of cost-effective technology for biogas production; (2) the lack of an efficient waste supply chain; (3) competition with more established energy technologies; (4) the high capital costs of the technologies; (5) the lack of efficient subsidies and compensations for waste in biogas-based systems; (6) the lack of coordination and cooperation on the part of the policy-enacting authority; (7) no comprehensive appropriate policies; and (8) the lack of policy enforcement and compliance.

As strategies for the effective implementation of the circular economy, Kapoor et al. (2020) suggest the establishment of policies, subsidies, incentives, compensations, and regulatory responsibility, the development of performance evaluation programs, the development of maintenance and regulatory programs, and the regular training and knowledge upgrading of stakeholders. The production of biogas has been uneven throughout the world, as it depends, in addition to the availability of raw materials, on policies that encourage its production and use. Currently, Europe, China, and the United States account for 90% of the global production and the main feedstocks are crops, animal manure, and MSW. Of the total amount of biogas produced in 2018, approximately 64% was used to generate electricity and heat (IEA 2020b).

8.3 Conclusion

The biofuels discussed in this chapter have major advantages over fossil fuels, such as reducing pollutant gas emissions and the disposal of waste in landfills. The use of waste to produce biofuels also adds value to these materials and introduces them back into the production chain, which is the objective of the circular economy approach. However, the percentage of biofuels in the world energy matrix remains low. There is a need for greater development and investment in production technologies as well as the dissemination of knowledge and the creation of incentive policies.

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Chapter 9
Circular Economy and Climate Change Mitigation

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Abstract The development of a circular economy seems more important than ever for cities. Due to urbanization and climate change, cities are forced to find new paths to a sustainable future. Climate change poses a significant threat to the environment in this regard, particularly in light of its impact on both natural and human systems. Humans are playing a vital role here. Approximately one billion tons of building debris is generated annually by the construction industry, which makes it one of the largest waste sources in the world. To mitigate climate change, we must be efficient with resources and reduce the consumption of materials and energy by delaying, shutting down, and shrinking the consumption cycle. Despite a recent spike in related literature, with 20 articles (83%) published in 2018–2019, this chapter shows that few studies have examined the connection between circular economy solutions and climate change mitigation. EVCIs (electric vehicle charging infrastructure) has been widely regarded as a strategic asset and a crucial public service for supporting the low-carbon transition in the transport sector since electrification became one of the most promising methods for a low-carbon transition. The deployment of EVCI requires massive investments, and the urgent need to combat climate change makes it important to maximize the environmental benefits of EVCI within limited resources. From a circular economy and energy transition perspective, this study proposes a set of targeted efficiency improvement strategies for provinces at various stages of development. Citizens' multiple actions that are directed at addressing climate change demonstrate extra commitment, which leads to progress to a circular economy among waste reduction, environmentally friendly shopping, eco-friendly transportation, and reduction of domestic energy consumption. A paradigm shift in citizens' attitudes toward climate change is necessary to combat climate change effectively, thus paving the way for a circular economy.

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9.1 Introduction

Climate change is quickly becoming one of the world's most pressing issues today. The main goal of international environmental policies is to achieve an agreement worldwide to maintain global warming below a critical threshold, i.e., to limit the temperature increase to 1.5 °C (IPCC 2018). The achievement of this objective will require a reduction of greenhouse gas (GHG) emissions (which are responsible for 55% of global emissions) and the transition to a zero-emissions economy by the year 2050 to achieve this goal. As a result of climate change policy, consumers and producers are responsible for limiting their contribution to climate change (European Environment Agency (EEA) 2015). For a long time, climate change strategies primarily focused on reducing energy use, improving energy efficiency, or utilizing renewable energy sources to combat global warming (Eurostat 2016). Fossil fuels contribute significantly to the production of greenhouse gases (EEA 2013), which is why efforts should be made to find alternative energy sources that require less carbon-intensive fuels, as well as to improve the efficiency of production on the production side of the equation. However, it remains to be seen whether energy-related improvements in production, such as those related to the Kyoto Protocol, will be sufficient to meet the targets of the Protocol regarding global warming (EC 2010). For example, household products use over a long period is one of the key indirect regulators of energy consumption during the entire production process (Jones and Kammen 2011). For production to proceed, it is important to keep in mind that the consumption demands catalyze the production process. There is, therefore, a need to focus on the consumption side of climate mitigation to reduce the impact of climate change. It has been found that the "take-make-use-dispose" economy model, which is widely prevalent in the modern world, is not sustainable over the long run due to its inefficiency when it comes to resource use. Our mission should be to promote a circular economy (CE), which uses closed-loop systems to reuse biological and technical resources to the maximum extent possible instead of relying solely on closed-loop systems to reuse biological and technical resources to the maximum extent possible (Mendoza et al. 2017). In the past few years, many factors have contributed to the increase in resource demands and the resulting problems concerning the environment, which are the direct consequences of those increases (Hoornweg et al. 2013). There is a prediction that global primary material extraction will triple by 2050 and that resource extraction and processing will account for 90% of biodiversity loss during this period (International Foundation for Research in Paraplegia, 2019). As raw material costs have been increasing in the past several years, a key reason for adopting the CE principles has been attributed to the unpredictability of raw material costs (Heyes et al. 2018) as a key economic driver. As an example, between 2014 and

2018, the price of cement and building metals in the United Kingdom (UK) rose by 9.4% and 7.2%, respectively 2014 and 2018 (Defra and NS 2019). In the CE model, the system is described as a regenerative system in which resource input, waste, emissions, and energy leakage are minimized by slowing down, closing, and narrowing the material and energy loops to minimize their input and waste (Geissdoerfer et al. 2017). Generally, the ability to slow down resource loops over time leads to items being used for a longer period, therefore maintaining their value over time, while closing resource loops provides opportunities for waste materials to be upcycled to create new value or restore value from them (Bocken et al. 2016). Last but not least, closing resource loops are associated with the development of eco-friendly solutions that will minimize the consumption of resources per unit of a product or service as well as the environmental impact that a product or service has on the environment (Mendoza et al. 2019). There are a number of obstacles that need to be overcome to implement the CE model. Approximately 9% of the world's materials are "circular," according to one estimate, which means that 8.4 Gt of materials are recycled input, while 84.4 Gt of resources are new virgin materials (Circle Economy 2019). There are over 10 times as many material inventories (mostly minerals and metals in buildings, infrastructure, and capital equipment) as there is annual material throughput (890 Gt against 92.8 Gt, respectively) (Circle Economy 2019). As far as the environment is concerned, there is no doubt that the construction and maintenance of houses, offices, roads and other infrastructure has the biggest impact on the environment, consuming about half of the global material consumption and resulting in about 20% of the world's greenhouse gas emissions (GHG) (Circle Economy 2019). Based on the consumption of 42.4 Gt of resources a year, this sector has the greatest environmental footprint. Additionally, it is estimated that at the level of the European Union (EU), there will be more than a billion tons of construction and demolition debris produced by the year 2020, of which half is expected to be excavation materials (Jiménez-Rivero and García-Navarro 2017). There is a need to take immediate action to significantly enhance the resource efficiency and environmental sustainability of urban development as a result. Although the implementation of a CE is thought to have a direct impact on one of the Sustainable Development Goals of the United Nations for 2030 (responsible production and consumption), CE strategies can also play an imperative role in achieving Goal 11 of making cities and human settlements inclusive, safe, resilient, and sustainable, as well as Goal 13 on the mitigation of climate change (Our World in Data team 2023). Therefore, CE is regarded as an essential component of sustainable development (Mendoza et al. 2017). It has been stated that by 2050, the EU wants to reduce greenhouse gas emissions by 80–95% compared to 1990 levels (European Commission 2018). It is estimated that the construction industry is responsible for more than a third of the overall greenhouse gas emissions in the EU (European Commission 2019). The Building Energy Performance Directive (European Parliament and Council 2010) and the Energy Efficiency Directive (European Parliament and Council 2012) aim to reduce the number of operating emissions associated with the use and maintenance of buildings, respectively. Although the restrictions apply to the development and deconstruction of structures, it must be noted that these restrictions do not consider the embodied emissions created through the construction and deconstruction processes (Giesekam et al. 2014). According to Scott et al. (2018), more than half of the 773 Mt of CO_2 emissions embedded in construction materials in the EU are not covered by the energy efficiency of buildings directive (European Parliament and Council 2010) and the program for trading greenhouse gas emissions (European Parliament and Council 2003). As a result, there has been a lack of attention paid to embedded emissions during environmental impact assessments. It is because typical environmental impact assessments place the greatest emphasis on operational emissions as the largest contributor to overall buildings-related emissions (Ng et al. 2013). It has been suggested that the implementation of circular economy (CE) techniques is one of the potential instruments which can be used to achieve the National Development Goals (NDGs) of the country. CE has had an increasingly pivotal role in meeting the CO_2 reduction objectives of several developing nations. There is no doubt that this trend will continue shortly. There is growing interest in applying this approach to both the scientific community, the industry, and the government arenas in developed and developing countries (Geissdoerfer et al. 2017). CE is a very well-accepted definition in the technology sphere, as it can be defined as a tool that can help reduce the rate at which natural resources are consumed in the technosphere as a result of slowing or blocking the flow of materials and resources at all levels (micro, meso, and macro) (Geissdoerfer et al. 2017; Haas et al. 2015; Iacovidou et al. 2017). It has been reported that a number of scientific studies have been conducted to investigate the relationship between CE and the reduction of greenhouse gas emissions because of CE (Cantzler et al. 2020; Pauliuk et al. 2020). As part of the study, researchers examined the impact of CE measures that are implemented at different levels, such as those implemented at the local level such as municipalities (Christis et al. 2019), as well as those implemented on a larger scale, such as nations or continents (Liu et al. 2018). However, it is critical to note that their assessments are often incomplete, with some materials or industry sectors being excluded from the assessments. Therefore, they do not take into account the activities of a whole country. There is also a tendency in some parts of the world for CE to be limited to activities involving material recycling or, in a broader sense, waste management. However, other elements, such as reuse, repair, or remanufacturing, are also vital factors to consider (Kirchherr et al. 2017). Consequently, the scientific literature on CE lacks a comprehensive methodology that can be used to assess the contribution of CE to climate objectives at the country level, with the additional option of identifying significant emitting sectors that might contribute to the development of NDCs. According to the Ellen MacArthur Foundation (2019), to achieve such reductions in carbon emissions, the energy system will need to decarbonize by 11.3% annually, which is seven times greater than its current pace (Ellen MacArthur Foundation 2019). Although, climate change policies should not simply focus on reducing GHG emissions from energy sources, but should also be directed towards reducing the number of raw materials used in fossil-fuel-based industrial processes since they represent 45% of the total current global GHG emissions (Behrens 2016). Due to the increasing number of people on the planet, the increasing demand for finite resources and energy, and the stress on the environment, climate change policy becomes essential for constructing a sustainable future civilization. To reverse the trend, it is imperative to replace the existing production and consumption paradigm with a more sustainable paradigm to reverse this trend. Even though traditional energy-related mitigation strategies, such as modifying energy systems together with the use of renewable energy or improving energy efficiency, will not be able to meet the 1.5 °C targets by 2050 since they only tackle a part of total emissions (IPCC 2014).

Furthermore, it will also be crucial to develop solutions that can address the growing demand for materials used in the production of goods and services to meet the increasing demand for materials used in the production of those goods and services. Due to the use of these materials, carbon emissions are generated as a result of their use or land resources are depleted as a result of their use. From a technical point of view, it is no surprise that the circular economy (CE) concept emerged from the field of industrial ecology as a means of finding new, sustainable business models and is attracted a wide range of attention from all corners of the globe that is looking for new sustainable business models. This concept was developed as an alternative to the old production model by altering the way things are produced and consumed. This is to alter how things are produced and consumed to alter how things will be created and consumed in the future. To increase efficiency and long-term sustainability, an increasing number of organizations are incorporating CE concepts into their business models to achieve better resource utilization and long-term sustainability (Lüdeke-Freund et al. 2019; Kraus et al. 2018). The evidence on the importance of CE in supporting the Sustainable Development Goals (SDGs), and specifically the 13th objective of the SDGs, which is related to climate change, is widely acknowledged (Schroeder et al. 2019). There is an argument in the Circular Gap Report that by shifting to a circular economy, we may have a greater chance of avoiding serious climate change, and this would allow societies to fulfil their commitments under the Paris Agreement on Climate Action, as outlined in the Circular Gap Report (Circle Economy 2019). There have been several research agendas in various parts of the world that have been reshaped as a consequence of CE gaining the attention of policymakers all over the world. Taking the Chinese government as an example, the Chinese government has incorporated this notion into its recent Five-Year Plan for National Economic and Social Development (Su et al. 2013; Wu et al. 2014), and has developed programs to promote cleaner manufacturing pollution prevention, and waste management across the country. Some non-governmental organizations (NGOs) in the United Kingdom, such as the Ellen MacArthur Foundation (Ellen MacArthur Foundation 2012), have addressed the implementation of CE by addressing such topics as skills development (Ellen MacArthur Foundation 2012). It should be noted that in addition to Denmark, France, Germany, the Netherlands, South Africa, Sweden, and Vietnam, other nations have organized conferences or undertaken projects that are related to trash reduction or recycling programs that are connected to the CE model, including Denmark, France, Germany, the Netherlands, and South Africa. It has become apparent that with the introduction of the expanded producer responsibility proposal to the EU Waste Directive in 2008, it has become the main strand for introducing a CE at the European level as it is the primary strand for the introduction of a CE. The next report in the series is entitled

"Towards a Circular Economy: Zero-Waste Program for Europe." In this document, the European Commission outlines steps that can be taken to reduce the use of natural resources as well as the emission of waste (European Commission 2014). It is also important to note that the EU Action Plan 2015 for the CE package aims to increase the competitiveness of the EU by creating new business opportunities as well as by encouraging creative, circular methods of production and consumption through the use of circular technologies to increase European competitiveness (European Commission 2015). As a result of a report on the implementation of the Circular Economy Action Plan in 2019 (European Commission 2019), the need for a Circular Economy Action Plan was reaffirmed. More recently, the European Commission developed a New Circular Economy Plan for a Cleaner and More Competitive Europe in 2020 (European Commission 2020).

9.2 Consequences of CE Transition in Various Businesses

The Ellen MacArthur Foundation (2013) estimates that if the CE model is implemented in three resource-intensive industries (transport, food, and construction) by 2030, and an 83% reduction by 2050, there will be a 48% reduction in CO_2 emissions in the EU as compared to the levels of 2012 (Ellen MacArthur Foundation 2013). It is expected that the use of CE techniques in the energy-intensive cement, aluminium, steel, and plastics industries will result in a 56% reduction in European emissions by the year 2050 as a result of the use of CE techniques in these industries. The Material Economics publication estimates that global CO_2 emissions can be reduced by as much as 3.6 billion tonnes by 2025 due to reducing fossil fuel use. According to a report released by the Ellen MacArthur Foundation (2019), if CEs were to be implemented in the food industry, there would be a reduction of 49% in emissions, or 5.6 billion tonnes of carbon dioxide. The International Research Project (IRP) has recently evaluated how the material efficiency of residential structures and light-duty vehicles contributed to the mitigation of greenhouse gases. According to the study, material efficiency techniques can significantly reduce emissions from materials and operational energy in housing by 40% in G7 nations by 2050. This is compared to up to 70% in India and China and 30 and 40% in G7 countries for automobiles by 2050. In our opinion, there is no doubt that increased resource efficiency and a reduction in raw material consumption are essential components of a climate policy that will lead to a reduction in emissions (Behrens 2016). Bijleveld et al. (2016) have shown that these techniques can reduce GHG emissions significantly (Bijleveld et al. 2016).

Further, the necessity of CE has also been emphasized to minimize any future barriers to the adoption of innovative technology in the future and reduce direct emissions (European Commission 2018). As part of its New Circular Economy Action Plan, 2020, the European Commission advocates that to build a more sustainable future, it is important to develop a systematic approach to analyzing the impact of circularity on climate change mitigation (Spani, 2020). In addition, it should be noted that all of these earlier investigations have provided similar insights. There is a possibility that the CE can positively impact the mitigation of climate change as a whole as a result of its implementation. According to some studies, the research has also pointed out that a finer-grained analysis might be useful since CE treatments may not always result in a reduction in emissions (Gallego-Schmid et al. 2020). This is why it is crucial to conduct a case-by-case quantification of each case on a case-by-case basis.

Additionally, Deloitte (2016) recommended that a life cycle perspective be used to enhance the potential of CE policies rather than just focusing on production-based emissions to assess the potential of CE policies so that various steps of a life cycle could be enhanced to maximize the potential of CE policies. Although many studies have shown that climate change and CE are interconnected, they have mainly focused on the need to reduce resource use, improve the efficiency of the energy we use, and develop industrial sectors that can combat climate change. Climate change is one of the most complex issues in the world, and it requires the attention of the government, the involvement of numerous stakeholders, and the synthesis of information from different fields and levels of society to be solved (Grundel and Dahlström 2016). In response to the request for a methodological approach to the CE-climate change nexus, this essay proposes a methodological approach to the CE-climate change nexus. A significant part of the study is devoted to eco-innovations, as well as the roles played by several stakeholders, to provide the theoretical basis and fresh justifications for the relationship between climate change mitigation and green policies. The article proposes an analytical framework and useful recommendations that can be used to analyze both CE and climate change policies in light of the interrelationships between them. A vital part of combating climate change is the implementation of a circular system of production and consumption, which shifts from a linear system of production and consumption into a circular system of production and consumption (de Jesus et al. 2018). There is no doubt that eco-innovations can help both the goals of clean energy and the mitigation of climate change in the long run. We believe that policies should support these technologies' advancement to achieve both goals.

9.3 Quintuple Helix Model: A Framework for Analysis of the Relationship Between CE and Climate Change

9.3.1 Circular Economy

It has been suggested that the CE model can be viewed as a systemic reaction to environmental limits in that it attempts to separate economic growth from the consumption of finite resources through resource efficiency (energy and materials) and the use of renewable resources for energy generation. It has been suggested by Ferrasso et al. (2020) and Johansson and Henriksson (2020), that the CE model represents a systemic response to environmental limitations. As a result, this unique perspective is mainly based on the premise that it was the introduction of eco-innovations that was intended to promote more efficient use of energy and raw materials, a design of durable goods, a higher rate of recycling and reusing materials, as well as the elimination of waste products (Eco-Innovation Observatory 2018). By reducing the consumption of energy and resources, creating jobs, and reducing emissions, it is this combination of benefits that benefits society as a whole, which, in turn, helps to mitigate the impact of climate change on society by reducing the consumption of energy and resources (Sulich et al. 2020). A key feature of CE is that it implicitly recognizes the necessity of resource preservation and the idea of industrial symbiosis, which is also implicitly acknowledged within the model. As the idea of "waste as a problem" is changed to "waste as a resource" through upcycling trash from one business into valuable feedstock for another business, the idea of "waste as a problem" is maintained. At the same time, the materials themselves remain a valuable resource in themselves (Okere et al. 2019). The CE principles reveal that there is a direct link between the production of goods by manufacturers and the consumption of goods by consumers. This link is the management of waste, and the use of raw materials by consumers, resulting in greater efficiency in the use of resources and energy. There is no doubt that the CE model relies on legislation and policy as its theoretical foundation. To make it a reality, however, revolutionary changes must be made along the value chain of a company. This is to make it go from a concept to a real product for it to become a reality. It is important to remember that these changes can be technical, organizational, or social in nature (Ghisellini et al. 2016). For the CE initiative to be successful, energy consumption must be reduced since it reduces the amount of waste and the number of virgin resources needed for manufacturing, both of which are harmful to the environment (European Environment Agency 2015). The reason for this is that it is necessary to incorporate modifications to business models which focus on sustainable production, such as environmental lifecycle analysis, technological advancements in goods and procedures, as well as new social awareness into business models, to promote sustainable production (Kraus et al. 2018).

The manufacturing industry may be able to take advantage of the benefits of CE, but this does not mean that all businesses will be able to modify their business models at the same rate once CE is implemented. It has been found that small and medium-sized enterprises (SMEs) do not have a consistent distribution of CE expertise, which is primarily found in large industries rather than in SMEs (Christis et al. 2019; Ferasso et al. 2020). It is important to note that there are many barriers that SMEs may need to overcome when trying to make the transition to CE, including differences in culture, markets, supplier behaviour, administrative difficulties, a lack of knowledge, technical skills, and funding (Rizos et al. 2015; Kirchherr et al. 2018). A key element in facilitating the transition to CE is the creation of an innovation ecosystem that can be accessed by other stakeholders, such as the government, civil society, and academic institutes, and that allows them to participate in encouraging innovation to facilitate the transition.

9.3.2 The Linkage Between Climate Change and CE

There is a need for global collaboration to reduce greenhouse gas emissions and maintain a global average temperature below 2 °C. We also need to work as hard as we can to keep it at 1.5 °C to combat climate change. Due to this, it is evident that there is a need for a paradigm shift based on the interaction between the process, the environment, and the economy since CE is an essential force for achieving these objectives (Ghisellini et al. 2016). CE methods can be used to further reduce emissions by developing innovative solutions that open the door to a sustainable future, thereby reducing greenhouse gas emissions further, since it has shown that implementing the laws and measures put forward by nations to limit global warming to 1.5 °C by 2030 is not sufficient to limit global warming to 1.5 °C by 2030. As a result, CE methods can be used to further reduce emissions by developing innovative solutions that open the door to a sustainable future. To achieve the objective of achieving climate neutrality, a wide range of stakeholders, including businesses, governments, academic institutions, and civil society organizations are all required to participate in the process. An effort to address issues that are shared by several stakeholders is referred to as an "institutional capacity," which is a commitment from a number of stakeholders to address an issue that is shared by them (Murray et al. 2017; Saavedra et al. 2018). The Triple Helix Model of innovation is similar to this in that it involves institutions such as government, industry, and academia. This is to promote collaboration that leads to knowledge generation and methodological innovation as a result of collaboration. As a result of the implementation of a triple helix system, actors should operate within a networked system that focuses on circular innovation, to ensure that the transition to a CE can be made effectively (Barrie et al. 2019). It is also noteworthy that a new helix (Quintuple helix) has been added to the model to represent natural environmental issues to find answers to the environmental problems that are emerging today. An influential characteristic of this concept is that it is viewed as a catalyst for knowledge creation and innovation (Carayannis et al. 2012) that facilitates cooperation and the creation of synergies between economies, societies, and democratic institutions, and can be viewed as a contextualization of the quadruple helix's four helices. This model is designed to provide coherence throughout all helices, from the official institutions at the top to the businesses at the bottom, striving to achieve a balance between economics and the environment, incorporating civil society at the same time. For a sustainable future, the QHM's various subsystems must interact in a way that encourages innovation, adds value, and supports a sustainable future (Carayannis et al. 2012; Carayannis and Campbell 2019). This includes the subsystems that deal with education, industry, politics, society, and the environment. It is also dependent on the flow of knowledge that serves as their input. Consequently, programs that encourage innovation in each helix of the economy, where public and private entities interact, are intended to influence the other subsystems and society as a whole in a positive manner and to create an environment that is conducive to the sustainability of the whole economy. It has been shown in several studies that the model can be used to explain the forces that promote knowledge creation and innovations that are required for environmental protection, the development of green technologies, problem-solving, and the transition to a bio-economy or CE (Grundel and Dahlström 2016; Anttonen et al. 2018). Carayannis et al. (2012), presented QHM as a possible approach for dealing with the problem of global warming, taking into account that knowledge sources are the most significant assets and that the dissemination of knowledge leads to the emergence of new ones as a result of the ongoing dissemination of knowledge. They used QHM to estimate the cost of tackling the global warming problem. Based on Yun and Liu's (2019) research, there is a well-established argument that open innovation enhances sustainability in all three helixes of the value chain, including the financial one. In light of the current advances in the field of climate change and the shift to CE, it may be considered an acceptable framework for dealing with the situation of climate change and the shift toward CE. A transdisciplinary approach to climate change as well as a transdisciplinary approach to environmental conservation and education require several stakeholders to be involved, as well as the acceleration of innovation across all helixes (Behrens 2016; Yun and Liu 2019). The concept of CE, which emerges at the heart of the innovation system, is crucial to achieving the goal of decarburization. As the name suggests, it implies a holistic perspective based on the premise that production and consumption are intertwined with, and influenced by, the biophysical environment as a whole. There is evidence that economic institutional actors, both on a local and global scale, can lessen the environmental damage caused by their actions both at the local and global levels. Eco-innovations represent the main force behind the development of environmental technology and its application to achieve the integration and collaboration of many players at macro, meso, and micro levels, thus helping to reduce the impact of global warming as a result of these innovations. In a few studies about the role of context in shaping climate change (Flagg and Kirchhoff 2018), the role of meso-level policy networks, or the contribution of tacit and explicit knowledge to climate change mitigation, this view about the significance of expanding the levels of analysis of climate change has been highlighted (Kaklauskas et al. 2013). In other words, the QHM framework provides a method by which a method can be identified for determining the types of information produced within each helix that can be shared among actors and that, consequently, can lead to eco-innovations that are compatible with the CE model, thus helping to achieve climate change objectives. Government assistance for eco-innovation adoption inside businesses comes in the form of regulations that serve as "push–pull" forces part of the development of the concept of "reduce, reuse, recycle, and recover" (or "4-Rs of CE"), another paradigm has also been developed and put into practice (Manickam and Duraisamy 2019).

It is important to connect producers' and consumers' interests when it comes to CE and climate change objectives, but it is also necessary to develop market signals and secure financial backing. Further, it is important to implement tools and incentives that will facilitate the efficient creation, acquisition, deployment, and dissemination of eco-innovations, as well as innovation facilitation through improved product design and recycling that may result from eco-innovations. As a result of the collaboration of businesses and governments, educational helix offers creative solutions to contemporary societal issues (Farré-Perdiguer et al. 2016). Educators should play an active role in teaching students about issues related to CE and climate change so that the next generation can develop a new ability and way of thinking. The university needs to play a key role in driving the CE process since it is a strategic institution and an institution that contributes to knowledge development. The importance of improving cooperation between businesses, colleges, and research institutions cannot be understated. Due to their expertise and experience, scientists can provide solutions to technical problems that arise during the innovation process, using their expertise and experience to solve them. Such a partnership between businesses and academic institutions is essential to the development of research that will meet the actual requirements of climate change and CE. The adoption of eco-innovations is determined by external stakeholders, although CE models require a greater strong commitment. For companies to become more competitive in the market, they need to reconsider and alter their business strategies, while reinforcing their obligations as producers to do the same. As a result, manufacturers and their suppliers need to take into consideration the entire product lifecycle, from manufacturing to disposal and take steps related to product design strategies, such as choosing materials inputs for the manufacturing process that will facilitate future repair, reuse, or recycling of the product and respecting the product's lifespan.

This paradigm of sustainable manufacturing or resource-conservative manufacturing proposes an alternative approach to linear production systems by focusing on the dynamic interaction between business models, product design, supply chains, and customers (Rashid et al. 2013; Kim et al. 2013). There is also a need for incentives, markets, and infrastructures. As well as the development of other types of innovations, such as Information and Communications Technology (ICT), is essential for the transmission of information between firms and their customers (Nascimento et al. 2019). There has been a significant increase in public awareness of sustainable development over the course of the past few years. In addition to the need for a cleaner environment, environmental protection has also acted as a catalyst for the production of eco-innovations in consumer habits and production processes. Due to these changes, it has been observed that there has been a change in the value that consumers place on goods and resources, as well as shifts in consumers' consumption patterns and preferences as a result, leading to the adoption of sustainable business models as key players in the transition from linear to CE models (Figs. 9.1 and 9.2; Tables 9.1 and 9.2).

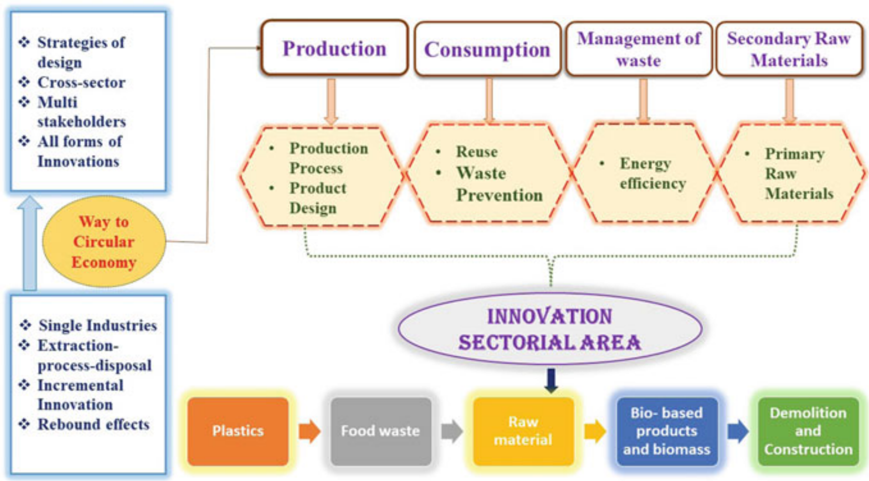

Fig. 9.1 Model of circular economy

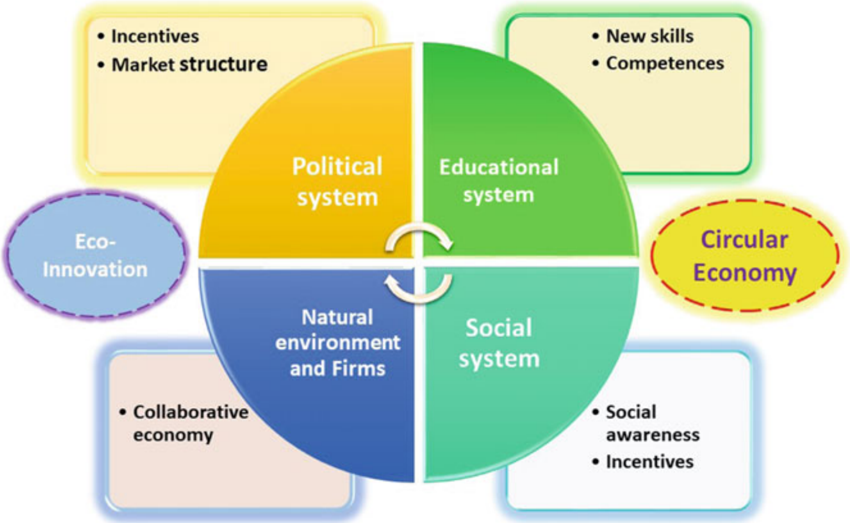

Fig. 9.2 Quintuple Helix model relation with the circular economy and eco innovations

Table 9.1 Different solutions to slow down the resource loops

S. No.	Elements of construction	Solutions for circular economy	Greenhouse emissions variations	Reference
1	The roof of train stations	Reuse	Reduce the greenhouse emission by 2.3 t of carbon dioxide equivalent per infrastructure	Brütting et al. (2019)
2	Covering floor	Durability	Range up to + 38.9 carbon dioxide eq/m^2 for more intensive use, replacement, and maintenance as additional emissions,	Ros-Dosdá et al. (2019)
3	Buildings	Refurbishment	Increases in 6.9% of carbon embodied result in major changes	Castro and Pasanen (2019)
4	Steel–concrete composite system	Reuse	− 80 kg of carbon dioxide eq/m^2 to − 120 kg of carbon dioxide eq/m^2	Brambilla et al. (2019)
5	Various structures of building and materials	Recycling, reuse, and refurbishment	Reuse − 15% to − 21% of CO_2 eq/m^2 Resuse and optimization upto − 26% of CO_2 eq/m^2	Ghisellini et al. (2018)

A negative value (−) indicates emission savings with the implementation of circular economy as compared to the linear solutions; Positive values (+) indicate an increase

9.4 Eco-innovations of CE with Climate Change

9.4.1 Eco-innovation

It has been stated that the concept of eco-innovation refers to the development of new and improved procedures, methods, systems, and products that are aimed at preventing or lessening effects on the environment (Arundel and Kemp 2009). During the transition from a linear economy to a circular economy, several stages of the production process will be reorganized, as well as a number of significant industries that are important in mitigating the effects of climate change will also change. The Ellen MacArthur Foundation has developed three techniques to reduce greenhouse gas emissions under the CE framework: one technique involves designing out waste and pollution, the other involves conserving goods and resources, and the third technique involves restoring natural systems (Ellen MacArthur Foundation 2019). Managing to take advantage of eco-innovations in these initiatives is essential to the CE model these initiatives, as they allow the progressive development of environmental technology, and the collaborative efforts of many actors across macro, meso, and micro levels across these initiatives. As a result of eco-innovation techniques, the shift from a resource-intensive to a resource-efficient economy can be achieved by minimizing negative benefits to the environment, maximizing resource utilization efficiency, and promoting climate change neutrality (Wysokińska 2016;

Table 9.2 Climate change with circular economy eco-innovations

S. No.	Basic characteristics	Different approaches	References
1	Different drivers of eco-innovations	✓ Some organizational innovations, including environmental management systems and eco-innovation, relate to one another's drivers of eco-innovation ✓ The significance of technology-push and demand-pull instruments in driving environmental technologies ✓ The importance of outside causes like environmental regulations as a primary force behind the growth of eco-innovation in businesses ✓ Regulation is less successful than market-based tools like economic incentives ✓ Combining environmental laws with tools focused on the market ✓ consumer demand	Ashford et al. (1985), Jaffe et al. (2002)
2	Determinants and characteristics	✓ Management of the environment concerns ✓ Different fundamental features and determinants	Qi et al. (2010), Dibrell et al. (2011), Borghesi et al. (2013)
3	Eco-innovations benefits	✓ Benefits for both the environment and the businesses, or a win-win situation ✓ Better brand recognition and cost savings for businesses and emerging market possibilities ✓ Increased earnings per worker, enhancement of long-term effectiveness	Nidumolu et al. (2015), Sarkar (2013)

Hojnik and Ruzzier 2016). It is possible to reduce emissions of greenhouse gases from the production of raw materials and the generation of waste from raw materials by switching to renewable energy sources and improving energy efficiency in supply chains and business models (European Commission 2011). In addition to this, the company's profitability is also expected to increase as a result of these changes (Hojnik and Ruzzier, 2016). According to the literature on ecological innovation (de Jesus et al. 2019, 2018; Cainelli et al. 2020), its main characteristics can be traced to environmental management by businesses, the requirement for regulation from outside sources, as well as market and societal forces. It has been suggested that eco-innovations may provide businesses with a variety of advantages in the areas of sustainability, reputation, and meeting the demands of emerging markets. Although the study highlighted some conceptual elements of eco-innovation, it is still unclear how eco-innovations can be used to mitigate climate change and assist in climate adaptation. The role of each stakeholder must play a part in the creation of information that might serve as a catalyst for the development of eco-innovations for the CE model to be implemented for it to be successful. The CE model is driven by concerns regarding increased civil society awareness, governmental incentives, and the information produced within the educational system as part of the process. It is important to remember that inventions have a significant impact on how these forces are manifested in the world. There is a need to adopt a coherent and all-encompassing vision that takes into account both CE and climate change goals, as well as to integrate eco-innovations into every aspect of the manufacture and disposal of products at all stages of their life cycle, from the gathering of raw materials to end its life-cycle. There are several ways in which this strategy encourages best practices and reduces waste. This involves minimizing the number of materials needed to provide a given service (light-weighting), extending the useful life of products (durability), utilizing less energy and materials during production and use phases (efficiency), minimizing the use of hazardous or difficult-to-recycle materials in products and production processes (substitution), and developing a market for alternatives (European Commission 2014). Additionally, these methods force businesses to reevaluate their current strategies and create new ones as a result.

There has been a breakthrough in the development of activities connected to low-carbon pathways and technologies that can help mitigate the effects of climate change. As a result of cutting-edge technology in power generation or carbon dioxide capture and sequestration (CCS), many advances have been made in energy efficiency over the last few years. In recent years, the topic of energy efficiency has gained international attention, and a variety of initiatives aimed at decarbonizing this industry emphasize both the need for CCS integration as well as a rise in the use of renewable energy sources (Lausselet et al. 2017). In recent years, several projects have been undertaken to speed up eco-innovations to develop and implement low-carbon and affordable technologies for the development and use of the environment to achieve temperature stability (European Commission 2016). Because many of these technologies are end-pipe or preventative in nature and are in line with CE principles, they may present the possibility of speeding up the transition to the CE approach. Eco-innovation, climate change, and CE are all important issues that have been empirically examined in a variety of studies (de Jesus et al. 2018). A large proportion of the research involving the assessment of knowledge concentration, quantification of the rate and flow of eco-innovations, and exploration of specific subjects connected to mitigation strategies has been carried out by analyzing patent data (Durán-Romero and Urraca-Ruiz 2015; Ferreira et al. 2020). Several studies have demonstrated that competitive technologies, such as geothermal, hydro, wind, and solar energy, as well as biofuels, have higher rates of innovation in climate change mitigation technologies when compared to less competitive technologies (OECD 2010). It has also been shown that companies in more developed nations own the majority of the technological know-how for pollution management and that foreign direct investment serves as a primary means of transferring knowledge to companies in less developed nations (Urraca-Ruiz and Durán-Romero 2013). Research findings have primarily been applied to the industrial and energy sectors, based on a viewpoint analysis of the distribution of publications, while the field of green innovation has received less attention in agricultural literature, according to a viewpoint analysis of the distribution of publications (García-Granero et al. 2018). The effect of intellectual property on the availability of renewable energy (Barton 2007) or the role of environmental regulatory bodies can be seen as a direct result of intellectual property. The literature on eco-innovations has discussed the general connections between CE and climate change as well as the potential effects of eco-innovation applied in various sectors in terms of reducing GHG emissions, but it has not provided knowledge on particular technological innovations and their advantages concerning mitigating climate change. There will be an examination of the mitigation techniques for climate change and a general overview of the areas where policy, law, and research and development (R&D) can be strengthened to facilitate the mitigation of climate change.

9.4.2 Eco-innovation for the Mitigation of Climate Change

As part of its efforts to find a taxonomy of environmental areas that may contribute to the mitigation of climate change which can reduce greenhouse gas emissions, OECD has used the Thematic Areas of Environmental Technologies (OECD 2016) to identify a taxonomy of environmental areas. To provide a more thorough and in-depth understanding of environmental technology, each of the technical sectors has been divided into many subcategories to provide a deeper understanding (Appendix) of each technical area. As a result of a prior mapping of current and potential climate change mitigation technologies conducted by the UNFCCC in 2007 (IPCC 2007), these topical categories were derived from the IPC Green Inventory of the International Patent System1. Several studies have been conducted to evaluate the potential of CE eco-innovations to affect, enhance, or extend efforts designed to mitigate climate change. Due to the dependency on high levels of energy consumption, our study focuses on a variety of industries since their economic development depends on high levels of energy consumption and, as a result, has a greater impact on the environment.

9.5 Distribution, Transmission and Generation of Energy

Technology can be categorized under this category if it contributes to the production of fuel from non-fossil sources, if it contributes to the efficient generation, transmission, or distribution of electrical power, if it contributes to enabling technologies in the energy sectors, and if it contributes to the capture, storage, sequestration, or disposal of greenhouse gases. It is common to refer to climate change as an energy issue when discussing the issue of global warming. Consequently, the adoption of clean energy technologies (Witjes and Lozano 2016), the implementation of comprehensive efficiency improvement strategies (energy consumption reduction), and the reduction of the use of fossil-based fuels (energy transition and energy savings through optimization) have all been brought about by the need to decouple economic growth from resource consumption and to mitigate climate change. It is the goal of these ideas to reduce climate change, boost the use of renewable energy sources, and increase the efficiency of energy use in our homes. The development and deployment of cleaner, low-carbon energy sources that can provide electricity with much fewer emissions of carbon dioxide than traditional fossil fuels are the main objectives of eco-innovations in the energy sector (Gielen et al. 2019). The following categories can be used to categorize these innovations viz., the technology that is used for producing energy from non-fossil fuel sources, such as geothermal, hydro, solar, and wind energy; the technology that is used for the manufacturing of renewable biofuels, biodiesel, bioethanol, and biogas; and the technology that is used for producing fuel from waste or waste-to-energy (Okere et al. 2019). For these energy sources to be consistent with the CE model, they must not generate hazardous waste at the end of their useful lives, as is the case for some wind turbines. By implementing combustion technologies, such as integrated gasification combined cycles and alternative energy production cycles, we can reduce GHG emissions and promote the use of clean energy. The CE model, which uses biomass as one of the inputs to recover heat from industrial units, uses biomass as a source of renewable energy as well as a biological input. One of the most common examples of such facilities are the combined heat and power plants. These facilities produce electricity and heat by burning trash or biomass at the same time. It appears that although technology has been developed for the collection, storage, and sequestration of CO_2 in geological formations (CCS) for mitigation purposes, there are conflicting scientific opinions on its use and function in climate mitigation. Even though these technologies are considered to be efficient ways of completing the gas cycle since they are thought to reduce CO_2 emissions from fossil fuels. However, using them consumes a great deal of energy. As well as this, CO2 has recently been viewed as a valuable resource rather than a waste, which has led to the development of new and innovative technologies known as "carbon capture, utilization, and storage" (CCUS) and "carbon capture and utilization" (CCU), which support the development of a CE for carbon-based materials. In addition to energy conservation, which is also known as saving technologies (e.g., electric energy storage, electric consumption measurement, thermal energy storage, low-energy lighting, thermal building insulation, mechanical energy recovery), it is also focused on the development of new products, services, and processes that help reduce energy demand and consumption in manufacturing as well as other activities.

9.6 Treatment of Waste and Wastewater Management

This includes the management of solid waste, the treatment of wastewater, as well as the contamination of water. As a result of the high consumption of resources and materials, there is a link between climate change and the high use of resources. To reduce the impact of the planet's pollution and air emissions, resource efficiency, which is at the core of CE, entails reducing the amount of waste produced, enhancing trash recovery, and using waste as a resource in the manufacturing process to reduce the planet's environmental impact and emissions. It is, therefore, necessary that technology should be focused on increasing the amount of biological waste that is recycled in order to achieve this critical goal. There is a better way to manage waste than simply burning it or burying it. It would be better if we replaced incineration with methods that recover materials (different components can be recycled) and energy (waste to energy) instead of burning it or burying it. For instance, in order to reduce the use of other resources, such as water, and the emission of greenhouse gases, one of the best methods would be to recover energy, which helps to minimize the use of other resources, such as water, and the emission of greenhouse gases, whereas recycling, helps to reduce the consumption of materials (Pan et al. 2015). In terms of energy recovery, there are many options available, ranging from recovering energy from organic waste to producing heat by thermally processing non-recyclable waste, which is one of the most common types of energy recovery. It should be noted that the last choice should only be considered if there is a guarantee of a high level of maintenance. In spite of the fact that a large number of the waste management, pollution control, and wastewater treatment technologies produced in this sector are in compliance with CE standards, there is still a lot of room for improvement. The examples cited here are landfill technologies or end-pipe technologies, such as sewage treatment systems, soil remediation systems, or technologies for repairing damaged landscapes. There have been many bio-based substitutes for conventional plastics that have been created in recent years that are CE-compliant, such as bioplastics that are derived from corn or sugar cane (Spierling et al. 2019). Another pressing problem is the scarcity of water. To enhance water efficiency and treat wastewater sustainably, new technologies are needed. These advancements also help cut down on energy use. Jhansi and Mishra (2013) provide insight into the right technique for wastewater treatment in this way. Technologies for wastewater treatment provide certain benefits within the CE model. Separating biodegradable materials enables the extraction of materials that are highly valued non-renewable resources on the scale of human life, such as nitrogen and phosphorus. As fertilizers for farming, these compounds may be reused. There are certain disadvantages, though. First, decontamination calls for a significant investment in time and resources. The overall balance is negative even though it might be corrected with the energy produced by the combustion of sewage sludge. The high concentration of contaminants, such as heavy metals, that may pollute the food chain and groundwater, makes the use of sewage sludge dangerous, according to Rather et al. (2017).

9.6.1 Alimentary Industries: Agriculture and Livestock

There are two groups within this category: forestry and agriculture, which include both sectors and subsectors. In the agricultural and forestry industries, which have significant potential for implementing eco-innovations for the mitigation of climate change, evidence indicates that there exists a link between CE and climate change, especially in the context of agriculture (Durán-Romero and Urraca-Ruiz 2015). In terms of eco-innovations, it is worthwhile to mention in particular that a great deal of attention has been given to the creation of biocides, which are alternatives to chemical pesticides that are commonly used throughout a variety of industries. It is also known as recycled nutrients (recirculation of key nutrients), organic fertilizers that are made from recycled wastewater or food waste are recirculated to be used as fertilizers in agriculture, thereby reducing the need for other chemicals that have more severe environmental effects, and helping to lower emissions that are created. In the event of a 50% reduction in food waste, and a 30% increase in nutrients derived from organic waste or wastewater, Deloitte estimates that emissions will be reduced by 13% if food waste is reduced by 50% (Deloitte 2016). There is a belief that food waste can be reduced by 50% if food waste is reduced by 50%, and 30% of nutrients can be obtained from organic waste or wastewater, then a reduction of 13% in emissions can be achieved in the sector (Deloitte 2016).

9.6.2 Transportation

It is also within the category of transportation that you will find technology that is designed to help reduce pollution and increase fuel efficiency in the transportation industry. In the field of transportation, eco-innovations have focused on the creation of technologies that minimize the use of fossil fuels, reduce emissions, improve the efficiency of fuel consumption, or reduce the amount of material that must be used. CE has been recognized as being one of the challenges that the CE model faces when it comes to integrating both renewable and conventional energy sources into incremental eco-innovations that provide a sustainable lifestyle. The use of hydrogen and fuel cells in transportation also has a number of synergies that make them both attractive for use in transportation. There are many ways in which hydrogen can be used as an alternative to oil and natural gas, however, the process of generating hydrogen requires a great deal of energy. Consequently, if the product is produced using the use of renewable energy sources, it will be able to qualify as a green product according to CE guidelines if it is produced using renewable energy sources. Moreover, in order to achieve this goal, it would be necessary to be able to adjust the business structures, such as carpooling and car sharing, as well as implement technological advancements in order to make it possible.

9.6.3 Construction

In the category of construction, there is the use of renewable energy sources in buildings, the use of energy-efficient components in buildings, the use of architectural or construction components that enhance the thermal performance of buildings, and also the use of enabling technologies in buildings. Because the building sector is one of the biggest consumers and producers of raw materials, as well as one of the biggest producers of waste, it is imperative to minimize the loss of minerals, metals, and organic materials. As far as greenhouse gas emissions are concerned, this industry can be considered one of the most polluting in the European Union when it comes to greenhouse gas emissions, and it contributes a substantial portion to the planet's total carbon dioxide emissions, according to Gallego-Schmid et al. (2020). Similarly, along the value chain (businesses, technology suppliers, and construction materials and equipment) the construction materials and equipment sector should also be transformed into one that employs closed-loop circular design concepts to reduce waste and greenhouse gas emissions along the way. The recycling of waste can contribute to a decrease in emissions of roughly 17% in total, but further product reuse techniques need to be implemented in order to achieve a further reduction of up to 34% (Deloitte 2016). Despite the paucity of literature on CE and climate change mitigation, the EU Action Plan is focusing its efforts to bring the construction sector into CE, despite the lack of literature available (Gallego-Schmid et al. 2020).

9.6.4 Manufacturing of Goods

All of the processes involved in the processing of metals, chemicals, petrochemicals, and minerals are included in the category of products manufactured, and these are all very significant sectors of the economy that make up the manufacturing industry. Besides the fact that the manufacturing or processing of items such as chemicals, petrochemicals, metals, and minerals requires a significant amount of raw materials, it also produces a significant amount of carbon dioxide (CO_2) as a by-product of the process. It is necessary to create policies that promote their reuse and minimize the pollution produced by their operations in order to prevent pollution caused by their operations and ensure their procurement. There are currently numerous environmental technologies being implemented into the manufacturing process of many of these companies in order to make them more eco-friendly and sustainable in the long run.

9.7 Conclusion

This chapter aims to explore the theoretical foundations as well as the grounds for the various justifications that can be put forward in relation to the relationship between climate change mitigation strategies and climate change adaptation strategies, in order to identify both the challenges and the opportunities that can be found in such relationships and to develop an understanding of both in order to develop an understanding of both. It is part of the main objective of this study to provide an analytical framework that allows stakeholders to collaborate in an innovation ecosystem where information can be exchanged between them, thus allowing the creation of eco-innovations that will enable a circular economy to flourish and mitigate climate change as part of its main objective. To be able to use the resources to their full potential, eco-innovation seeks to make use of them as efficiently as possible, which is why concepts such as renovation, remanufacturing, and recycling are vital in the development of eco-innovation. As a result of analyzing the literature and doing a literature review, we identified specific CE eco-innovations and practices that contribute toward the attainment of climate change mitigation goals as well as the role that each key player in the QHM chain plays in ensuring that the CE transition and climate mitigation goals are achieved. Companies must take into account eco-innovations in order to introduce sources, achieve cleaner manufacturing techniques, and modify customer behaviour by influencing society's consumption in accordance with CE principles by implementing and optimizing recycling, remanufacturing, and renovating, the discovery of new raw materials with lower impacts on the environment, the identification of ways to minimize the use of virgin resources, the introduction of new and cleaner production techniques aiming for zero waste emissions are all ways that academia can help with this transition. As governments seek to reduce the impact of CE and climate change on the environment, they should place a primary focus on addressing resource-intensive and polluting businesses. In order to limit the creation of wastewater and waste as well as track energy usage, it must be possible to monitor the effects of the building sector, commodity production, and the use of lands for agriculture and forestry. As a result of the ongoing concerns regarding environmental challenges and climate change, it is essential that CE and climate change mitigation measures are strengthened as a means of addressing these issues. Consequently, it is necessary to take steps to expedite the transition from a CE model to a CE model result of this fact. Because of this, it emphasizes the importance of resource efficiency in a world that is limited when it comes to resources, as this makes sense in a world where resources are limited. In addition to this, it is also being done in order to achieve the goals that have been set in terms of climate change. When it comes to climate change, it has been the creation of eco-innovations that have been able to reduce greenhouse gas emissions that have received most of the attention that has been devoted to the topic. In the last few years, a number of proposals calling for a shift in the economic model of the future, towards a low carbon economy, a green economy, or even a CE model, comprising resource efficiency as a key component, have emerged. These proposals call for a shift in the economic model of the future toward low-carbon, green, and CE economies. When it comes to the transition to clean energy, there are a number of technologies being developed in order to reduce the impact of climate change on the transition. In order to ensure that the CE principles are ingrained in the public's consciousness, governments have enacted regulations and legislation to emphasize the importance of these principles, resulting in the emergence of technological eco-innovations as a result. There may be difficulties in including QHM stakeholders in the CE process in spite of this fact. In order for both consumers and businesses to benefit from government incentives, it is imperative that incentives are created. Increasingly, companies will be required to reevaluate and alter their business models (industrial symbiosis, remanufacturing, product-service systems, or PSS), as well as set strategic objectives that will help them close loopholes and improve their material and energy efficiency levels. It is also suggested that the creation of innovative and radical CE eco-innovations, as well as increased social awareness, are necessary for influencing consumer and producer behaviour towards a more collaborative economy in the future.

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Chapter 10
Circular Economy Indicators and Environmental Quality

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Abstract Sustainable energy is integral to the Circular Economy as it leaves no waste behind and does not increase the exploitation of natural resources. Furthermore, the circular economy is proving to be a viable alternative to the linear economy, not only because it is more eco-friendly but also because it is a practical alternative to the linear economy. Various metrics can be used to measure economic circularity. Even though sustainability and the circular economy are interconnected, few indicators can be used to measure them. Circular economy metrics correlate with key economic and environmental metrics for the growth and sustainability of an economy. The manufacturers and governments of developed economies constantly innovate to boost growth and help them transition from linear to circular economies. The issue of ecosystem sustainability is being challenged by a number of factors, such as global warming, the degradation of the environment, and garbage that ends up in landfills. By implementing circular economies, we can work towards ecological sustainability and development. In addition to the many indicators of a circular economy, there is the recycling of waste packaging, biowaste, municipal waste, e-waste, trade-in recyclables, and recycling patents. In recent years, increased energy intensity, economic expansion, and urbanization have adversely affected the environment. It has been shown that using renewable energy and various circular economy techniques can significantly improve the health of our planet.

Keywords Zero hunger · No poverty · Sustainability · Economy · Sustainability · Environment

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10.1 Introduction

Additionally to the fact that renewable energy is an essential component of a Circular Economy, it is also a component that does not generate waste and does not increase resource exploitation on top of being an essential component of a Circular Economy. Circular economies are emerging as an alternative to linear economies in terms of their environmental friendliness and capacity to provide a more sustainable future. This is in comparison to linear economies. This should be considered when comparing linear economies to the one described above. It is important to keep in mind that economic circularity can be measured in a number of ways, and you need to keep this in mind. It is important to realize that there are a variety of metrics that can be used to measure it in a variety of ways. Thus, it is important to remember that the concept has a lot of aspects that can be measured in various ways. There is a number of interrelationships between sustainability and circular economy. However, few indicators can demonstrate the impact both of these concepts have on one another in terms of the impact they have on one another in terms of their impact. To be able to analyze the relationship between the selected circular economy metric, which includes the growth of the economy and the protection of the environment, it is necessary to examine the relationship between both metrics to fully understand their relationship to be able to analyze the relationship between the two metrics. For the developed economies to be able to increase the growth of their economies, they continuously innovate and implement new technologies to achieve growth, for their economies to grow. This organization's fundamental role as an organization is to provide government assistance to manufacturers, whether by providing them with government assistance or by assisting them in transitioning from a linear economy to a circular economy via providing them government assistance that will facilitate this transition in their role as manufacturers. A growing number of challenges have been created by global warming, the degradation of the environment, and the volume of garbage that ends up in landfills. All of these factors make it extremely challenging to maintain a sustainable ecosystem as a result of these factors. In addition to promoting sustainability and development, many of the key elements of a circular economy are also beneficial to the environment. They are, therefore, beneficial to the environment as well. The purpose of this paper is to investigate how the new circular economy indicators, such as the recycling of waste packaging, the recycling of biowaste, the recycling of municipal waste, the recycling of e-waste, as well as the trade-in of recyclables, will affect the circular economy in the future. Undoubtedly, urbanization, economic expansion, and an increase in the amount of energy being used daily all negatively impact the environment. Due to the use of renewable energy and a variety of circular economy techniques, the quality of the environment has been significantly improved due to the use of renewable energy and circular economy techniques. A circular economy is a concept that promotes the cyclical and appropriate reuse of resources to create an environment that is more sustainable. The circular economy has been recognized as a method that reduces the environmental burden and restores the economy at the same time as it reduces the environmental burden. In terms of the umbrella concept of the Circular Economy, it entails reducing the input of materials into the economy and limiting the generation of waste to separate the growth of the economy from the consumption of natural resources (Blomsma and Brennan 2017; CIRAIG 2015; Homrich et al. 2018). As part of their economic development plans, many countries around the world are adopting circular economies as a part of their economic development strategies. According to the Economic Model of the Circular Economy, manufacturing, planning structure, reprocessing, procurement, resourcing, and management are inputs and outputs in the production process. The goal of this model is to increase the functioning of the environment while at the same time improving the well-being of humans by considering both inputs and outputs (EEA 2016; EASAC 2016). Through the macro analysis of inputs and outputs, the macro analysis of the flow of materials, and the macro analysis of energy at a macro level, it is possible to observe the circular economy at a macro level (Kalmykova et al. 2018). In the case of a specific piece of legislation, China was the first to pass it (Cullen 2017; EASAC 2016; Paulik 2018). Circular economy literature often mentions this nation in relation to the circular economy. Furthermore, it should be noted that Japan and Germany have been pioneers in promoting a circular economy and related policies relating to a circular economy (CIRAIG 2015). Additionally, evidence supports the circular economy policies of European countries, such as the efficiency of the regulations enacted since the 1970s that deal with resources and waste (Ghisellini et al. 2016; Homrich et al. 2018). There has been a proposal by the European Commission in recent months to develop a framework for monitoring the circular economy. Even though several attempts have been made to develop a circular economy, the concept has not been widely accepted (Geng et al. 2013). As a result, there are several different interpretations of what the Circular Economy is (Blomsma and Brennan 2017), and the relationship between the Circular Economy and sustainability is not always apparent (Kirchherr et al. 2017).

10.2 Energy and Its Importance in the Circular Economy

There is no doubt that energy is a vital component of any civilization and plays a significant role in improving a society's economic and social standing. Since the beginning of time, humans have used various resources to create energy, ranging from wood to nuclear energy (Mirza et al. 2008). A total of nine primary energy sources can be classified into two categories: renewable and non-renewable. The most significant renewable energy sources are wind, solar, hydro (water), biomass, and geothermal energy. These resources are limitless and can be renewed organically at any time, so any limitations do not limit them. Oil, nuclear power, gas, and coal are all examples of non-renewable energy sources that can be used to generate electricity. As this is a limited supply of items, it is not recyclable or replaceable in any way, and there is a limited supply of these items. When it comes to non-renewable resources, once they have been depleted, they cannot be replicated, and they cannot be regenerated in the same way they were once available. Therefore, they cannot be used indefinitely.

For even regeneration to be completed, it takes several years for the process to be completed. In the year 2100, global energy consumption appears to grow five times as compared to what it is now, with a five-fold increase in global energy consumption. The amount of energy consumed worldwide is accounted for by fossil fuels, which provide three-quarters of it. In addition, since fossil fuels are widely used, the amount of CO_2 emitted into the environment due to the widespread use of fossil fuels is also increasing (Halder et al. 2015).

Moreover, as fossil fuels become scarcer and the security of energy supplies is threatened, societies are also looking for alternative energy sources to replace fossil fuels. Renewable energy resources are increasingly being used to generate power in this environment as a source of energy. As many nations are developing, their need for energy for industrial and household use is increasing, yet insufficient energy supplies are available. The South Asian nations are densely populated, and while other conditions remain constant, the population density negatively impacts the countries' economic development. According to Ehrlich and Holdren (1971), in contemporary and technological civilization, each human has a negative influence on the environment. Increasing consumption of both renewable and non-renewable sources of energy has led to a significant increase in pollution in both developed and developing countries due to the vast consumption of renewable and non-renewable energy. It has been shown that the pace of population growth contributes directly or indirectly to the accelerated rate of deforestation (Thomas 1989).

In comparison to fossil fuels, which have a substantial impact on the environment and can even endanger human health as well as produce residues that are often not biodegradable, renewable energy can significantly minimize the environmental consequences associated with energy production, as opposed to fossil fuels, which have a substantial impact on the environment and have an impact on human health as well as the potential to produce residues that cannot be biodegradable. In addition to the obvious environmental effects of renewable energy, renewable energy can also significantly affect the environment. However, these effects can vary from one technology to another, depending on size, location, and the technology that is used. The fact of the matter is that there are a lot of examples of environmental degradation that occur, including erosion of soil, clearing of forests, disturbances of and losses of wildlife, pollution of air, water, and sounds, and problems associated with the use of land, destruction of attractive views, and so on. As far as the environment is concerned, there is no doubt that all energy sources have a negative impact on the environment because there are many types of renewable energy sources, all of which negatively impact the environment. The other side of the coin is that non-renewable energy has also been shown to be much more harmful to the environment than renewable energy (Nathaniel and Iheonu 2019) as compared to renewable energy.

10.3 Indicators Measuring Circular Economy

As a result of the circular economy definition, there is a need for specialized monitoring methods to continuously monitor the progress of the circular economy regularly. At various levels of implementation, indicators can be used to assess the status of the circular economy at various levels of implementation (Geng et al. 2012; EASAC 2016). Although, much of what should be monitored in the context of a circular economy is debatable due to the fact that the definition is unclear, and indications can lead to contradictory or even incoherent results as a result (Paulik 2018). Furthermore, a dashboard was presented to compare various indicators based on the British Institutes' standards to present a more accurate picture. Even though this standard is designed to assist enterprises, systems of production, and organizations in adopting circular economies, it does not contain any compliance criteria to determine compliance with its requirements (Paulik 2018). Five BSI-recommended qualities were taken into account as part of the proposed dashboard (regeneration, restoration, preservation, and maintenance of utility), as well as existing indicators for complementing characteristics (sufficiency, resource efficiency, energy, and climate), as well as existing indicators for complementing characteristics. As Murray et al. (2017) point out, the circular economy differs from the linear economy in two ways: it slows down the flow of resources and closes the cycle of resources in two different ways (Murray et al. 2017). In other words, this happens when the loop between post-use and production is closed, resulting in a circular flow of resources, which implies that linear flows of waste are converted into circular flows of resources as a result of closing the loop between post-use and production. There is a term referred to as "closing", which refers to the process of 'closing the loop between the post-use and the production process, resulting in a circular flow of resources,' which implies that linear waste flows are transformed into circular flows (Bocken et al. 2016).

10.4 Strategies of Circular Economy

To ensure the success of the circular economy, all stakeholders must agree on a common definition of a circular economy plan endorsed by stakeholders (Reike et al. 2017). There are many examples of such examples, including the generation of trash, the intake of raw materials, the design of eco-friendly products (such as the lightweighting of products), or the consumption of resources as a whole (Kirchherr et al. 2017). In this context, various ladders or R-frameworks are used to place three or more strategies in the context of a single ladder. To promote circularity, one R-framework employs ten strategies: reject, rethink, reuse, refurbish, repair, repurpose, reduce, remanufacture, recover and recycle (Potting et al. 2017). Regardless of definition, circular economy methods may protect items, their components (modules and components), or the materials (and substances) included inside each product's part.

Furthermore, CE techniques may help to maintain the energy inherent in resources (Iacovidou et al. 2017; Ghisellini et al. 2016; Potting et al. 2017). Circular economy initiatives may also encourage the development of creative business models that go beyond product preservation. Redundancy, multifunctionality, and product usage intensification strategies enhance the circular economy by avoiding the consumption of new items or establishing new consumption patterns. Consumers may, for example, refuse to purchase new items if services or multifunctional products generate duplication in the desired function (Potting et al. 2017). Renting, sharing, and pooling via Product Service-Systems may be effective tools for promoting the circular economy since items will be utilized more intensively (Tukker 2015). It is possible to create product service systems focusing on the product, its usage, or its outcome. As the name suggests, product-oriented product service systems are concerned with extra services provided after the sale of a product (for example, maintenance), so they focus exclusively on the products themselves (Kjaer et al. 2019; Tukker 2015). However, use- and result-driven Product Service-Systems are concerned with maintaining a product's function. In a circular economy, virtualization (instead of real meetings) and discussion sharing (like car-sharing) are examples (Kjaer et al. 2019). The first example is use-oriented, while the second is result-oriented. There are two types of Product Service Systems—Product Service Systems that preserve the function of a product while it is in use and Product Service Systems that preserve the product while it is in use (EMF 2015a) (Fig. 10.1).

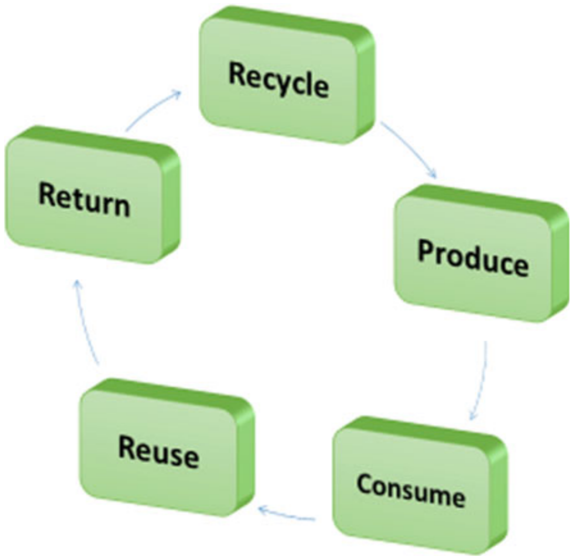


Fig. 10.1 Circular economy: an overview

10.5 Classification of Circular Economy Indicator

As a result of its LCT (life cycle thinking technique) and model level, circular economy indicators can be divided into three measurement scopes (technological cycles and their cause-and-effect chains) according to their measurement scope.

(a) Scope 0: the indicators assess physical attributes derived from technological cycles without using the LCT technique, for example, the Rate of Recycling (Graedel et al. 2011).
(b) Scope 1: the indicators measure physical properties from technological cycles using a full or partial LCT approach. For example, the indicator Reusability/Recyclability/Recoverability (RRR) in mass includes the potential rate to reuse (components, products) and recover (energy) and recycle (materials) (Ardente and Mathieux 2014).
(c) Scope 2: In a cause-and-effect chain modelling, the indicators quantify the consequences (burdens/benefits) of technology cycles on environmental, economic, and societal problems, e.g. RRR benefit rate (RRR in terms of environmental impacts) (Huysman et al. 2015).

The measured strategies can be differentiated based on the indicators, and the measurement type for all the investigated indicators is Direct CE with Specific Strategies. It is important to note that most metrics in the CE approach assess the preservation of material based on the CE approach. As a rule, indicators are presented in scopes 1 and 2 of the measurement scope- that is, they are based on a set of parameters chosen according to the measurement scope, and they study a part or all of the LCT technique. There are a number of indicators included in the scope 1 that measure more than one type of technological cycle, such as the Material Circularity Indicator (MCI) (EMF 2015b), which has been introduced as a measure of the quality of products, their components, materials, as well as their potential to produce waste. There is no need to measure the outcomes of more than one approach within scope 1 or 2 categorizations. It is possible to use the Lifetime of Materials in the Anthroposphere (LMA) (Paulik 2018) as well as the Number of Times of Use of a Material (NTUM) (Matsuno et al. 2007) to measure the cascade of materials across product categories. This is because the two indicators focus on recycling and downcycling to ensure that the material residence time is considered when assessing the LCT approach. However, only strategy 4 is assessed since it also considers the material residence time, so it is evident why this is the case.

10.5.1 Indicators Focusing on Functions

There was no assessment of functions in the indicators that were analyzed. However, several tried to quantify functions by combining quantitative and qualitative data to quantify them even though none of the indicators assessed functions. It has been reported that Scheepens et al. (2016), to develop a PSS for water tourism, utilized the Eco-Cost Value Ratio (EVR) (a quantitative LCA-based indicator) alongside the Circular Transition Framework (a qualitative framework) to develop a PSS for water tourism. The purpose of this qualitative framework was to provide a deeper understanding of the procedures that would be required for the deployment of PSS, whereas the purpose of the EVR had to do with the items that would be included in PSS. Even though the function-related approach in this evaluation was unclear, the purpose of the study was to examine the possibility of replacing a PPS with a diesel engine with a PPS with an electric engine even though the function-related approach was unclear. As a result, it can be concluded that the EVR has improved the eco-design of the product positively, even though the product's functionality has yet to be demonstrated. As a result of the higher risk of affecting functionality than the other techniques, the preservation of functionality when using this technique is more challenging than when using the other techniques since it poses a greater risk of affecting functionality than when using the other techniques. There is, therefore, a need to consider some specific features of CE, such as the effects of changing customer behavior when comparing services and goods, which must also be considered when comparing services and goods (Zink and Geyer 2017) when comparing services and goods. We can gain a deeper understanding of how functions can be accessed from a global perspective to make better decisions by utilizing the Circularity Gap study (Wit et al. 2019) to assess functions from a global perspective to make better decisions (Table 10.1).

10.5.2 Indicator Focusing on Component and Product

An assessment of the strategy for a product or component should be made in light of the possibility of slowing down resource loops when assessing the strategy for that product or component. To quantify this characteristic, a number of indicators can be used, but there are two indicators, in particular, that stand out from the rest compared to the rest of the indicators. Taking into account the fact that some of the physical components of the product are not user-friendly when evaluating the quantity and quality indicators that track the quantity of the product, it is possible to take into account the fact that some of the physical components of the product are not user-friendly as a result of evaluating the quantity and quality indicators that track the quantity of the product. The Total Restored Products (TRP) (Paulik 2018) is an MFA-based metric that takes into account the end-of-life items that are refilled, reconditioned, redistributed, and remanufactured (EoL). A quality indicator, on the other hand, is an indicator that takes into account the time or the economic value of a product and is an example of a character that is affected by the user of a product. In their study, Linder et al. (2017) explain that the Product-Level Circularity Metric (PLCM) measures the relative economic value of flow recirculation compared to the total economic value of the flows at a product level. Franklin-Johnson et al. (2016) have developed a quality indicator called the Longevity Indicator that considers the

Table 10.1 Microscale circular economy indicators

Strategies of circular economy	Scope zero Cycle of technology without LCT aspects	Scope one Cycle of technology with LCT aspects	Scope two Modeling effect and causes with or without LCT aspects
Component (repurpose, reuse)	eDiM	TRP	PLMC
Function (reduce, rethink, refuse)			
Embodied energy (energy recovery)		MCI	SCI CPI
Product (remanufacture, reuse)	eDiM	TRP Longevity MIC	PLMC EVR SCI
Material (downcycle, recycle)	CR RR OSR RIR EOL-RR	NTUM Longevity CIRC LMA	PLMC SCI GRI CEI CPI VRE
Reference(waste generation, landfilling without energy recovery)		Longevity MCI	SCI

- eDiM (ease of Disassembly metric) from Vanegas et al. (2018)
- CR (old scrap Collection Rate)
- PLCM (Product-Level Circularity Metric) from Linder et al. (2017)
- CPI (Circular economy Performance Indicator) from Huysman et al. (2017)
- RR (Recycling process efficiency Rate)
- EOL-RR (End of Life Recycling Rate)
- RIR (Recycling Input Rate)
- OSR (Old Scrap Ratio) from Graedel et al. (2011)
- Longevity from Franklin-Johnson et al. (2016)
- LMA (Lifetime of Materials on Anthroposphere) from Paulik (2018)
- SCI (Sustainable Circular Index) from Azevedo et al. (2017)
- GRI (Global Resource Indicator) from Adibi et al. (2017)
- MCI (Material Circularity Indicator) from EMF (2015b)
- CEI (Circular Economy Index) from Di Maio and Rem (2015)
- NTUM (Number of Times of Use of a Material) from Matsuno et al. (2007)
- CIRC (Material Circularity Indicator CIRC), TRP (Total Restored Products) (Paulik 2018)

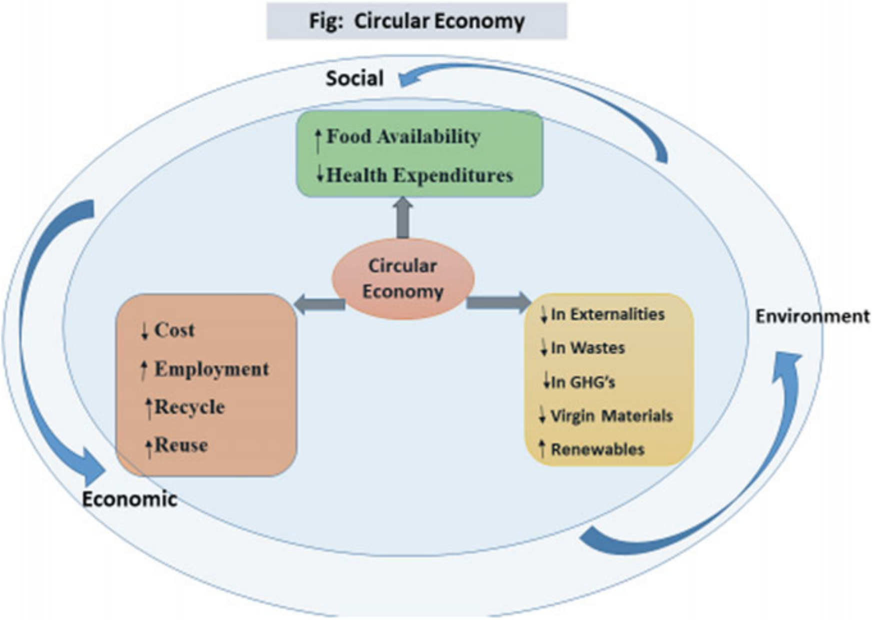
duration of time that the product will last based on statistical data and expert estimations to take into account the longevity of the materials the product is constructed from. Despite the fact that the results of the PLCM may differ in a few respects from those of the Longevity Indicator, they may be equivalent when compared to comparable items with varying lifespans (products with similar functions and recirculated flows). The Longevity indicator, however, only includes the average lifespan. Thus, it is important to consider the data variability that can be attributed to various consumer behaviours over time. In addition to that, the Material Circularity Indicator (MCI) (EMF 2015b) is an index that combines the mass of the product (raw materials, recycled materials, and trash) and the product's lifetime into a single figure.

10.6 Material Quality in Circular Economy

Material quality plays a crucial role in determining the circularity of the economy as it determines the quality of the products. Two critical qualitative elements of recycling will be discussed in this section: the quality of the recycled material and the functionality of the compounds contained within the recycled material. As a result of the recycling process, recycled materials may have a quality that is different from the original material and is often inferior to the original material in terms of quality. It will be necessary for us to be able to study this topic in depth if we can produce material of the same quality as the recycled material obtained from the main sources in order for us to be able to study this topic in depth. In order for a circular economy to function efficiently, preserving functionality "for as long as possible" is important for maximizing the utility of the compounds contained in materials. This consideration is aligned with the concept that preserving functionality "for as long as possible" is essential for the successful operation of a circular economy. It is important to address two issues when it comes to functionality:

1. There is a loss of functional compounds within the raw material due to processing.
2. To prevent the formation of dysfunctional substances in the recovered product, it is necessary to prevent their appearance.

As a result of chemical partitioning and leftovers from the material manufacturing, the chemical functionality of the material can be lost as the chemicals from the material become separated. For example, it may be conceivable that the proportion of functional alloying elements such as Mn, Nb, and V lost to the slags is significantly higher than the percentage of functional Fe lost to the slags in the process of remitting recycled steel. In a study by Iacavidou et al. (2017), it has been reported that functionality loss can occur when a chemical has functionality in the main product but not in a secondary product.



10.7 Renewable Resources and Circular Economy

A successful CE must have a worldwide approach to resource efficiency to ensure that raw materials and energy sources are used effectively. To put it another way, renewable energy sources should be used to generate energy. There is no doubt that CE, renewable energy, and energy efficiency are all intertwined for long-term development to be possible. There is no doubt that global resource-producing companies are increasingly looking for ways to ensure that they meet market demands while reducing the amount of energy they consume and the amount of environmental impact they have on the planet. As a way to connect their operations with a sustainable closed system that is based on the CE, many businesses are attempting to "mix the CE with the bio-economy" in their efforts to come up with a way to combine both elements in their operations in a sustainable manner. Putting it another way, the CE's goals may be better served by a growing reliance on renewable energy sources. For carbon dioxide to be absorbed into the atmosphere, it is necessary to expand renewable resources. Unlike fossil-based goods that contribute to greenhouse gas emissions in the atmosphere when converted into trash (through consumption), renewable resources serve as carbon sinks in the atmosphere when they are converted into trash (by burning). They are not a source of greenhouse gas emissions in the atmosphere when converted into trash (by burning). In addition to being a renewable resource, forestation also contributes to the bio-economy as a source of carbon sequestration. One billion people lack a reliable source of electricity, which is why renewable energy solutions are dependable and expand access. Recent research has shown that in the past five years, there has been an increase of 1.3% in energy-related emissions, which can be reduced by modifying lifestyles, such as reducing, reusing, and recycling resources, as well as recycling virgin materials and water, all of which could reduce emissions related to energy use. It is also possible to improve the structure's efficiency through structural modifications. The relocation of industrial units and the modification of public transportation (such as public transportation and shared passenger vehicles) are examples of such developments that are taking place today (IRENA 2019).

10.8 Circular Economy and Environmental Quality

One of the most significant components of CE is to reduce the externalities (waste and pollution) and to use limited resources as efficiently as possible. It has been shown that CE reduces the depletion of natural resources and enhances the performance of natural resources (Moraga et al. 2019a, b; MacArthur 2013). As well as that, the CE's primary objective is to disentangle economic growth from the limited (finite) resources in the economy and to design institutions that can foster the development of economic, social, and natural capital so that the economy can grow in a sustainable way (Ellen MacArthur Foundation 2019; Elia et al. 2017). It is a central theme of the CE to enhance resource efficiency to minimize the environmental effects and, at the same time, increase the well-being of future generations by reducing the environmental impact they have on the environment (Magnier 2017). It has been suggested that a shift from linear CE to restorative, reproductive, and cyclical CE could be beneficial for the sector, the organization, the nation, and even the international boundaries. Since it is cost-effective, reduces the costs associated with the production of new products, does not produce waste, and can decrease product losses across the value chain (Korhonen et al. 2018). As CE is based on the closed-loop concept, it reduces the consumption of virgin materials since it is based on a closed-loop system, which is based on a closed-loop concept. For a transition to a CE to be successful, it must be evaluated beyond just a material point of view, as it may also affect the quality of the environment and climate change in the long run (Demurtas et al. 2015). It is expected that the use of CE practices will reduce energy consumption and emissions due to its application (IRENA 2019).

10.9 Implications for Theory and Policy

Using renewable energy minimizes the extraction of fossil fuels, the emission of greenhouse gases as a result of fossil fuel combustion, the amount of trash that ends up in landfills, water pollution, and the effects of climate change associated with the use of fossil fuels. Recycling garbage is similar to using renewable resources in that it contributes to reducing the deterioration of the environment, just like using renewable resources. Essentially, this can be attributed to the fact that it does not undermine the system's regenerative abilities and allows resources to be utilized for longer. In addition to contributing to the protection of the environment, the recycling of biowaste and municipal waste helps to reduce pollution. In addition, there is an improvement in the quality of the environment due to the increase in patents in recycling and secondary raw materials that have been issued. This is because when resources are used more effectively, there is also a presence of "ecological modernization and eco-industrial growth". Although technological backwardness and inefficiency in resource use initially degrade the quality of the environment as economies grow and industrialize, awareness of the development and technological advancement arising from innovation will improve the quality of the environment and enhance the relationship between the environment and mankind. The government of every economy should strive to enhance the circular economy, including the use of renewable energy, to ensure energy security as well as shift the reliance away from non-renewable finite resources to those that can be sustained and are readily available in all countries, regardless of their level of income. The use of renewable energy promotes the concept of conservation of energy by shifting dependence away from virgin resources. This shift favours renewable resources that have no negative impact on the environment. There is a greater impact on the environmental quality of a company's competitiveness and innovation than a company's compliance with other CE criteria (Schroeder et al. 2019).

10.10 Innovations and Competitiveness in Circular Economy

In terms of competitiveness and innovation, patents which are associated with the recycling of raw materials or the use of secondary raw materials, the gross investment in tangible items, the number of people employed, and the value added at factor cost are examples of competitiveness and innovation (Ekins et al. 2019). As a result of technological advancements and innovations, there has been an increase in the efficiency of resources and a reduction in the rate of environmental degradation. As a result of the advancements made in the industrial sector, CE has been able to reduce energy consumption by lowering energy consumption to decrease the amount of energy consumed by CE. More specifically, CE has decreased energy consumption by decreasing energy consumption. In the last several decades, the advent of "digital and communication technology" has resulted in greater connectivity, which has led to a reduction in the energy consumption associated with the transportation of heavy cargo (Majeed 2018). When buildings are constructed to meet zero energy standards, it will reduce the amount of energy used in high-temperature zones. As technology progresses and is introduced into the marketplace, many modern cooking gadgets, such as electric stoves and liquefied petroleum gas (LPG), are eroding the dependence on traditional bioenergy sources, thus reducing the dependency on traditional sources of energy. As new models were launched, manufacturers were encouraged to produce vehicle components that could be used for a longer period of time, preserving value and encouraging the use of electric vehicles. It is estimated that almost 16,000 electric buses serve the city, which contributes to a reduction in noise pollution and heat and noise. Increasing the efficiency of secondary manufacturing may have a "rebound effect." This could lead to a reduction in the cost of the end product and its end value, eventually leading to a rise in consumption and stimulating economic growth. This translates into further expansion, potentially jeopardizing increased efficiency and environmental improvements (Millar et al. 2019). This study emphasizes the importance of CE and its numerous characteristics for the quality of the environment in the context of the preceding research.

10.11 Secondary Raw Materials and the Circular Economy

A number of examples of secondary raw materials can be provided, such as end-of-life recycling input rates, circular material use rates, and trade-in rates for recyclable raw materials as examples of secondary raw materials. There are many characteristics of a circular economy, including the recycling and reusing of goods throughout the value chain, as well as the conversion of trash into a resource through the management of waste to further promote the circular economy (Elia et al. 2017). As one of the most important aspects of the CE, the use of recycled materials is of great importance since it supports the use of natural resources in a sustainable manner. A critical aspect of CE is the notion of industrial symbiosis, which refers to the use of one company's waste as a resource by another company while at the same time attempting to limit the amount of waste produced within the latter company. To extend the life of a product by improving manufacturing methods and maintaining the product properly in order to reduce the number of replacements and the number of resources used, the aim of this project is to extend the life of a product. For the CE to work, the three Rs (reduce, reuse, and recycle) must be followed (Murray et al. 2017). As a result of the MacArthur Foundation's research, the Ellen MacArthur Foundation believes that the replacement of single-use bottles with "refill" designs in the packaging, personal care, beauty goods, household cleaning, and transportation sectors could result in a reduction in greenhouse gas emissions of 80–85% (Ellen MacArthur Foundation 2019).

10.12 Agri-food Sector Circular Economy

In order to protect biodiversity as well as use natural resources responsibly, agriculture and the food industry play a crucial role. Furthermore, it is believed that compared to other options, it has a significant potential for alleviating climate change and segment of the economy compared to other options. It is indeed true that the expansion of agricultural activities has important negative environmental effects: the overexploitation of natural resources, the pollution of soil and water, the change in land use, the loss of biodiversity, as well as CO_2 emissions, among others. The perspectives for the future emphasize that these effects will be exacerbated in the future. On the other hand, it is also necessary to increase agricultural production in order to meet the food demands of the rapidly growing global population. Changes in food demand, on the other hand, cause changes in agricultural output. These tendencies will have a greater impact. The amount of intensification of natural resource pressures.

In this case, in this sense, more external inputs (nutrients, agrochemicals, etc.) will be used. More polluting outputs (sub-products, etc.) will be created. Organic and inorganic wastes, nitrates, and so on). The food industry is growing. Inextricably related to agriculture, it provides several opportunities for increasing its circularity by recycling resources and valorizing by-products. In addition, the cascade use of biomass can also help to reduce food loss and waste through the reduction of food loss and waste.

For example, by-products and food industry waste can often be used in agriculture, as feedstuffs and fertilizers. A range of CE indicators must be developed and utilized for a wide range of agricultural systems (intensive/extensive) and settings (urban/rural) to assess agricultural systems' circularity. However, despite this progress, reliable indicators for measuring and documenting the progress towards CE principles are still lacking, particularly in the agri-food sector (Kalmykova et al. 2018). For the transition to a circular economy in agriculture and food systems to be successful, it is vital to evaluate the circularity of such indicators to achieve tangible actions and quantifiable outcomes throughout the process. Likely, the pledges made by agrarian firms and food producers to the CE will remain unspecific and idealistic in the absence of clear metrics. It is also possible that the development of these methods of measuring may result in producers and consumers being able to distinguish between food and agricultural goods that are truly circular from those that are not. A number of other sustainability indicators are required as well as circularity indicators, to determine whether CE techniques contribute positively or negatively to the United Nations Sustainable Development Objectives (SDGs), especially in a sector like agri-food, which is critical to achieving a number of the SDGs (e.g. zero hunger and clean water and sanitation) (Moraga et al. 2019a, b). New socioeconomic indicators at various levels to assess the agri-food sector's circularity. Examine the synergies and trade-offs between agri-food CE plans and the SDGs (Paulik 2018).

1. New criteria to assess the potential of CE regeneration techniques for land used for agriculture.
2. New metrics for evaluating the resource and sustainability savings of agri-food cascade processes.
3. Metrics indicating the use of CE concepts and techniques in food production and consumption systems.
4. Quantitative and qualitative comparisons of novel CE tactics with conventional linear agri-food practices.
5. Systems for monitoring agroecosystems and agro-food linkages.
6. SDG-derived sustainability metrics for assessing bio-economy systems.
7. New data derived from case studies or successful practices demonstrates CE techniques' positive and negative effects with wide implications in the agri-food industry.

10.13 Conclusion

There are a number of indicators that have to do with the preservation of material. There is no doubt that material-focused strategies, which include recycling, are well-established activities, but they are just some of the available options for promoting a circular economy. Recycling, although important to the economy, is not the only feature of an economy that is sustainable in the long run. There are two types of indirect CE indicators, on the one hand, waste and material indicators, on the other hand. On the other hand, the indirect circular economy indicators based on recycling rates use waste data to present information on feasible measures to preserve materials in the future. An estimated portion of the trash will be upgraded as a secondary resource due to the 'circular economy monitoring framework'.

The materials side of the 'Circular economy monitoring framework' may be crucial since only a portion of the trash produced for recycling will be converted into recycled material. However, the efficiency and quality of those materials are crucial to their overall success. When it comes to evaluating functionality, the process is difficult because it affects customer behaviour in a variety of ways. For example, sharing platforms may encourage customers to use items with less caution than they would if they owned them (Tukker 2015). It has been suggested that high-level CE plans require socio-institutional changes in the product chain, which increases the complexity of the evaluation process (Potting et al. 2017).

Research and development of innovative and efficient energy sources in order to promote economic growth rapidly and actively, as well as a reduction in the production of CO_2 emissions. Renewable energy sources are environmentally friendly and reduce emissions. To ensure that our environment stays clean and pollution free, we must implement policies that rely on renewable energy sources in order to boost our economic development and maintain a clean environment. Incentives that encourage businesses to go green should be provided. Technology has been developed in order to reduce carbon emissions by giving incentives such as tax breaks and financial incentives. However, while these policies are being implemented, the governments of these countries should focus on preserving the natural resource pool by establishing public property rights in the form of public–private partnerships. As a result, there may be a decrease in the use of fossil fuels and an increase in the use of renewable energy, which will lower the emissions of greenhouse gases. Although authorities should gradually implement this transition from fossil fuel to green energy solutions, the economic growth pattern may be hindered throughout the course of this transition.

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Chapter 11
Biofuel Circular Economy in Environmental Sustainability

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Abstract Rising climatic concerns, declining fossil fuel stocks, and the need for independence in energy security have made policymakers and researchers look for low-carbon domestic fuels that can fulfil the energy demands of the growing world. Biofuels are seen as potential alternatives that can serve as future clean energy sources. Life Cycle Assessment (LCA) studies are being carried out worldwide considering biofuels' impact on climate and land-use changes they bring during the cultivation of respective feedstocks to assess their environmental suitability. However, environmental sustainability of biofuels in terms of various aspects such as Global Warming Potential (GWP), Land Use Changes (LUC) (such as eutrophication, water footprint, NO_x emissions, and soil acidification) vary as per feedstocks available, production technologies, and assessment methodologies. Among biofuels, 1st generation biofuels are the current commercialized technology but have several negative environmental implications, especially when land-use changes are considered, leading to an overall carbon debt with their use. The 2nd generation of biofuels has the potential to minimize environmental degradation without altering land-use patterns. Crop, forest residue, and agriculture waste-based 2nd generation biofuels speed up the sustainability and resource-efficient approaches to the circular economy. The 3rd and 4th-generation biofuels have yet to achieve their commercialized potential due to their high cost of production and have been unverified to reduce the environmental impact compared to currently used fossil fuels. Therefore, to conclude the environmental suitability of biofuels, LCA studies need to be meticulously carried out *w.r.t.* the changes they bring in our ecosystems.

Keywords Biofuels · Circular economy · Life cycle assessment · Global warming potential · Environment

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11.1 Introduction

The industrial revolution of the eighteenth Century was the beginning of the dependence on fossil fuels for fulfilling energy demands (Singh et al. 2022). As of 2019, 84% of global energy demands were met using non-renewable fossil fuels (Khan et al. 2021). Overexploitation of non-renewable sources of energy combined with the changing climatic pattern triggered by the emission of CO_2 and other greenhouse gases (GHGs) have made the scientific community look for sustainable alternatives (Khan et al. 2021; Devi et al. 2022; Bórawski et al. 2022). On the Kardashev scale, the civilization on Earth falls below Type I, the current value being 0.72, signifying the failure of humans to tap our own planet's natural and renewable resources completely (Kardashev 1964). The sun, wind, water and agricultural waste are promising candidates in the current scenario. Recently, scientists made a breakthrough in nuclear fusion, which coincidentally also powers our very own Sun. The energy produced is claimed to be the cleanest source of energy if stabilized properly. Similarly, nuclear fission, tidal, hydro, wind, and biomass-based energies must be incentivized and worked on to make them economically viable, socially acceptable, and sustainable. The urgency of green energy sources and reducing emissions of GHGs has been stressed on more than one occasion through international policies such as the Montreal Protocol, the Kyoto protocol and the Paris agreement. However, the amount of CO_2 keeps rising, bringing catastrophe to the world in the name of rising sea levels, changes in the weather pattern, and extremes of drought and floods (Leong et al. 2021). Fossil fuels have a global stake of 58% in the transportation sector with a 16% contribution to the GHGs emission (Khan et al. 2021). Amidst green energies, biofuel can be a viable renewable source of energy considering its low carbonizing nature in contrast to existing non-renewable fossil fuels. Biofuel is "liquid, solid, or gaseous fuel produced by conversion of biomass such as bioethanol from sugar cane or corn, charcoal or woodchips, and biogas from anaerobic decomposition of wastes" (OECD 2002). Bioethanol, biodiesel, biohydrogen and biogas are the biofuels currently used to meet global energy demands (Devi et al. 2022). Among biofuels, bioethanol is more favoured as a replacement for petrochemicals because of its good conversion quality, except for European Union, where biodiesel has the major share (Araújo et al. 2017; Devi et al. 2022). Biofuels have been classified into four categories based on the physical state, level of technology, generation of feedstock and generation of product. In the current chapter, the authors will discuss the biofuels classified based on feedstock generation. The type of feedstock used greatly influences the biofuel produced. The feedstock is procured based on its price, hydrocarbon content and biodegradability. The price affects the economic adaptability of the bioenergy, and degradability influences the speed with which the production process can be accomplished, whereas the hydrocarbon content is related to the conversion quality (Awogbemi et al. 2021).

11.2 First Generation Biofuels

The raw materials used to produce first-generation or conventional biofuels are food-based, for instance, sugarcane, rapeseed, palm oil, wheat, rice, etc. The raw materials undergo either fermentation or transesterification processes to produce bioethanol or biodiesel. The carbohydrates-based raw materials in the presence of industrial yeast, i.e., *Saccharomyces cerevisiae,* produce biofuel through fermentation of simple sugars (IEA 2011; Kojima and Johnson 2006; Seelke and Yacobucci 2007; Araújo et al. 2017). The oil extracted from the plants undergo transesterification, a chemical reaction responsible for producing fatty acid methyl esters (FAME) or biodiesel (Awogbemi et al. 2021; Bailis et al. 2014; Araújo et al. 2017).

11.3 Second Generation Biofuels

Lignocellulosic biomass constitutes second-generation biofuels. They include crop residues, agro-industrial wastes, etc., which can be converted to bioethanol or biodiesel. Cellulosic ethanol is the major biofuel under the lignocellulosic biomass class (Raghavendra et al. 2020). The transformation of lignocellulosic biomass, which includes cellulose, hemicellulose and lignin, is a chemically complex process where complex raw material is broken into simpler units using hydrolytic reactions followed by fermentation and distillation.

11.4 Third Generation Biofuels

The primary and secondary generations directly or indirectly depend on the food sources for the development of biofuels. Third-generation feedstock overcomes the shortcoming by using algae, a non-food source, as the raw material. They are the photosynthetic microorganisms that can absorb atmospheric CO_2, increase their biomass rapidly, and release O_2 besides being the fuel source. Instead of complex sugars, algae produce mostly simple sugars that can be fermented to produce bioethanol. Thus, they can be easily converted into a variety of fuels. The absence of lignin, low hemicellulose and high cellulose concentration make algal fuels a suitable candidate for producing advanced biofuels (Behera et al. 2015).

11.5 Fourth Generation Biofuels

The fourth-generation biofuel is the consolidation of genetically modified algae or feedstock. They are engineered to increase the oil content, resulting in increased capacity to convert the sun's energy and CO_2 into potential green fuel. Hence the net effect of CO_2 is negligible on the environment. This area is currently under research (Khan et al. 2021; Kumar et al. 2022).

The country's development is represented in the form of the industries it caters resulting in the rise of industries in developing and underdeveloped countries. Consequently, they could not tackle the problem arising due to the generation of non-biodegradable waste and the pollution of the environment. To cope with such a scenario, United Nations Conference on Trade and Development highlighted the potential of the Circular Economy in 2015 to reduce waste, enhance input use efficiency, make products durable and curb ever-rising CO_2 in the atmosphere. Originally, the circular economy as a system of energy and material flows was given by Kenneth E. Boulding in 1966. A circular economy can be defined as a restorative, regenerative system wherein all the components and products are at their highest utility level and value throughout the system besides balancing the economic, social and environmental objectives. The concept of a circular economy depends on reuse, recycling, repair, remanufacturing, alterations in consumption patterns and product sharing (Chobanova 2020; Rashid et al. 2013; Braungart et al. 2007; Korhonen et al. 2018). United Nations described the circular economy as one of the catalytic approaches to attain the Sustainable Development Goals (SDGs) by 2030 (Valverde and Avilés-Palacios 2021). The circular economy aims to change the societal approach so that products are utilized sustainably with minimum waste production and the least negative environmental impact. Innovation in management technologies is a stepping stone to a circular economy (Devi et al. 2022). A circular economy comes with benefits such as reducing the dependence on the non-renewable source of energy, reducing the emissions of GHGs, improvising the efficiencies of the resources, and enhancing the value of the waste generated from various sources. Hence, the circular economy shows the prospect of a sustainable and greener environment. Perennial grasses, forest biomass, and other biomass-based biofuel feedstocks keep greenhouse gases in a circular loop by absorbing most of them released into the atmosphere during combustion. Such biofuel feedstock-based root biomass and litter decomposition further have the potential to sequester carbon in the soil, reversing climate change and resulting in a low-carbon economy. Waste and residues-based energy sources support the transition of the linear economy to the circular economy model and sustain the energy-environment nexus in a low-carbon mode. The recycling and reuse concept keeps the product's value longer than the usual linear model and minimizes the greenhouse gas footprint in the absence of waste-based release of greenhouse gases in the atmosphere (Leong et al. 2021).

11.6 Environmental Sustainability of First-Generation Biofuels

The sustainability of liquid biofuels is a function of additional feedstock cultivation for biofuels (Searchinger 2010; Haberl et al. 2012; Wang et al. 2021; DeCicco et al. 2016), the extent to which biomass is being replaced in the food chain (Searchinger et al. 2015; Tilman et al. 2009; Naylor et al. 2007) and the changes in land use that arises with the production of biofuels (Searchinger et al. 2008; Fargione et al. 2008; Fargione et al. 2010; Gibbs et al. 2008a, b; Hertel et al. 2010; Gelfand et al. 2011). Initially, the energies were graded as eco-friendly based on the CO_2 emitted from the source without considering the amount of CO_2 absorbed by the source. However, Life Cycle Assessment (LCA) studies or cradle-to-grave approach takes into account the environmental footprint of the products during their entire life cycle so that their environmental sustainability can be assessed (Rathore et al. 2013). Consumption of CO_2 by first-generation biofuel feedstocks made scientists worldwide believe first-generation biofuels are carbon neutral and environmentally friendly.

11.7 Sustainability of First-Generation Biofuels Without and with Land Use Changes

The first-generation biofuels have the potential to reduce greenhouse gas emissions substantially when utilized as energy sources, thereby leaving a positive impact on the environment (Finco et al. 2012; Dressler et al. 2012; Faist Emmenegger et al. 2011; Adler et al. 2007). Among feedstocks, sugarcane-based bioethanol was most effective in terms of environmental sustainability, i.e., around 60% reduction in GHGs emissions over conventional fuels (Jeswani et al. 2020). The reduced emissions of harmful gaseous pollutants like nitrous oxide (N_2O), 1,3-butadiene, and benzene were observed from the E85 blend, i.e., 15% bioethanol and 85% conventional fuel (Yanowitz and McCormick 2009). Besides, a drop in the release of carbon monoxide, particulate matter, and other toxic materials was observed with biodiesel blends (McCormick 2007). Among biodiesel feedstocks, oil palm-based biodiesel had the potential to curtail GHGs emissions by 60%. Therefore, biofuels can be considered safe for the environment in terms of air quality compared to their predecessor. A positive scenario of first-generation biofuels was established well before the LCA studies, where land use changes (LUC) were considered for assessing environmental suitability. Following the environmental evaluation, the government made bio-energies commercially available. This led to controversies like food *vs* fuel competition or elevated GHGs emissions compared to conventional biofuels. According to the Tier-1 methodology developed by IPCC, 1–1.5% of nitrogen fertilizer applied each time is lost as N_2O, which has 265 times more potential to cause greenhouse effect than the CO_2 besides causing acid rain and other respiratory diseases (IPCC 1996, 2013;

Crutzen et al. 2008; Phalan 2009). In China, maize-based bioethanol was observed to have 40% higher GHGs emissions when compared to petrol due to the high rate of synthetic nitrogen fertilizer applied and coal-based energy consumption patterns (Ou et al. 2009). Due to the water deficit, low crop yields for rapeseed, soybean, and sugarbeet led to reduced greenhouse gas emissions in South Africa (Stephenson et al. 2010; Tomaschek et al. 2012). Malaysia-based oil palm plantations are responsible for a higher release of volatile organic compounds (VOCs) and nitrogen oxides than rainforests, which may increase substantially when oil palm-based biodiesel is used in automobile engines (Hewitt et al. 2009). When production techniques were included in source-to-wheel emission studies, it was observed that first-generation biofuels had a worse impact on the environment in terms of emissions of carbon monoxide, volatile organic compounds (VOC), nitrogen oxides, and sulphur oxides when compared to conventional fuels (Brinkman et al. 2005). Corn-based ethanol harmed human health with its higher particulate matter (PM 2.5) release in the environment compared to conventional fuels.

As discussed earlier in the chapter, LUC was doubted for its role in altering the quantity of GHGs released during the cultivation of feedstock for first-generation biofuel production (Fargione et al. 2008; Fargione et al. 2010; Pawelzik et al. 2013; Tonini et al. 2016; Humpenöder et al. 2013). Land Use Changes are one of the contributors to atmospheric CO_2 levels, with a contribution amounting to 660 ± 290 Gt of CO_2 between 1750 and 2011 (IPCC 2013). Such LUC-based GHGs emissions depend on several factors such as the type of ecosystem affected, the amount of area affected, and the GHG emissions from each hectare area. Conversion of land for sugarcane cultivation boosted the release of particulate matter and ground-level ozone in Brazil because of the burning of crop residue (Goldemberg 2007; Uriarte et al. 2009). Displacement of perennial carbon-rich plantations such as forests, peatlands, and savannas by annual biofuel crops will worsen climate change rather than ameliorate it (Gibbs et al. 2008a; b; Fargione et al. 2008; Righelato and Spracklen 2007; Danielsen et al. 2008; Danielsen et al. 2008; Fargione et al. 2010; Phalan 2009). Food security issues worldwide made different nations think of sustainable alternatives to biofuels or advanced biofuels having less GWP (Global warming potential) and no competition for land or food resources. To eliminate such socio-environmental threats, European Union (E.U.) has developed new policies, such as the Directive on Renewable Energy II, wherein first-generation biofuels will represent only 7% of total energy consumption in the transport sector by 2030 (E.U. Directive 2018).

11.8 Soil and Water Quality

Present approaches for judging the sustainability of biofuels often ignore the negative impact on soil and water quality (Soil and water pollution, Eutrophication, Algal blooms, Acidification, etc.) when it comes to checking the environmental suitability of such alternative fuels (Iriarte et al. 2012; González-García et al. 2012, 2013; Belboom et al. 2015; Cavalett et al. 2013; Bessou et al. 2013; Arpornpong et al.

2015; Panichelli et al. 2009; Wang et al. 2013). The water quality of water reservoirs has significant effects from agrochemicals applied in agricultural fields. The amount and nature of agrochemicals, i.e., fertilizers, pesticides, etc., vary with the feedstock being cultivated. Cultivation of annual crops is responsible for higher nutrient and runoff losses compared to perennial grasses (except switch grass) and thus has a severe impact on water quality (Randall et al. 1997; Cherubini and Strømman 2011; Whitaker et al. 2018). Leaching and runoff losses for nitrogen and phosphorus often result in eutrophication events in water bodies. Feedstock cultivation generally for 1st generation bioethanol is responsible for 3–20 times greater eutrophication in water bodies than conventional fossil alternatives (Yang et al. 2012; Belboom et al. 2015; Bessou et al. 2013; Cavalett et al. 2013). Similarly, the cultivation of 1st generation biodiesel feedstocks results in 3–14 times higher eutrophication than its respective fossil-based alternative (Iriarte et al. 2012; González-García et al. 2013; Panichelli et al. 2009; Arpornpong et al. 2015). The type of crop being cultivated influences to a great extent the amount of fertilizer being applied as in maize-soybean rotation, less fertilizer is being consumed compared to maize-maize rotation due to the nitrogen-fixing capability of soybean and its ability to serve as a green fertilizer for the subsequent crop (Hennessy 2006). Similar to 1st generation biofuels, elevated levels of eutrophication and Acidification were observed with micro-algae cultivation as fuel feedstock (Singh and Olsen 2013).

11.9 Environmental Sustainability of Advanced Biofuels

Life Cycle Assessment studies for biofuels based on lignocellulosic biomass have often revealed that GHGs emissions were less for biofuels when compared to gasoline or other fossil fuels. The world faces many threats to humanity, such as hunger, globalization, urbanization, global warming, and higher environmental pollution. Initially, first-generation biofuels were seen as a promising alternative to non-renewable energy sources to meet-out energy demands. However, when exploited on commercial scales and studied, it was revealed that they pose a threat to food security and are responsible for much more environmental damage. As per a projection, second-generation biofuels can reduce fuel-based atmospheric carbon emissions by up to 90%, and with such potential, by 2040, they will replace 40% of non-renewable fuels (Krisztina et al. 2010; Prasad and Dhanya 2011). The global production of annual lignocellulosic biomass is around 1.3 billion tons, which offers a huge potential for industries to produce second-generation bioethanol. Among various lignocellulosic biomass sources such as woody crops, crop residues, and perennial grasses, crop residues are abundant at the end of every agriculture season. Major grasses utilized as sources of lignocellulosic biomass are Switchgrass, *Miscanthus*, Giant weed, and Reed canary grass, and can substantially reduce greenhouse gas emissions to the atmosphere (Korres et al. 2010; Adler et al. 2007; Monti et al. 2009).

Furthermore, perennial grasses can substantially enhance carbon stocks when planted over barren lands, absorb the amount of CO_2 released during bioethanol combustion as photosynthates and thus have the potential to control/reverse climate change (Wang et al. 2012; Tonini et al. 2016). Waste utilization for producing biofuels or other industrially valuable energy sources created a win–win situation for tackling carbon-based environmental issues and paved the way toward a circular economy (Alzate Acevedo et al. 2021). A biomass-based circular economy can be seen as a low carbon economy with lower GHGs emissions, higher resource use efficiency, and less dependence on non-renewable energy sources (Carus and Dammer 2018; Venkata Mohan et al. 2016).

When it comes to waste-based feedstocks Food and Agriculture Organization stated that 33% of the food produced is lost either during harvesting or supply management (FAO 2011). Regarding waste generation among the various food-based industries, beverage or drink industries rank first with 26%, followed by the dairy industry with 21%, the vegetable and fruit industry with 14.8%, and the cereal industry with 12.9% (Baiano 2014). For 2019 alone, food waste generated globally was around 931 million tons (UNEP 2009b). The waste generated can have two fates either a potential greenhouse gas emitter or a source of sugars/carbohydrates that can cause bioenergies (Karmee 2016; Arapoglou et al. 2010; Akpan et al. 2008; Hong and Yoon 2011; Kim et al. 2011; Kumar et al. 1998; Oberoi et al. 2011; Sharma et al. 2007; Tang et al. 2008; Yan et al. 2011). Around 95% of food waste ends up in landfills and is responsible for releasing GHGs equivalent to 113 mt CO_2 annually. (Buzby et al. 2014; Venkat 2012; Karmee 2016). The latter approach defines the concept of a circular economy with minimum waste generation and keeping the product value as long as possible across the system (European Union 2015). France's national policies are focused and deriving bioenergy continuously from food waste across the country (Clercq et al. 2017). Food wastes include crop residues on farms, fruit or vegetable waste, processed food waste, cooked leftover food at home, restaurants, hotels, or other food residues across the food supply chain. Agricultural residues are "non-edible plant portions left over in farm fields after crop harvest that vary in their properties and nutritional composition" (Lal 2005). Out of the total biomass in crop cultivation, 40–60% is considered the residue and is mostly left in cultivated fields (Go et al. 2019). On a global scale, such residues can come up as an imperative bioethanol source with the potential of around 51.3 billion litres per year from sugarcane residue, 58.6 billion litres per year from maize straw, 104 billion litres per year from wheat straw, and 205 billion litres per year from rice residue (Sarkar et al. 2012; Saini et al. 2015). The vast potential of agricultural residues lies in their low lignin content and high hydrolytic efficiency compared to other recalcitrant biomass residues (Sathitsuksanoh et al. 2012). The issue of global warming can be melted with such residues as feedstocks for biofuel production. This can eliminate plant-based CO_2, fertilizer-based N_2O, NH_3, or paddy field-based CH_4 emissions and have positive credits with lignin-based power, energy generation for the process, or surplus amount supplied to the grid. Moving along the path, some feedstocks with higher credits than their GHGs emissions have the potential to reduce atmospheric CO_2 levels, i.e., negative global warming potential.

By 2030, the United States of America will solely have enough agricultural residues to generate bioenergy to 240 million dry t/year (Stichnothe et al. 2016).

Globally 134 million tons of rice husk are generated annually, managed improperly and not utilized to their full potential (Kaniapan et al. 2022). Most of these residues, especially rice and wheat straw, are burnt in open fields, disposed of improperly, or piled across corners of cultivated fields in the Indo-Gangetic plains of India and the North Eastern region of India (UNEP 2009a; Gadde et al. 2009). Such practices are responsible for elevated pollution levels, for example, 70% CO_2, 7% CO, 0.66% CH_4, and 2.09% N_2O, affecting human health when exposed to such conditions (Quispe et al. 2017; Samra et al. 2003). Bioethanol generation from rice straw has been proved to be environmentally benign compared to open straw burning. Current (2020) surplus levels of rice straw have the potential to produce 9770 million litres of bioethanol and reach about 11,165 million litres by 2030. With this production level, the potential to reduce GHGs is 12579 kt CO_2eq in 2020 and 14,498 kt CO_2eq by 2030 (Hassan et al. 2021; Park et al. 2011a, b). Residue-based ethanol generation avoids the land use changes and emissions faced during the cultivation of first-generation bioenergy crops, endangering food security and competition for land resources (Basaglia et al. 2021). India produces around 683 million tons of crop residues annually (Devi et al. 2022). In the Philippines, 41% and 24% of the land is under agriculture and forest; hence, its dependence on external energy supplies can be reduced if they move towards biomass-based energy sources (FAO 2014). With 174.1 million tons of agricultural residues, Thailand has the potential to produce 20,213.5 million litres of bioethanol annually (Jusakulvijit et al. 2021). The potential of straw and wood-based bioethanol is high, and they can reduce GHGs emissions to 90% compared to gasoline and other petroleum-based products (Bird et al. 2013). According to a report by the University of Michigan, cellulose-based ethanol was responsible for reducing greenhouse gas emissions to 97% when land use changes were considered (Anonymous 2021).

Around the world, agro-industries such as paper, sugar, tobacco, pulp industry, distilleries and palm oil industries, specifically in Indonesia and Malaysia, have bio-products, wastes, or by-products having lignocellulosic biomass as their major composition, and such agro-industry-based residues can contribute to bioethanol production (Spatari et al. 2010; McKechnie et al. 2011; Devi et al. 2022). One example of agro-industry waste is citrus waste in Florida, wherein annually, 3.5 million tons of waste is generated. Parallel to this, globally, 88 million tons of citrus fruits are produced, and the bioethanol production potential from the destruction of fruits is around 1.2 billion litres (Marín et al. 2007; Pourbafrani et al. 2010, 2013). As per the study, citrus, waste-based bioethanol was observed to reduce greenhouse gas emissions by 134% (GHGs) when used as an E85 blend in light-duty vehicles. Tree bark is a major residue or waste generated by the pulp industry. For every 100 tons of pulp generated, 20 tons of tree bark is produced as a by-product (Neiva et al. 2018). Being rich in lignocellulosic biomass, tree bark can be a potential source for bioethanol generation. Such residues produce bioethanol when undergoing pretreatment and subsequent simultaneous saccharification and fermentation. A study observed that 252 L of bioethanol could be generated per ton of such residue (Romaní et al. 2019). Following citrus, banana is the second most important fruit crop globally, with around 16% contribution to fruit production. Out of the total biomass, 60% of its biomass is left as waste after harvest, i.e., about 114.08 MMT of banana waste globally (Alzate Acevedo et al. 2021). Such lignocellulosic biomass-based waste of bananas can contribute to producing new valuable resources such as biofuels (Gumisiriza et al. 2017). Banana biomass (banana peel, rachis, pseudo-stems, etc.) can be converted into biofuels such as bioethanol, biogas, biohydrogen, and biodiesel as it undergoes respective chemical transformations (Han et al. 2019; Al-Mohammedawi et al. 2019; Urzúa-Valenzuela et al. 2017). The production of useful and highly valuable resources from banana waste closes the loop of material or energy flow wastes and justifies the concept of circular economy (Vilariño et al. 2017; Morseletto 2020).

11.10 Third-Generation Biofuels in the Circular Economy

Algae have a boundless potential to serve as a source of bioenergy that can mitigate the negative impacts of global warming and reduce pressure on land and water resources (Ahmad et al. 2022; Ferreira Mota et al. 2022). Algae-based bioenergy sources represent third-generation biofuels that can be cultivated on industrial scales using low-cost carbon sources such as bio-waste or by-products from industries, households, etc. (Leong et al. 2018; Chen et al. 2021). One example of generating treasure from waste is the utilization of domestic or industrial wastewater to cultivate microbial cultures such as microalgae. Sewage-sludge or wastewater-based microbial cultivation promotes bio-remediation of pollutants in these wastes as well as harvest their potential to serve as nutrient sources for lipid generation (Zeng et al. 2015; Christenson et al. 2011; Park et al. 2011a, b; Madakka et al. 2019; Sarris et al. 2013). Deriving lipids from micro-algae to generate bio-oils is a safe and non-toxic alternative and a potential source to produce biodiesel commercially (Yong et al. 2021; Khoo et al. 2020; Tang et al. 2020). As a renewable, carbon–neutral fuel, microalgae-based biodiesel can be an excellent fuel with its low viscosity (Chia et al. 2018). However, current low yield levels for algae and high energy consumption patterns during its cultivation and management suggest higher GHGs emissions for algae-based biodiesel production (Passell et al. 2013; Mu et al. 2014). Assumptions that have suggested algae-based biodiesel as an environmentally friendly fuel are not feasible commercially, for example, exploiting cement plant-based CO_2, nutrients from cane sugar and wastewater-based nutrient exploitation for algae cultivation (Pragya and Pandey 2016; Yuan et al. 2015; Soratana et al. 2012).

11.11 Biofuel Production on Water Footprint and Biodiversity

The water footprint for ethanol production depends on whether the feedstock is irrigated or rainfed (Berger et al. 2015). Although major feedstocks worldwide are rainfed, future intensive cropping techniques will create more pressure on water resources. In the United States of America, only 18% of corn irrigated is being used in bioethanol production. In contrast, in Brazil, it is only 1% for sugarcane, and most oil palm plantations are currently rainfed in Malaysia and Indonesia. On average, 115 gallons of irrigation water is used to produce 1 gallon of ethanol in the USA (Wu et al. 2009). Biofuels with such an impact on water use are believed to have higher water consumption than petroleum-based energy sources, and the issue worsens when the regional water stress is also taken into account along with water use. Thus, the overall impact of water use varies across regions, but it will depend mainly on local water demand, hydrological cycle, supply and the displaced water use with feedstock cultivation. Water consumption for micro-algae-based biofuel production depends on production systems, geographical location and conversion technologies. Water footprint was observed to be high for open pond cultivation and wet conversion processes compared to closed photo reactor-based and dry conversion processes, respectively (Gerbens-Leenes et al. 2014).

Biofuels are observed to be responsible for declining biodiversity with habitat loss, unsustainable exploitation of land resources, over-application of agrochemicals, rising pollution levels and other forms of environmental degradation (Webb and Coates 2012). The type of feedstock used, production scales, land use changes and management practices are the factors that influence the impact of biofuels on biodiversity (Correa et al. 2017). Rising demands for first-generation biofuel feedstocks are responsible to a great extent for biodiversity loss with excessive application of agrochemicals, intensive tillage practices, land use changes and the conversion of biodiversity-rich ecosystems to agro-ecosystems with sole feedstock-based cultivation systems (Liu et al. 2014; Elshout et al. 2019; FAO 2013; UNEP 2009a). Second-generation biofuels have a less negative impact on the ecosystem's biodiversity (IEA 2010). For perennial grass-based lignocellulosic biomass, less agrochemical application, reduced tillage practices and rising carbon stocks, especially due to their deep root systems and long growth periods, minimize disturbances to the biodiversity of the region (Rowe et al. 2009). Uncertain consequences over biodiversity could be there with microalgae cultivation. However, invasive species of algae could bring down the biodiversity near coastal ecosystems with their large-scale cultivation and dominance (Liu et al. 2014). Most of the negative impacts are offset by the reduction in greenhouse gas emissions and the potential to mitigate climate change.

11.12 Conclusion

Biofuels are seen as an eco-benign alternative to fossil fuels to meet-out global energy demands. Among these, first-generation biofuels (based on linear economy models) have been commercialized worldwide, but their sustainability has been questioned ever since the life cycle assessment studies have been involved in assessing the impact of such technologies on climate. Including land use changes in soil and water quality proved corn ethanol to be even worse than fossil fuels. Second-generation biofuels have been keenly observed and proved to be sustainable and effective in curtailing greenhouse gas emissions with wider availability of photosynthetic biomass, less need for agrochemicals, accumulation of significantly higher CO_2, and release of fewer pollutants. Utilizing the product to the fullest, keeping its values across various stages, agriculture-based residues, and their industrial waste-based biofuels in a circular economy model create a win–win situation in terms of the global warming potential of biofuels. Third and fourth-generation biofuels, however, are being seen as promising future technology but need research incentives, futuristic advancements, and innovations to be developed as commercialized technologies.

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Chapter 12
Accelerating the Transition to a Circular Economy: An Investigation on the Enablers of Blockchain-Based Solar and Wind Energy Supply Chains

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Abstract Solar and wind energy installations are growing rapidly to satisfy the clean energy need worldwide. It is suggested that to meet the rising demand for renewable energy in a resource-effective manner, solar and wind energy supply chains should be streamlined through a variety of means. It is also suggested that one of the most significant instruments to help improve a supply chain toward environmental sustainability is to ensure its circularity via information technology. Blockchain, for example, is a novel information technology that has the potential to improve the circularity of solar and wind energy supply chains. Blockchain can achieve that through its features including trust, traceability, immutability, and audibility. However, it is argued that ensuring an effective blockchain-based supply chain requires identifying and achieving the enablers of these ecosystems. This research, therefore, is aimed at scrutinizing the enablers of blockchain-based solar and wind energy supply chains systematically. To this end, first, a literature review was performed. Then, DEMATEL was used with the help of expert opinions. The findings of this research classify the enablers of blockchain-based solar and wind energy supply chains into two distinct groups: cause and effect. This categorization is invaluable because it provides decision-makers with a guideline to effectively improve their supply chains. The findings of this study concluded that cause enablers regarding regulatory structure, incentive scheme, and blockchain's technological readiness level should be improved to address the effect enablers on, for example, collaboration and policymaking.

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12.1 Introduction

The emergence of renewable energy has a significant impact on "energy security", "environmental sustainability", "access to power", and "economic growth" Erol et al. (2021a). Among the renewable sources, 10% of the world's power was produced by wind and solar in 2021 (Ember 2022). The International Energy Agency (IEA) suggested that solar and wind energy had a significant role in the recent worldwide transition to renewable energy thanks to significant cost advantages in solar and wind installations. The IEA (2022) also suggested that secure supply chains in solar photovoltaic solar and wind overall must ensure that they are adequate, resilient, affordable, and sustainable. However, note that solar panels and wind turbines won't always be in use even though scholars have agreed to their contribution to overall sustainability globally. Instead, photovoltaic PV panels and turbine parts have already started to build up in landfills all over the world due to the existing linear supply chain approach that relies on the "take, make, dispose of" paradigm.

The circular economy (CE), on the other hand, is based on "the premise of closing the loop" in a supply chain. The CE is defined as "an industrial system that is restorative or regenerative by intention and design" (Ellen Mac Arthur Foundation 2013). Given the basis of CE, it is argued that individual components of solar panels and wind turbines, including solar panel aluminium and glass, and turbine steel towers may be reprocessed to pave the way for better resource efficiency (Erol et al. 2021a). Similarly, as information technology continues to evolve, businesses in the solar and wind energy supply chains try to come up with better means to streamline component trackability and recoverability. As the public's awareness of CE rises, further studies are being done about disruptive technology implementations to enable CE's effectiveness in solar and wind energy supply chains. For instance, it is suggested that the development of creative business models toward circularity can be facilitated by blockchain, which has the potential to disrupt the energy industry. In a nutshell, blockchain characterizes itself as the forthcoming technology that will support expansion in the energy sector due to its advantages including trust, immutability, auditability, and visibility (Teufel et al. 2019). Based on these characteristics, many cases such as "real-time data management", "carbon credits", and "renewable energy certificates" can be operated through blockchain.

Until recently, researchers have been working on several frameworks to implement blockchain across supply chains (Gupta et al. 2021). For example, it is argued that one of the most effective frameworks is to identify and use the relevant enablers to ensure successful implementations (Samad et al. 2022). An enabler is described as an aspect that upholds and facilitates any implementation process (Risk et al. 2019). In other words, enablers are actions required to ensure the efficacy and efficiency of core program activities. With that in mind, note that there are a number of enablers that may support the effectiveness of blockchain applications in solar and wind energy supply chains towards better circularity. However, to the best of our knowledge, researchers have not paid sufficient attention to this domain of research although some attempts have been made in various industries (Sahebi et al. 2022; Samad et al. 2022).

This chapter, therefore, is aimed at analyzing enablers of implementing blockchain in solar and wind supply chains towards improved circularity. To achieve that, the subsequent research questions are answered: (1) what is the list of enablers of implementing blockchain in solar and wind supply chains? (2) What are the associations among these enablers? (3) What are the suggestions for decision-makers in solar and wind supply chains to enable enhanced circularity?

To this end, in this chapter, a multi-criteria decision-making (MCDM) approach based on DEMATEL is employed systematically through expert opinions. The main contribution of this study is twofold: First, this is the first research attempt to scrutinize the enablers of blockchain-based solar photovoltaic and wind energy supply chains toward building improved circularity. Second, because of the integrated approach utilized in this research, which includes qualitative and quantitative analysis, the findings of this study may be useful to practitioners as well as researchers.

The rest of the chapter is organized as follows: Sect. 12.2 discusses blockchain and the enablers of blockchain-based solar and wind energy supply chains towards better circularity. Then, Sects. 12.3 and 12.4 provide Methodology and Application, respectively. Finally, Sect. 12.4 demonstrates discussion and implications followed by Conclusions in Sect. 12.5.

12.2 Background

12.2.1 Blockchain in Renewable Energy Towards Circular Economy

Blockchain is a secure database-sharing platform for computer networks. It is sometimes referred to as a digital ledger technology and may be compared to a spreadsheet that has been copied thousands of times and is kept in a distributed network spread out over several different places (Ar et al. 2018, 2020; Ozdemir et al. 2019; Erol et al. 2021b). By doing this, a network is built that automatically and often updates the spreadsheet wherever it may be. Hence, a database that cannot be changed without the consent of all members is formed. In other words, it is argued that one is left with a list of records that securely hold data that cannot be altered or damaged by any entity since it is maintained across a network of computers rather than by a single organization that has overall authority over the system (Ar et al. 2018).

Energy, logistics, health, food, agriculture, banking, government, and tourism are just a few of the sectors that blockchain is predicted to disrupt in the ensuing ten years (

Önder and Treiblmaier 2018; Ar et al. 2018, 2020; Ozdemir et al. 2019; Erol et al. 2021b, 2022; Rajasekaran et al. 2022; Marchesi et al. 2022; Patel et al. 2022; Cao et al. 2022; Guo et al. 2022). Take renewable energy generation as an example. Note that the majority of electricity and power infrastructure worldwide is founded upon centralized energy systems. On the other hand, blockchain is projected to change this traditional framework as conventional consumers develop to concurrently consume, create, and sell energy, for example by installing solar panels and selling excess electricity through a P2P transaction using blockchain (Guo et al. 2022). With blockchain, energy sales transactions may be completed instantly and directly, as opposed to previous methods that call for a central middleman. This results in a decentralized energy supply system by allowing so-called "prosumers" to conduct transactions with a high degree of autonomy—free from intermediaries and regulators (Gawusu et al. 2022).

In addition, supply chains may become more sustainable with the help of blockchain. It is possible to track information about past products and resources as well as the entities in the supply chains. Blockchain data may show carbon footprint, nonrenewable resource use, and waste generated throughout supply chains. To guarantee that the environmental harm caused by supply chain operations is kept to a minimum, this information may be utilized for circular economy objectives (Erol et al. 2022; Kouhizadeh et al. 2022).

Until recently, a significant amount of research has been performed with respect to blockchain adoption in the energy industry. Some researchers, on the other hand, have conducted studies on blockchain in renewable energy supply chains with their main focus on CE and environmental sustainability. This literature review is based on the context of CE and environmental sustainability in renewable energy supply chains. For example, Gawusu et al. (2022) discussed the existing literature on the integration of renewable energy with blockchain. The authors finally argue that blockchain is a crucial instrument for achieving a future powered entirely by renewable energy sources. They also argue that for the transmission of power, the use of blockchain will necessitate considerable policy adjustments as well as regulatory action. In another study, Ahl et al. (2022) conducted interviews with experts to identify the challenges to adopting blockchain in energy supply chains towards sustainability. They conclude that factors including scalability, cost, interoperability, data availability etc. are the most important issues to address. They also conclude that more country-specific research is needed to elaborate on local challenges to blockchain adoption in the renewable energy industry. Erol et al. (2021a) explore critical success factors of blockchain applications in the solar energy supply chains of Turkey toward a circular economy. They maintain that blockchain can be used to generate renewable energy effectively as well as to address end-of-life materials in the supply chain to ensure improved circularity. They conclude that similar research should be performed in other developing countries. Yildizbasi (2021) investigate the challenges to blockchain implementations in renewable supply chains to ensure an improved circular economy.

To achieve that, the author uses a multi-criteria decision framework through expert opinions. He concludes that major investment is still needed to ensure blockchain helps improve circularity in renewable energy supply chains.

12.2.2 Enablers of Blockchain-Based Solar and Wind Energy Supply Chains Towards CE

Blockchain-based supply chain enablers towards CE are the factors that work to create better supply chain designs to allow for better circularity and environmental sustainability. However, note that enablers are sometimes confused with the advantages of a certain system. Therefore, one must ask the right questions to identify the true enablers of a system. To the best of our knowledge, until recently one research has been performed on the enablers of blockchain-based renewable energy supply chains towards CE. In that study, Sahebi et al. (2022) analyze the enablers of a supply chain in the renewable energy industry. To this end, they first identify the enablers by reviewing the literature. Then, they come up with the relationships among the enablers using the integration of DEMATEL and ISM. However, we argue that the main problem with this study is the way the authors identify enablers. The authors suggest that "immutability", "shared database" "auditability", "traceability", and "anonymity", "provenance", "decentralized database" among others are one of the main enablers of the blockchain-based renewable supply chain. Nevertheless, one should note that these factors that the authors listed in their study are not enablers. Rather, they are the inherent functions (characteristics) and (or) benefits of blockchain. Secondly, their analysis is only based on some technical factors. Therefore, additional research is needed for a thorough and true investigation of enablers.

In addition, despite their different industry focus, there are four studies worth discussing here. First, Bai et al. (2022) explored the enablers of blockchain-enabled supply chain transparency in the African cocoa industry. To this end, they first determine the enablers by reviewing the literature. Then, they use the best–worst method to prioritize the enablers. Finally, they conclude that the most important enabler is blockchain security. In another study, Zkik et al. (2022) investigate the enablers of the sustainable blockchain-enabled supply chain in agriculture. They first list the enablers based on the existing studies. Then, they employ multi-criteria decision-making to rank the enablers. The findings of the study indicate that collaboration among the partners and management commitment turns out to be the most important enablers. Finally, Samad et al. (2022) scrutinized the enablers of blockchain in the logistics industry. They used integrated ISM-DEMATEL to reveal the relationships among the enablers. The findings of their study suggested that "Real-time connectivity and information flow" was the most influential enabler. They concluded that new studies are needed using the alternative sets of enablers in various blockchain-enabled industries.

Given the existing studies on the enablers of blockchain-based supply chains towards CE and sustainability, a set of enablers are identified in Table 12.1. Table 12.1 includes enablers, their description and references.

12.3 Methodology

This study investigates the enablers that facilitate the adoption of blockchain in solar and wind supply chains to improve circularity. To this end, the process steps in Fig. 12.1 were carried out sequentially. As can be seen from Fig. 12.1, first of all, the list of enablers of implementing blockchain in solar and wind supply chains was identified through a literature review. Then, the relationships between these enablers were revealed using DEMATEL.

The DEMATEL method, created by "Battelle Memorial Institute's Geneva Research Center" (Braga et al. 2021), is a useful technique that offers the analysis of the types and magnitudes of direct and indirect relationships between components (Asadi et al. 2022). By analyzing the overall relationships between components, DEMATEL can offer a perfect method for better understanding the structural links and for resolving issues with congruent systems (Zhao et al. 2021). The followings demonstrate the steps of DEMATEL (Zhang and Deng 2019; Sharma et al. 2020):

Step 1: *Creating a Direct Relation Matrix*: To form a direct relation matrix for the experts' pairwise comparisons, a "0–4 scale" is used. Table 12.2 provides the pairwise comparison scale utilized in the DEMATEL approach.

Data gathered through pairwise comparisons are used to generate a $n \times n$ dimensional direct relation matrix (D). It is determined using the average rating from the "U" number of experts. To obtain a direct relation matrix, apply the following Eq. (12.1).

$$d_{ij} = \frac{1}{U} \times \sum_{k=1}^{U} a_{ij}^{k} \tag{12.1}$$

Step 2: *Obtaining the Normalized Direct Relation Matrix*: The normalized relation matrix with a diagonal value of 0 is computed after the direct relations matrix (D) is created. To obtain the normalized direct relation matrix (N), Eqs. (12.2) and (12.3) are used.

$$N = \lambda \times D \tag{12.2}$$

$$\lambda = \min\left(\frac{1}{\max_{1\le i\le n} \sum_{j=1}^{n} d_{ij}}, \frac{1}{\max_{1\le j\le n} \sum_{i=1}^{n} d_{ij}}\right) \tag{12.3}$$

Step 3: *Calculating Total Relation Matrix*: Total Relation Matrix (T) is calculated by using a unit matrix (I) via Eq. (12.4):

Table 12.1 The list of enablers

Enablers	Description	References
Effective legal and regulatory structure (E_1)	To develop a blockchain-based supply chain toward better circularity, regulations that are parallel to similar international laws should be passed or updated	Kumar et al. (2021)
A well-designed incentive system (E_2)	Incentives frequently encourage projects and information exchange. Simply put, an effective incentive framework is a prerequisite for effective blockchain-based projects toward CE	Wang et al. (2021)
Getting top management commitment (E_3)	One of the essential elements for successfully implementing any project is to get top management support. However, some senior managers may not show the essential commitment to applying new business models	Hina et al. (2022)
Improved interoperability (E_4)	To further boost CE effectiveness, several blockchain systems should be able to communicate with one another. Interoperability is thus one of the most significant enablers of blockchain adoption	Perrons and Cosby (2020), Gupta et al. (2021)
Creating a set of capabilities for blockchain (E_5)	For CE to be implemented more effectively, sufficient understanding and competence in the blockchain-based supply chain are required. Its presence and sufficiency should thus be carefully assessed	Teufel et al. (2019), Erol et al. (2021a)
Building a collaborative environment in the supply chain (E_6)	Collaboration is an important phenomenon that improves the performance of the supply chain by ensuring integration	Wang et al. (2019), Kouhizadeh et al. (2021)
Increasing the technological readiness level (TRL) of the blockchain (E_7)	TRLs evaluate the reliability level of technology during its research, development and implementation phase. It is measured in terms of cyber-security, data privacy, latency, scalability, and throughput	Gupta et al. (2021), Ranta et al. (2021)
Adopting effective supply chain policies toward blockchain implementation (E_8)	Organizations benefit from policies' direction, soundness, liability, effectiveness, and openness in how they do business. As a result, it is important to verify whether any new organizational policy exists regarding blockchain-based structure	Kouhizadeh et al. (2021)
Creating a supportive organizational culture (E_9)	Businesses are pushed to change their competitive mindsets to ones that value collaboration and partnership. Building an effective blockchain-based supply chain for CE also requires a culture that is based on collaboration	Ozen et al. (2020), Erol et al. (2021a)

(continued)

Table 12.1 (continued)

Enablers	Description	References
More emphasis on increasing stakeholder awareness of blockchain (E_{10})	Increasing stakeholder awareness of blockchain and CE is needed to effectively implement a blockchain-based supply chain	Milios (2021)
Picking the right blockchain platform (E_{11})	Blockchain applications can be created using appropriate blockchain platforms. Although there are several blockchain platforms, most of them lack a consistent design, a loyal user base, and implementation. Therefore, selecting the right one is crucial	Büyüközkan and Tüfekçi (2021)
Building an effective blockchain implementation plan (E_{12})	Implementation guides in general are needed to successfully apply a new business model. An effective guide for a blockchain-based supply chain should include tasks and actions	Rajasekaran et al. (2022)
Formulating a comprehensive performance management system (E_{13})	Blockchain-based supply chain performance management is the ongoing process of enhancing performance by establishing system goals that are in line with the long-term objectives of various organizations	Kouhizadeh et al. (2022)
Improved data validation and certification process (E_{14})	The issue of fraudulent information being recorded in the blockchain and the need for an external validation and certification procedure was the only difficulty that was discussed more in practice than in research and was also the subject that has received the greatest attention in practice	Böckel et al. (2021)
Building an effective blockchain-enabled reverse supply chain system (E_{15})	Improved circularity requires building the blockchain-enabled reverse network, including collection, inspection and recovery facilities	Erol et al. (2021a)
Effective financing of new business models toward blockchain-based CE (E_{16})	To continue playing their role in development, innovation, and employment, companies must have access to a wider variety of funding options. In the pursuit of better CE, financial stability, financial inclusion, and financial depth should be viewed as interdependent goals	OECD (2015), Erol et al. (2021)

$$T = N \times (I - N)^{-1} \tag{12.4}$$

Step 4: *Determining Causal Relations between Criteria (Influential Relation Map)*: T matrix is utilized to compute the values of D and R. D and R values are obtained from the sum of the rows and the sum of the columns of T matrix are calculated using Eqs. (12.5) and (12.6), respectively.

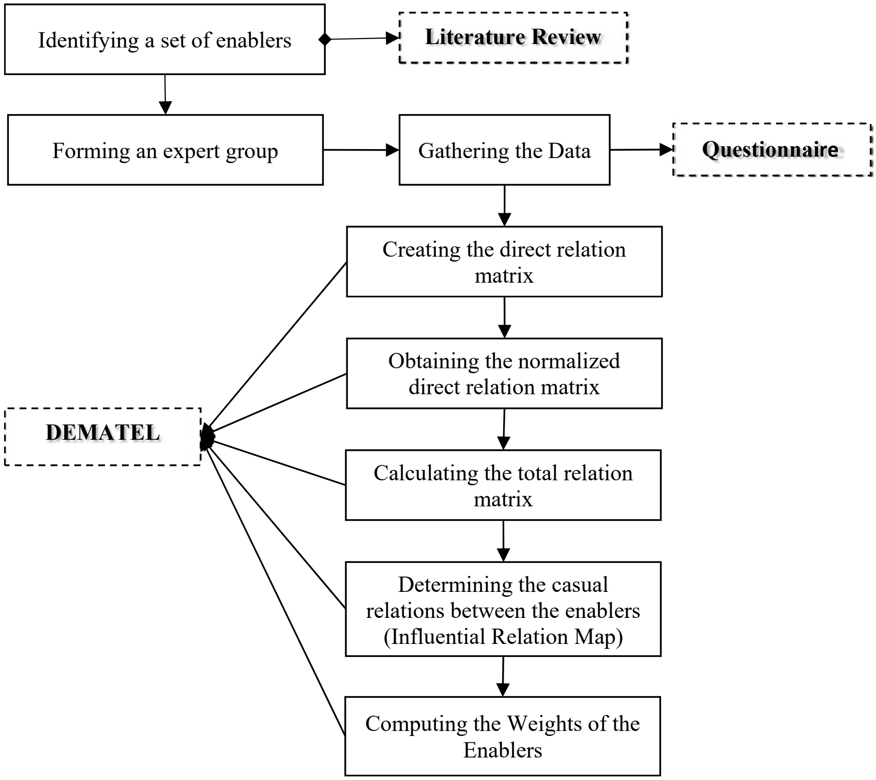

Fig. 12.1 Proposed methodology

Table 12.2 Pairwise comparison scale

Numerical values	Definitions
0	No effect (N)
1	Low effect (L)
2	Medium effect (M)
3	High effect (H)
4	Very high effect (VH)

$$D_i = \sum_{j=1}^{n} T_{i,j} \quad (i = 1, 2, \ldots, n) \tag{12.5}$$

$$R_j = \sum_{i=1}^{n} T_{i,j} \quad (i = 1, 2, \ldots, n) \tag{12.6}$$

The relevance and overall effects of the enablers are established through the values of $D + R$, whilst relationships between enablers are defined based on the values of $D - R$. A greater $D + R$ value for an enabler indicates that it interacts with other enablers to a greater extent. Additionally, $D - R$ enablers that are classified as positive are placed in the "sender (cause) group," whereas $D - R$ enablers that are classified as negative are placed in the "receiver (effect) group." Put simply, enablers with positive $D - R$ have an impact on other enablers, whereas enablers with negative $D - R$ are influenced by other enablers.

Step 5: *Computing the Weights of the Enablers (W):* The weights of the enablers are calculated using Eqs. (12.7) and (12.8).

$$W_i = \sqrt{\left(D_i + R_j\right)^2 + \left(D_i - R_j\right)^2} \tag{12.7}$$

$$W_i = \frac{w_i}{\sum_i^n w_i} \tag{12.8}$$

12.4 Application

In this research, the methodology demonstrated in Fig. 12.1 is employed. The details of the process are provided below:

12.4.1 Identifying the Enablers

The enablers of blockchain-based solar and wind supply chains presented in Table 12.1 were ascertained through an extensive literature review. Then, an expert group reviewed Table 12.1, and they concluded that no modifications to the list were required.

12.4.2 Forming the Expert Group

The data set, in this research, was collected with the help of an expert group through a DEMATEL questionnaire. This questionnaire allows experts to evaluate the degree of influence of the enablers on each other by taking into account the scale in Table 12.3. Note that it is vital to select participant experts who have sufficient theoretical and practical knowledge and experience in supply chains for solar and wind energy and blockchain. With that in mind, in this study, researchers, decision-makers, and practitioners who have a sufficient understanding of blockchain technology and the

Table 12.3 Expert group

Experts	Size	Features
Faculty members	7	They have published research on the application of blockchain in the renewable energy industry
Governmental decision-makers	5	They are responsible for initiating state projects on how disruptive technologies, such as blockchain can be used to ensure resilience in the renewable energy industry
Software company managers	3	They have more than 5 years of hands-on experience in the implementation of artificial intelligence, the internet of things, and blockchain in solar and wind energy supply chains
Energy company managers	7	They are employed in the information technology departments of major renewable energy companies. They have more than 10 years of experience in IT implementations

supply chains for solar and wind energy are referred to as experts. Therefore, to find the right experts who met the above criteria, purposive sampling improved by snowball recruitment was used in this study. To this end, an extensive search and investigation process was carried out. Once this investigation has been done, experts as displayed in Table 12.3 were found to establish a heterogeneous composition.

It is argued that there is no formula for determining the ideal sample size of experts. In other words, the size of an expert group is normally ambiguous in similar investigations (Bulut and Duru 2018).

12.4.3 Analysis (DEMATEL)

At this stage, the analysis was carried out by following the process steps of the DEMATEL method. The steps taken are provided as follows: first, the DEMATEL questionnaire was presented to the expert group. Then, the answers from the expert group were combined using Eq. (12.1), and the direct relation matrix was created. In the following step, a normalized relation matrix was obtained by using Eqs. (12.2) and (12.3). Next, Eq. (12.4) was used to calculate the total relation matrix. Lastly, $(D + R)$ and $(D - R)$ values of the enablers were calculated by using Eqs. (12.5) and (12.6), which are exhibited in Table 12.4. Table 12.4 also suggests the cause (C)-and-effect (E) groups of the enablers. The relationships between the enablers based on the Influential Relation Map are shown in Fig. 12.2.

Given Table 12.4, for example, while an Effective legal and regulatory structure (E_1), A well-designed incentive system (E_2) turns out to be cause enablers, Creating a set of capabilities for blockchain-based supply chain (E_5) and Building a collaborative environment in the supply chain (E_6) is effect enablers.

Table 12.4 "$D + R$ and $D - R$ values" of the enablers

Codes	Enablers	D + R	D − R	(C) /(E)
E_1	The effective legal and regulatory structure	10.562	4.962	C
E_2	A well-designed incentive system	10.195	3.181	C
E_3	Getting top management commitment	10.097	3.143	C
E_4	Improved interoperability	9.288	1.862	C
E_5	Creating a set of capabilities for blockchain	9.323	− 0.304	E
E_6	Building a collaborative environment in the supply chain	9.298	− 0.394	E
E_7	Increasing the technological readiness level of blockchain	9.175	1.862	C
E_8	Adopting effective supply chain policies for blockchain implementation	9.490	− 0.132	E
E_9	Creating a supportive organizational culture	8.310	− 0.856	E
E_{10}	More emphasis on increasing stakeholder awareness of blockchain	7.047	− 1.047	E
E_{11}	Picking the right blockchain platform	8.996	1.600	C
E_{12}	Building an effective blockchain implementation plan	9.573	− 0.103	E
E_{13}	Formulating a comprehensive performance management system	6.306	− 0.1246	E
E_{14}	Improved data validation and certification process	8.641	1.217	C
E_{15}	Building an effective blockchain-enabled reverse supply chain system	5.885	− 1.318	E
E_{16}	Effective financing of new business models	10.059	2.714	C

Figure 12.2 indicates that enablers with positive $D - R$ have an impact on other enablers, whereas enablers with negative $D - R$ are influenced by the rest.

Finally, the importance weights of the enablers were obtained by using Eqs. (12.7) and (12.8) as in Table 12.5.

As can be seen in Table 12.5, the most important enablers were discovered to be "E_1—Effective legal and regulatory structure, E_2—A well-designed incentive system, and E_3—Getting top management commitment" with the weight of 0.080, 0.074 and 0.073, respectively.

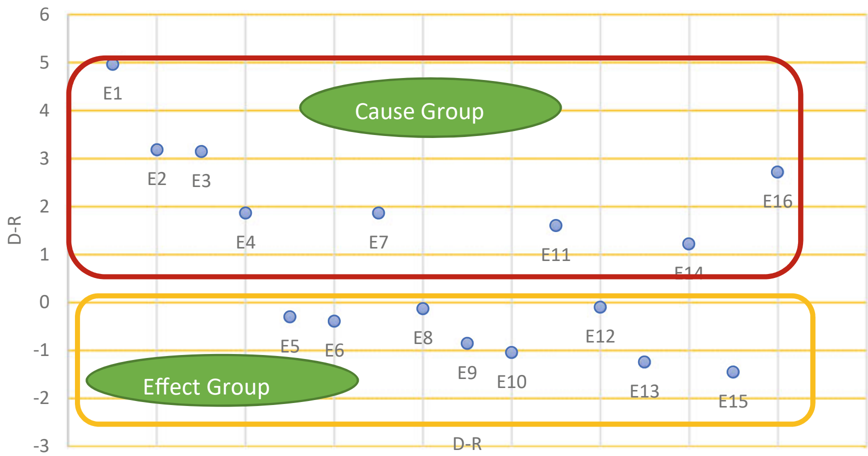

Fig. 12.2 Influential relation map

Table 12.5 The weights of the enablers

Criteria	Enablers	Weights
E_1	Effective legal and regulatory structure	0.080
E_2	A well-designed incentive system	0.074
E_3	Getting top management commitment	0.073
E_4	Improved interoperability	0.064
E_5	Creating a set of capabilities for blockchain	0.066
E_6	Building a collaborative environment in the supply chain	0.065
E_7	Increasing the technological readiness level of blockchain	0.061
E_8	Adopting effective supply chain policies for blockchain implementation	0.067
E_9	Creating a supportive organizational culture	0.056
E_{10}	More emphasis on increasing stakeholder awareness of blockchain	0.055
E_{11}	Picking the right blockchain platform	0.060
E_{12}	Building an effective blockchain implementation plan	0.068
E_{13}	Formulating a comprehensive performance management system	0.054
E_{14}	Improved data validation and certification process	0.058
E_{15}	Building an effective blockchain-enabled reverse supply chain system	0.052
E_{16}	Effective financing of new business models	0.072

12.5 Discussion and Implications

This study provides several findings that may pave the way for building effective blockchain-based solar and wind energy supply chains for the circular economy. In this section, more elaborate commentary on the results through referencing the previous research is provided. Specifically, first, the results of the existing studies are compared with the ones of this study. Note, however, that there are only a few studies conducted on the enablers of blockchain-based supply chains. Note also that since the existing studies have been performed in various industries along with a different set of enablers, their results are not exactly compatible with the results of our study.

With that in mind, for example, this study indicates that Effective legal and regulatory structure (E_1), A well-designed incentive system (E_2), Getting top management commitment (E_3), Effective financing of new business models toward blockchain-enabled CE (E_{16}), Adopting effective supply chain policies towards blockchain implementation (E_8), Adopting effective supply chain policies towards blockchain implementation (E_8), and Creating a set of capabilities for blockchain-based supply chain (E_5), Building a collaborative environment in the supply chain (E_6) turned out to be the most important enablers based only on the importance weights. Zkik et al. (2022) concluded that collaboration and top management commitment are the most crucial enablers among others. However, Bai et al. (2022) and Sahebi et al. (2022) fully focused on technical enablers of blockchain-based supply chains and revealed that transparency, improved risk management and security were discovered to be the most significant enablers.

In addition to the ordinary rankings of the enablers, this present study classified the enablers into cause and effect. Causality is the process by which one incident, activity, condition, or attribute influences the development of another incident, activity, condition, or attribute, where the cause and effect are both somewhat influenced by one another. A cause is an activity that leads to an event or incident. Given this definition, the findings of the present study concluded that Effective legal and regulatory structure (E_1), A well-designed incentive system (E_2), Getting top management commitment (E_3), Improved interoperability (E_4), Increasing the technological readiness level of the blockchain (E_7), Picking the right blockchain platform (E_{11}), Improved data validation and certification process (E_{14}), Improved data validation and certification process (E_{14}), and Effective financing of new business models towards blockchain-enabled CE (E_{16}) were found to be the cause enablers. That means building effective blockchain-based solar and wind energy supply chains toward better CE requires addressing these enablers first. Compared with the findings of previous research (Zkik et al. 2022; Bai et al. 2022; Sahebi et al. 2022; Samad et al. 2022) that focus mostly on the technical enablers of blockchain-enabled supply chains, the results of this present study reveal a significant emphasis on forming effective general legal structure and incentive systems towards blockchain-based networks in addition to increasing the technological readiness level of blockchain.

An effect, on the other hand, is the outcome or ramification of a cause. This implies that effect enablers can be ensured only after cause enablers are addressed. According to the findings of this study, Creating a set of capabilities for a blockchain-based supply chain (E_5), Building a collaborative environment in the supply chain (E_6), Adopting effective supply chain policies toward blockchain implementation (E_8), Creating a supportive organizational culture (E_9), More emphasis on increasing stakeholder awareness of blockchain (E_{10}), Building an effective blockchain implementation plan (E_{12}), Formulating a comprehensive performance management system (E_{13}), and Building an effective blockchain-enabled reverse supply chain system (E_{15}) were found to be the effect enablers. More specifically, for example, E_5 and E_6 can only be ensured only if the cause enablers with respect to, for example, legal and regulatory structure, incentive system, top management commitment, interoperability, technological readiness level of blockchain, and blockchain platform are achieved. On the other hand, Samad et al. (2022) indicated a different set of effect enablers since the list of the enablers they used is based on various technical features of blockchain. Therefore, they argued that the features of blockchain, including traceability and immutability, are the most important resulting (effect) blockchain enablers.

The findings of this study also provide several managerial implications. For example, more effective blockchain-based initiatives towards CE for solar and wind energy supply chains depend heavily on the regulatory and incentive climate of a country and the technical readiness level of blockchain. With that in mind, it can be argued that depending on the extent of support, procedures that directly provide incentives to blockchain-based supply chains can strengthen their business cases. Hence, note that governments worldwide should enact regulatory frameworks as well as build incentive schemes towards improving the technical readiness level of blockchain. To start with, direct incentives reduce the need for an initial investment, which immediately strengthens the economic case for blockchain-enabled solar and wind energy supply chains toward CE. While government loan guarantees subsidies, low-cost financing is typically granted during the initial investment phase. Other incentives may also be provided over several years.

However, indirect incentives seek to create a welcoming atmosphere for investment by fostering favourable circumstances for development or removing obstacles to blockchain-enabled supply chains for better CE. The first group consists of monetary incentives for innovation, R&D, and human capital. R&D funds may be used to create new blockchain technologies that have not yet reached the commercialization stage or to increase the efficiency of already existing ones. While innovation and skill development may not always lead to sustainable economic activity, they do contribute to a better supply chain infrastructure.

Furthermore, recently, there are several voluntary programs worldwide for recycling solar panels and wind turbines. Although such voluntary initiatives indirectly help firms and the industry by maintaining a good reputation, the non-profitability of present recycling techniques prevents their widespread adoption. Therefore, we argue that it is essential to build regulatory frameworks that specify stakeholder obligations, financial models for EoL management, and minimum standards for collection and recycling to expand solar panel and turbine recycling capabilities. Finally, more research based on blockchain-enabled networks towards CE is required to increase recovery rates and enhance material value conservation since solar panel and wind turbine recycling is still technologically challenging.

12.6 Conclusion

Researchers argue that solar and wind energy are vital for accomplishing net zero emissions. Therefore, installations of solar panels and wind turbines are exponentially growing worldwide, which ultimately raises concerns about the effectiveness and sustainability of solar and wind energy supply chains. The traditional linear supply chain approach, for example, is a recipe for resource inefficiency that leads to insecure supply chain performances in terms of sustainability. Researchers and decision-makers agree that a new paradigm is needed to address the current problems. The Circular Economy is a robust approach that may provide novel means to deal with resource inefficiencies. However, note that even if CE is based on a powerful foundation, it needs various types of support from several disciplines for its effectiveness. For example, information technology has the potential to provide invaluable assistance to pave the way for the effectiveness of supply chains. Blockchain through its impact on supply chain visibility, collaboration and trust is a novel technology that may uphold solar and wind supply chains towards their journey to circularity. To this end, it is argued that exploring critical enablers of blockchain-based supply chains is crucial. To the best of our knowledge, despite its importance, only a few studies have been conducted on this subject recently. Therefore, it is suggested that new studies on the enablers of blockchain-based supply chains in the context of CE are needed.

This study aims to scrutinize the enablers of blockchain-based solar and wind energy supply chains. To this end, first, a set of enablers was listed with the help of the current state of the art. Then, DEMATEL was used to reveal the associations among the enablers. The findings of this study indicated the cause and effect enablers of blockchain-based solar and wind energy supply chains. Specifically, while Effective legal and regulatory structure (E_1) and A well-designed incentive system (E_2) turned out to be the most important cause enablers, Creating a set of capabilities for a blockchain-based supply chain (E_5), Building a collaborative environment in the supply chain (E_6) and Adopting effective supply chain policies towards blockchain implementation (E_8) were the most significant effect enablers. Note that this set of findings is invaluable for decision makers because addressing effect enablers is only plausible once cause enablers have been achieved.

There are also future research opportunities, some of which are derived from the weakness of this study. For example, first, more conceptual studies are needed to clear up the concepts such as critical success factors, enablers, drivers, barriers etc. in the context of circular supply chains. Second, new empirical studies should be conducted in various industries of developing and emerging countries so that their findings can be compared to better analyze the associations among the alternative sets of enablers. Lastly, new quantitative methods based on operations research and statistics can be used to more effectively explore blockchain-based supply chain enablers.

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Chapter 13
Circular Economy and Energy Efficiency: The Role of the Energy Management Systems (EnMS) in Industrial SME

Marco Agustín Massacesi, Iker Laskurain-Iturbe, and Germán Arana-Landín

Abstract As stated in the academic literature, energy management by industrial companies in general, and industrial SMEs in particular, must be a central aspect on the road to meeting sustainable development objectives, as they are responsible for more than 40% of global energy consumption. It is an element closely linked to the circular economy due to its influence on the promotion of renewable energies, energy consumption and emissions generated. For this reason, the process of adopting an energy management system based on ISO 50001 in an industrial SME has been analyzed, as well as its influence on economic and environmental results. The findings show the link between the EnMS and the circular economy with implications for academics and public authorities.

Keywords Circular economy · SME · Energy management system · ISO 50001 · Energy assessment · Energy efficiency · Carbon footprint

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13.1 Introduction

According to Geissdoerfer et al. (2018), the promotion of a sustainable, responsible economy that maximizes the use of all possible resources has been termed a circular economy (CE). CE is a closed flow of materials minimizing the use of raw materials, water and energy through several phases and is based on 3 principles (3R: reduce, reuse and recycle) (Yuan et al. 2006). The rise of CE is increasing and very recently the European Union Parliament approved the EU CE Action Plan (European Commission 2020) and it is expected that in the coming years these steps will go viral around the world. In this document appears the model used by Laskurain-Iturbe et al. (2021) and shown in Fig. 13.1, based on the reductions covered by the CE (CERs): reduce consumption of inputs (R1) such as materials, energy and water; reuse (R2); recover (R3); recycle (R4) and reduce outputs (R5) such as waste and emissions.

Even though the main focus when talking about CE is usually on reuse, recovery or recycling, energy plays a fundamental role. Specifically, it could say that it directly influences R1 (inputs) and R5 (outputs) and indirectly influences the other 3Rs. In addition, the industrial sector is responsible for more than 40% (IEA 2020) or 50% (Trianni et al. 2019) of energy consumption and it is the most influential in reducing the territory's energy consumption (Abdelaziz et al. 2011). Furthermore, small and medium-sized enterprises (SMEs) have a key role to play in this change. Calogirou (2010) estimated that SMEs cause approximately 64% of industrial pollution in developed countries. Therefore, the collaboration of industrial SMEs in energy efficiency actions is necessary to reduce greenhouse gas (GHG) emissions. Energy management is considered one of the best ways to improve energy efficiency and reduce greenhouse gases in organizations (Sola and Mota 2020). To this end, one of the tools available to companies is energy management systems. This paper aims to

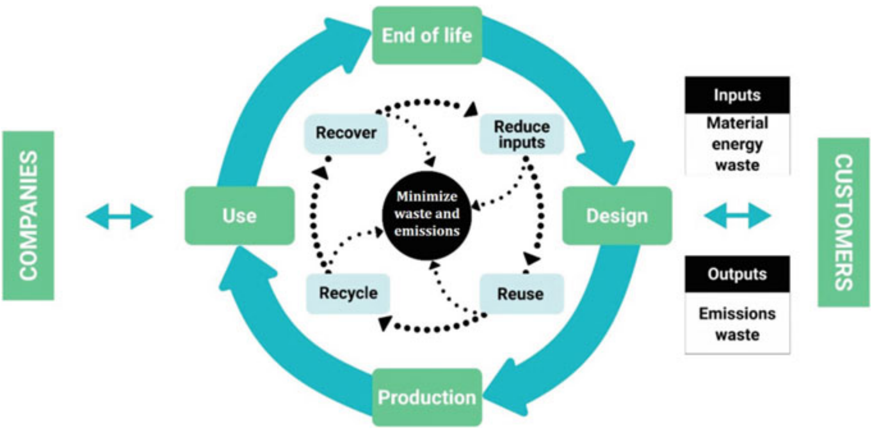

Fig. 13.1 Circular economy model. *Source* Elaborated by authors

show the potential of an energy management system based on ISO 50001 in an SME as a tool to support the circular economy in the industry.

The article is organized as follows: in the second section, the introduction to the ISO 50001 standard has been carried out, in Sect. 13.3 the theoretical framework and research question is showed, in Sect. 13.4 methodology is presented, in Sect. 13.5 the results are described, and before the references, the discussion and conclusion sections are shown in Sect. 13.6.

13.2 Energy Management System Based on ISO 50001

The most widespread EnMS is based on the ISO 50001 standard (Wulandari et al. 2015). The first version of ISO 50001 was published in July 2011 and the second and last version was published on August 28, 2018. It is a voluntary standard that provides a framework for organizations to integrate energy efficiency into their management practices. Its requirements are based on the high-level structure (HLS) following the plan-do-check-act (PDCA) (Jovanović and Filipović 2016; Lee et al. 2014) continuous improvement model, as the ISO 9001 (quality management) and 14001 (environmental management) standards (Ates and Durakbasa 2012; Karcher and Jochem 2015). For this reason, it is easy to integrate into the enterprise with other management systems.

The standard was created to increase the impact on energy management and it was estimated to influence up to 60% of global energy consumption (Wulandari et al. 2015). ISO 50001 can be applied in any organization regardless of its sector and size.

The pillars of this standard are as follows: defining an energy policy, the energy management team and the energy leader; establishing an EnBs, identifying energy performance indicators (EnPIs); setting targets and incorporating controls and procedures to address energy use; measuring what is done and documenting energy performance and reporting to management (Laskurain et al. 2015). Kanneganti et al. (2017) added that the ISO 50001 standard requires an intensive energy assessment process to identify significant energy uses (SEUs) and EnPIs to make targeted energy reductions.

Simon et al. (2019) detected in their literature review that the main challenges found by organizations during the adoption of ISO 50001 were: "lack of resources-limitations (human resources, technologies, infrastructure, financial, time)", "difficulty to determine the EnB and EnPIs", "human resources deficiencies (competencies, knowledge, and abilities)", and "lack of management support and/or commitment". Gopalakrishnan et al. (2014) developed a software tool to help companies overcome possible barriers and facilitate the implementation of an EnMS based on the ISO 50001 standard.

Sometimes, the diffusion of the certification in a country is linked to public policies of each country as subsidies or deductions that companies can access through certification. Several national policies apart from supporting and encouraging energy practices, also encourage the implementation of an EnMS (McKane et al. 2017).

Table 13.1 Evolution of certified companies in the world

Region	2011	2012	2013	2014	2015	2016	2017	2018	2019
Africa	0	13	36	18	40	58	61	75	85
Asia	83	285	729	1081	1624	2902	3526	3833	4340
Central/ South America	11	10	34	63	92	81	132	145	199
Europe	364	1919	3993	5526	10,152	17,102	17,655	13,550	13,507
North America	1	9	34	77	77	73	127	109	88
Oceania	0	0	10	20	22	86	23	11	8
Total	459	2236	4836	6785	12,007	20,302	21,524	17,723	18,227

Source ISO (2019)

For example, the Clean Energy Ministerial comprise 25 countries and the European Commission works to improve energy efficiency (CEM 2019). CEM includes the Energy Management Working Group, which provides an international forum to accelerate the widespread use of EnMSs (EMWG 2019).

However, Yuriev and Boiral (2018) stated that sometimes, these programs do not have a significant positive impact on energy efficiency (as happened in Germany), although some studies (e.g. Stenqvist and Nilsson 2012) suggest that they do (Table 13.1).

13.3 Theoretical Framework and Research Question

According to Fuchs et al. (2020), regulations or government incentives are important factors in pursuing ISO 50001. The implementation of an EnMS implies carrying out efficient energy practices to obtain satisfactory results. Otherwise, According to Rampasso et al. (2019), the most important barriers to the implementation of an EnMS are: "Lack of resources-limitations (HR, technologies, infrastructure, financial, time)", "Difficulty in determining the energy baseline and energy performance indicators", "Human resources deficiencies (competencies, knowledge and skills)" and "Lack of management support and/or commitment".

Several studies have shown that the implementation of an EnMS helps to consume less energy and consequently reduce GHG emissions to the atmosphere fostering the circular economy. For instance, Da Silva Gonçalves and Dos Santos (2019) stated that an EnMS is effective on energy performance and energy cost reduction. Moreover, Therkelsen et al. (2018) demonstrated that the adoption of EnMS savings is four times greater than that achieved in a "business as usual" scenario, obtaining a return on investment of fewer than 1.5 years. In other words, the energy consumption reductions are approximately 25% (Gordić et al. 2010) and 39% (Imel et al. 2015).

The results of Thollander and Ottosson (2010) showed that approximately one-fifth of the mills and half of the foundries lacked a long-term energy strategy. In addition, only 40% and 25%, respectively, of the factories and foundries studied could be classified as successful in terms of energy management practices. If energy management is not a priority in energy-intensive industries, it is unlikely to be a priority in other less intensive sectors or less developed countries than Sweden. Backlund et al. (2012) estimate that the energy efficiency potential of organizations would be higher if energy management practices were considered. Individual energy efficiency actions cannot reach their full potential without ongoing maintenance and monitoring.

Therefore, SMEs must start massively addressing the implementation of EnMS based on ISO 50001standard to support the circular economy and fight against climate change. Although the relationship between the circular economy and an EMS is quite evident, these two concepts have been superfluously related in the academic literature (Cámara-Creixell and Scheel-Mayenberger 2019; Dieterle et al. 2018; Wysokinska-Senkus 2017). Therefore, this article aims, through a real case, to show how an EnMS can influence the RCE of an SME and how it can be implemented in a simple way and with a low budget.

13.4 Methodology

13.4.1 Data Collection

It is not unknown that energy efficiency measures have barriers throughout their implementation in each end-use energy sector (industry, transport, household, services and agriculture). In Argentina, a study carried out by the GFA (2019) has demonstrated that barriers to the implementation of energy efficiency measures in SMEs are the same for larger industries. Mondino SRL is an SME that has no extraordinary resources that might differentiate it from other manufacturing SMEs, thus it is considered a sample for this study (Odyssee-Mure 2020). A single case study, with the participation of diverse agents and actors, can be an exploratory study of an under-researched specific issue (Eisenhardt 1989).

In this paper, the adoption of an EnMS taken by an SME and their outcomes have been conducted. The definition of a theoretical framework has to be used to define the research work (Yin 2009). The unit of research, methods, and design of the protocol to obtain data was based on the theoretical framework and characteristics of the case. They are relevant to obtain the internal validity of the research (Eisenhardt 1989; Yin 2009).

Therefore, this paper has been constructed after collecting internal company data between 2013 and late 2019 (it has been decided not to consider 2020–2021 because of pandemic-related deviations). The obtained data included the entire process of implementation, certification, and subsequent monitoring. For this purpose, data from historical records of energy and production output levels were gathered and compared to the results of the implementation of energy conservation measures; alongside, a total of 10 interviews with operators, technicians, managers, and the internal auditor were carried out. Besides, every consuming-energy device was surveyed and studied upon its use and load factor. All the interviewees have participated in the company's awareness program and four of them are members of the company's energy management team. In the meetings, the interviewees provided us with information and the current status of the EnMS, but also discussion of action plans and new ideas had taken place.

Mondino SRL uses electricity for manufacturing equipment. In Sect. 14.4.2 (Energy Review) a better understanding of the company in terms of energy is provided.

Data from 2013 provided by the EnMS certifying company and (Almerix) (the company which has calculated the carbon footprint in different years), has been used to define the EnB. Records of electricity bills from the distribution company and production output levels between June 2013 and November 2016 were established as input for their EnBs (defined as the baseline period).

13.4.2 Energy Baseline Methodology

According to ISO 50001:2011[1] the EnB is the quantitative reference(s) providing a basis for comparison of energy performance. Besides (ISO 50001 2011):

- An EnB reflects a specified period.
- An EnB can be normalized using variables which affect energy use and/or consumption, e.g. production output level, degree days (outdoor temperature), etc.
- The EnB is also used for the calculation of energy savings, as a reference before and after the implementation of energy performance improvement actions (EnPIAs).

Calculating the EnB is essential to show the saving benefits of adopting an EnMS. To this end, the implementation of EnMS started in November 2016, while December 2019 is set as the endpoint for the matter of this study (this 3-year term is defined as the reporting period). As a requirement for the standard, an EnB and an EnPI were calculated to measure the impact of the different actions carried out.

It selected the "specific electricity consumption" as EnPI, which is the electricity consumption per produced unit. Its EnB is formulated by using the values of this EnPI up until late 2016. The EnB reflects the electricity consumption during the baseline period, and it allows to estimate the electricity consumption that Mondino SRL would have had in case the organization decided not to adopt an EnMS (with no energy conservation measures adopted whatsoever) (ISO 50006 2014; ISO 50046:2019).

[1] In the implementation, the 2011 version of ISO 50001 was used, the one existing in Argentina at that time.

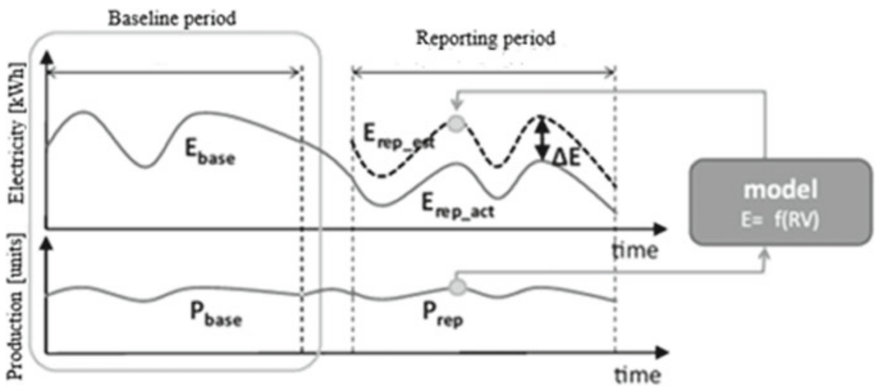

Fig. 13.2 Evolution of certified normalization calculation process and energy savings. *Source* Adapted from ISO 50006 (2014)

The analysis is approached by comparing the EnPI during the baseline period against production output levels, as the latter is the main driver for electricity consumption in Mondino SRL and calculating the coefficient of determination R^2 as a parameter for measuring and verification of the model fit. It is stated that an R^2 higher than 0.7 (as it is set in this paper) cannot be the only criterion to define whether a model correctly fits the supporting data or not, according to its uncertainty (Poquet and Sastre 2014). Hence, CV(RMSE) (coefficient of variation of the root mean square error) and NMBE (net mean bias error) were also calculated (EVO 2020).

After that, energy conservation and energy efficiency measures were applied during the reporting period and changes are calculated by using data of the EnPIs and their corresponding value from the EnBs, both being evaluated at the same state for the relevant variable. Energy savings are encountered if the expected value (consumption according to the EnB) is higher than the real value (consumption recorded in electricity bills). In this study, energy savings are obtained during the 3-year term, instead of setting up new baselines every year. This choice was made by the company according to the requirements of ISO 50001.

This model is shown in Fig. 13.2, according to ISO 50006:2014 (here, the relevant variable is the "production output level", which is the same for this case study).

13.4.3 GHG Inventory Methodology

The greenhouse gas inventory is the calculations of GHG emissions caused directly or indirectly by a person, an organization (like a manufacturing plant), an event, a product, or a service (such as energy carriers, i.e., electricity and fuels). It is a way to measure the impact and contribution to climate change of the activities carried on during a period, generally a year.

The greenhouse gases considered are those identified by United Nations (2005): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), perfluorinated compounds (PFC) and sulfur hexafluoride (SF_6).

The company followed the Greenhouse Gas Protocol Corporate Standard (GHGProtocol 2020), developed by the World Resources Institute and the World Business Council for Sustainable Development, which is one of the most used protocols at the international level to quantify and manage GHG emissions. In the GHG Protocol, the scopes of study about the emissions are described. Scope 1 considers emissions produced by the direct use of energy (fossil fuels, gas, and carbon), Scope 2 approaches grid electricity consumption, and Scope 3 pursues other indirect energy consumptions.

13.4.3.1 Global Warming Potential Index

Each greenhouse gas has a different level of impact in the atmosphere, which depends on the amount of emitted gas, its capability of absorption of radiation and the time of permanence in the atmosphere.

To make possible the comparison between gases, the Global Warming Potential index (GWP) is used. This is a metric of how much heat can be trapped by each greenhouse gas, compared to a reference gas, CO_2, with has a GWP equal to 1. The unit used and recommended by the Intergovernmental Panel on Climate Change (IPCC) is the CO_2 equivalent (or CO_2-eq). The GHG Protocol (2020) proposes two methodologic approaches to consolidate GHG emissions: the shareholding approach, in which the organization accounts for its emissions about the possessed proportion in the shareholding structure, or the control approach, in which the company accounts for the emissions attributable to the operations controlled by the organization. In the GHG Inventory of this case study, the control approach was used, accounting for the emissions of the company during the years 2016 through 2019 (the year 2020 has been discarded because of the pandemic).

The GWP of the main gases can be consulted in Table 13.2. These potentials were calculated considering a temporal horizon of 100 years, the most frequently scientifically used period.

Table 13.2 Global warming potentials

Gas Name	Formula	GWP to 100 y
Carbon dioxide	CO_2	1
Methane	CH_4	28
Nitrous oxide	N_2O	265
Sulfur hexafluoride	SF_6	23,500
Hydrofluorocarbons	$C_xH_xF_x$	4–12,400
Perfluorinated compounds	C_xF_x	6630–11,100

Source Developed from GWPV (2020)

13.4.3.2 Calculation Methodology

To elaborate the GHG Inventory of an organization, it is required to collect data about the activities carried on by the company and about emission factors. Activity data is the energy parameter that defines the level of the activity that produces the emission. For example, the amount of kWh, the travelled distances, etc. In this case, activity data refers to the consumption of the energy sources used by the company.

The emission factor is the amount of emitted GHG for each unit of activity, expressed as CO_2 equivalent.

The equation that integrates both parameters is the following one:

$$GHG_{emissions} = \sum_i Activity\ Data_i \times Emission\ Factor$$

The previous formula provides the amount of CO_2-eq for each energy source. By doing this, the company knows how much CO_2-eq its organization produces.

13.4.3.3 Base year Definition and Operational Limits

The elected base year should be the most far in time, but it also must be relevant to the present normal operating conditions. In this study, a period of 4 years, from 2016, when no energy efficiency policies were applied, to 2019 was selected. It is necessary to obtain reliable information about the produced emissions. The main purpose is to analyze how the energy efficiency policies are applied to reflect a reduction in the GHG emissions of the company. The results are expressed in CO_2 equivalent for better understanding, using the GWPs of the gases.

Once the organization's boundaries are defined, the operational limits must be established. Firstly, the emissions related to the company's operations are identified. Secondly, according to the scopes defined in the GHG Protocol, they are classified as direct and indirect emissions (RAEE 2020):

- Scope 1: Emissions sources are owned or are controlled by the organization: not detected.
- Scope 2: Emissions from the generation of purchased electricity that is consumed:
  - Electricity consumption. The conversion factor (tCO_2-eq/kWh) varies according to the year (RAEE 2020). The selected factor is the combined margin with 0.5 build margin and 0.5 operational margin ($W_{OM} = W_{BM} = 0.5$).
- Scope 3: The emissions of scope 3 are not controlled by the company.

13.5 Results: Mondino SRL Case Study

13.5.1 Case Study Environment and Production Process

Mondino SRL is a family business born in the middle of 1980 in Argentina. It is an SME manufacturing plant located in south Rosario, Santa Fe, Argentina. In the beginning, the company was dedicated to the manufacturing of commercial refrigerators as a tool to satisfy the needs of its customers. Their first clients were grocery stores and minimarkets, but soon they started producing more types of exhibitors as responses to other clients' requests. Later, it began to arise as a leading company giving its companionship to customers through the design and development of new projects involving refrigerated equipment for commercial usage. Nowadays, its main clients are minimarkets, supermarket franchises, bakeries, hotels and companies' canteens and grocery stores. A total of thirty people work in the company, making it a very SME in terms of personnel.

The manufacturing process is described in the following items:

- Stainless steel sheets or galvanized steel sheets are cut and chopped in a hydraulic guillotine shearing machine according to the respective refrigerator's cabinet design plan.
- Inner side and outer side of every piece are then punched and bent over in a punching machine and a bending machine, respectively.
- Foam personnel take the corresponding inner and outer sides and make a sandwich-like panel, then operators press these panels and polyurethane foam is injected within. This process must be done for every panel that functions as structural support.
- Personnel from the assembly sector then cleanse the panels and start the assembly, thus constituting the refrigerator's cabinet. At this moment, pieces such as base support and shelves are needed, in addition, every stainless-steel piece that required welding is also required.

Every pneumatic tool, as well as all the machine tools (hydraulic guillotine shearing machine, punching machine, and bending machine), require compressed air, which is supplied by an 18-kW air compressor.

Table 13.3 expresses the production output levels in the 2014–2019 period:

Mondino SRL's first motivation to implement an EnMS was through an offer from a consulting firm in late October 2016. The firm stated that, if both ISO 9001 and ISO 50001 were certified within one year of the signing contract, they would be subsidized (from the Government of Argentina) 60% of the consultant's fees. The

Table 13.3 Production output levels in the 2014–2019 period

Year	2013 (half)	2014	2015	2016	2017	2018	2019
Production (units)	467	638	663	753	710	670	442

organization agreed to sign the contract tempted in part by the recovery of funding by mid-November 2016.

During the implementation process, an energy policy was formulated according to ISO 50001:2011 requirements.

13.5.2 Energy Review

Firstly, an energy review was required to determine the 2016 status of the implementation. Hence, an energy audit was developed. This is essential to understand the organization's energy use and consumption (ISO 50004 2020).

In terms of energy requirements, electricity is used by pneumatic and mechanical tools (such as compressors and machine tools); this electricity is acquired from the grid. In addition, its invoices were used to make comparisons between estimated total use and how much electricity was metered by the distribution company and billed to Mondino SRL.

In this step, Significant Energy Uses (SEUs) are set to be defined, which, accordingly to ISO 50001:2011, are the "energy use accounting for substantial energy consumption and/or offering considerable potential for energy performance improvement" (significance criteria are determined by the organization). The criteria applied by the company was Pareto Principle.

Given the criticality of compressed air, "Pneumatics" was established as energy use on its own. As a result, SEUs for electricity consumption, in descending order, were pneumatics (21.5%), bending (19.7%), cutting (19.6%) and polyurethane foam injection (18.4%). These use sum up almost 80% of the company's electricity consumption. Thus, energy conservation measures (ECMs) and energy performance improvement actions (EnPIAs) should address these uses (ISO 50001 2011).

Energy uses such as welding, offices' thermal comfort and assembly were defined as Non-SEUs. Nevertheless, ECMs and EnPIAs in Non-SEUs may be addressed in a secondary place, or simultaneously to the SEUs. Applied measures in these uses may provide confidence in the EnMS.

13.5.3 Establishing the Energy Targets

Table 13.4 sums up the comparison between energy targets and energy savings for electricity consumption and LPG consumption.

Table 13.4 Energy targets versus energy savings

	Energy targets (%)	Energy savings	
		2018 (%)	2019 (%)
EnPI: Electricity consumption/unit	5	10.11	7.48

13.5.4 *Improving Energy Performance*

The Energy Review from the ISO 50001:2011 standard indicates in subclause 4.4.3 that the organization shall "identify, prioritize and record opportunities for improving energy performance" (ISO 50001 2011). Hence, EPIAs and ECM related to SEUs were applied to achieve the energy target. Table 13.5 sums up the implemented opportunities between 2017 and 2019 to improve energy performance (time sorted). It is also indicated if they correspond to either an SEU, Non-SEU or Both. These opportunities were designed mainly by the Energy Management Team, while the consultancy firm aided in the measures related to ISO 9001.

13.5.5 *Impact of the EMS on R1 (Inputs) of the Circular Economy*

13.5.5.1 Calculation of the EnB and EnPI

Calculating the EnB is essential to show the saving benefits of implementing an EnMS. By expanding Sect. 14.4.1 an EnB is obtained by using the values of EnPIs during the "baseline period"; a normalization shall be taken into consideration in this aspect. The correlation between the relevant variable (by definition, the independent variable) and energy consumption (by definition, the dependent variable) is provided through a fitness model. However, correlation does not imply causality, therefore it first must be analyzed whether a variable is relevant by validation.

The main cause of electricity consumption is the production output levels, hence this should be the relevant variable. Production output levels are often the result of multiple factors operating simultaneously, such as the production system, the personnel's suitability for their jobs and the level of automation (Groover 2016).

According to IPMVP (2022) and (Poquet and Sastre 2014), there are at least three statistical metrics for a model to be considered as fittingly: (i) a coefficient of determination (R^2) higher (at least $R^2 = 0.7$ in this case), (ii) a coefficient of variation of the root mean square error less than or equal to 15% ((CV)RMSE ≤ 0.15); (iii) and a net mean bias error less than 0.005% (NMBE < 0.005%). These thresholds were selected by Mondino SRL as a criterion according to "BPA Regression for M&V: Reference Guide", although there are other guidelines that industries could use (BPA 2012).

Table 13.5 List of improvement opportunities regarding energy performance

Period	Action	Frequency	The investment (USD)	SEU?
2017–2019	Preventive maintenance of the air compressor since it feeds compressed air to the whole plant	Yearly	500	Yes
2017–2019	Repair of all compressed air leaks	When needed	50	Yes
2017–2019	Replacement of compressed air hoses	When needed	100	Yes
2017–2019	Management of reworks, to avoid re-consumption, as part of the application of ISO 9001	Always	N/A	Both
2017–2019	Raising workers' awareness of energy care and its relationship to climate change	According to plan	N/A	Both
2017–2019	Awareness of how production impacts energy performance	According to plan	N/A	Both
2017–2019	Training of staff on ISO 9001 and ISO 50001 standards	According to plan	N/A	Both
2017–2019	The transition from fluorescent tube to LED	According to plan	550	Non
2019	Reduction of the compressor's operating pressure	According to plan	0	Yes
2019	Reduction of the compressor's differential pressure	According to plan	0	Yes
2019	Sectioning of on/off light switches to avoid illuminating zones when unnecessary	According to plan	50	Non
2021	Installation of pressure regulators at the "PU foam injection" zone	According to plan	60	Yes
2021	Installation of switches to cut off electricity at some locations in the plant	According to plan	60	Non

At this point, the reliability of sources of information and periods is essential since they provide the input data that would be adjusted through a fitness model. In case production output levels are not recorded properly in their corresponding bimester, uncertainty is generated and therefore it constitutes a risk in modelling the input data. Therefore, standardized records might help to avoid certain types of errors, especially if entries are set to be automatically written up (ISO 50004 2020).

The interpretation of "not recorded properly" applies both in the time and quality of the information according to the organization. For example, it may occur in one or more of the following situations (even simultaneously):

(i) production output level entries are recorded the day after, so it may end up adding units in the next period (there is a lack of consistency between electricity consumption and what was manufactured with *that* electricity consumption);
(ii) production output level entries may only count finished products but do not take into account the work-in-process units (since resources were used for these units but did not count at the end of the day, an equivalency may take place to address this situation);
(iii) in an SME, finished products may differ between families in terms of used resources, and on normal days, products from several families may have been manufactured, hence a difference in consumption may appear amongst periods, nevertheless, the number of finished products may coincide (once more, a sort of equivalency might help to compare different families);
(iv) human errors may appear if the information on production output levels is recorded manually, and they may not be traceable in case no error detection mechanism exists (e.g., analysis of possible outliers when typing for the entries).

Should one or more of the previous situations arise, sources of uncertainty are added to the data, which must be taken into account to assess the model fitness of the EnB. An EnB that was calculated with this information (ISO 50006 2014) may be stronger (e.g., lower data dispersion, hence, lower standard deviation and a more accurate model) than an EnB calculated with no information about uncertainties whatsoever. This type of risk should be assessed when developing the EnMS, at least, at the start of the Energy Review (ISO 50001:2011 addresses risks in sub-clause 6.1).

The obtained equation for the EnB, although uncertain, provides the basis for comparison as it has been calculated by using a period in which no measures were taken ("baseline period"). Therefore, it provides consistency for comparison against the value of the EnPI in the reporting period in which ECMs and EnPIAs were applied. The difference between these values is defined as "estimated energy saving".

13.5.5.2 EnPI: Specific Electricity Consumption

"Production output level" was defined as the independent variable while "specific electricity consumption" was established as the dependent variable with the result shown in Fig. 13.3.

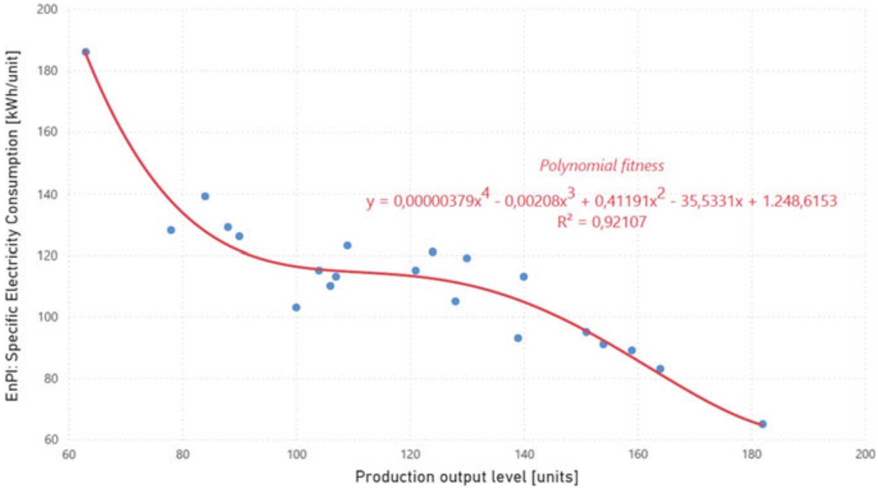

Fig. 13.3 Polynomial correlation between EnPI1 versus production output level (baseline period)

Various models were proved. The better fit according to the selected criteria was through a 4th-order polynomial. The coefficient of determination is 0.921, the (CV) RMSE is 16.9%—above the threshold by 12.67%—and NMBE is − 0.39%. With this polynomial, its baseline is projected for the end of 2016 onwards to calculate savings (reporting period). The billings were bimonthly, and the actual values are shown in Fig. 13.4.

According to the organization, an energy performance improvement is obtained if the real value of electricity consumption is lower than the estimated electricity

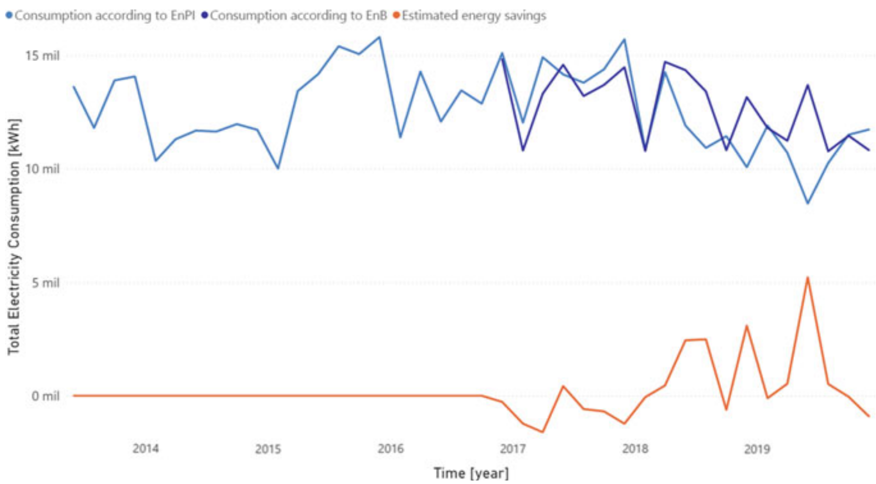

Fig. 13.4 Comparison between consumption according to EnB and consumption according to EnPI

consumption in a selected year (the latter is calculated through the EnB), and energy savings tend to demonstrate the overall impact of opportunities for improvement. The energy objective is accomplished if the difference between these values is greater than or equal to the energy target for the defined period. Thus, the real electricity consumption must be at least 5% less than the estimated electricity consumption for a selected year, being energy savings the method for accomplishing this.

Given that production output levels (and type of demand) in a selected year do not depend on the previous year's levels, it was established that the calculated EnB should be used for the 2017–2020 period; then, a new EnB must be constructed to reflect the normal operation of the manufacturing plant that includes the improvement actions applied during the 2017–2020 period, thus energy savings should be calculated with this newer EnB. The specific electric consumption improved due to the adoption of the EnMS transforms into the base consumption that must be improved in the following 3-year period. This mechanism evocates the Action of the PDCA, providing the basis for continual improvement.

A more demanding method for obtaining improvement (not used in this case) is to calculate an EnB for every year and consequently compare the actual consumption value against that from the previous year. This mechanism requires more resources as the organization needs to continuously improve every year, which may lead to a lack of opportunities for improvement at first, alongside the uprising investments to accomplish these targets. Nevertheless, energy savings tend to be greater.

While the first method may be not as strict as the second, leading to presumably lower energy savings, it may also need fewer resources to obtain information, thus, making it more suitable, at least at first, in case the industry does not monitor its data. Whether improvements follow the first or the second method, the mechanism is defined by the organization and must be documented (ISO 50001 2011).

In case an industry manages to monitor its data, EnB and EnPI might be more accurate. This is essential to measure the impact of each applied opportunity. Nevertheless, this data monitoring should include real-time metering as a mechanism for assessing energy savings (which could be addressed to a measure or a group of them). In case an industry does not monitor its energy data, like Mondino SRL, energy savings corresponding to a certain period account for the global impact of the adopted measures (instead of calculating individual impacts). A risk of the latter situation is double counting (ISO 17742 2015), which may inflate energy savings (e.g., the value for total energy savings due to sectioning on/off switches and changing fluorescent tubes to LED is higher than if the migration to LED occurs and then the sectioning happens). However, complexity and need for data depend mainly on the organization, as simultaneous processes of different natures occur minute by minute. The interactions that take place may be very sophisticated and the benefits of obtaining energy savings from each measure might consume more resources than the benefits themselves. Hence, according to ISO 50001:2011, the measurement plan is defined by the organization.

It can be observed that from the beginning of 2017 when the path to the EnMS began and the actions indicated above started to be carried out, stabilization of its values seemed to happen. By the end of 2018, the industrial sector in Argentina

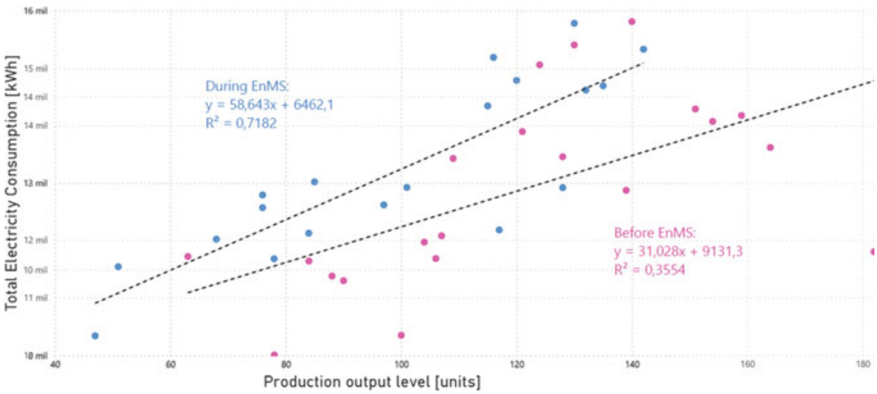

Fig. 13.5 Comparison of electricity consumption (kWh) versus production (units) in baseline and reporting period

began to be affected by political and macroeconomic decisions. This is where the EnMS helped substantially as it avoided the energy cost impact of lower sales than in previous years, as evidenced from the baseline projection, where EnPI contributed to absorbing that impact.

Regarding system stability, Fig. 13.5 is presented as a pure exercise of comparison, where the adjustments to a straight line for the values before the EnMS and with the EnMS during its implementation and maturity are shown:

Before the EnMS it can be observed that the fit through a straight line provided lower values for R^2 ($R^2 = 0.36$). This was inadequate to establish as a baseline. Figure 13.5 only must be understood in terms of a linear comparison between the period before the adoption of EnMS and during this implementation. With the EnMS already implemented and looking for maturity, the fit through a straight line of values since 2017 provides an $R^2 = 0.72$. Therefore, the EnMS may have helped to stabilize the curve and improve the correlation between the variables. This may be supported mathematically through the analysis of the parameters of the linear equation:

- Reduction of the basic load by 29%. The "basic load" is the minimum energy consumption of the system (energy consumption at zero production: y-intercept). During the baseline period, this value was 9131 kWh/bimester, being reduced to 6462 kWh/bimester in the reporting period.
- The value of the slope of the linear equation went from 31.03 kWh/unit for the baseline period to 58.64 kWh/unit for the reporting period, strengthening the relationship between the involved variables.
- R^2 went from $R^2 = 0.36$ for the baseline period to $R^2 = 0.72$ for the reporting period.

Given the correlation between “production output level” and “specific electric consumption” stated through a 4th order polynomial, it may be expected that, in the case of lower production output levels, electricity consumption shall be higher.

No other variables influencing electricity consumption were detected, mainly due to the non-existence of air conditioning equipment in the plant, while standing fans are the only devices for cooling spaces.

13.5.6 Impact of the EMS on R5 (Outputs) of the Circular Economy

Table 13.6 shows the results of the company's emissions by source.

According to this Table 13.6, the amount of CO_2-eq has experimented with a 35.3% reduction between 2016 and 2019. Also, Table 13.6 is completed with emissions per produced unit data.

As stated, political and macroeconomic factors explain the increase in emissions per unit. It is due to a reduction in sales figures. The decrease in the sales figure has forced an increase in the number of machine start-ups and this explains that emissions per produced unit went higher instead of what was expected and desired. Since values are aggregated in terms of years, the sample size reduces significantly. It is expected that the carbon footprint has a similar pattern to electricity consumption.

Table 13.6 Emissions by a source per yearly production output

Year	Source	Emissions (kgCO_2eq/source)	Production output (units)	Emissions (kgCO_2eq/unit)
2016	S1-(none)	0		
	S2-Electricity	37,513.1		
Total		37,513.1	753	49.8
2017	S1-(none)	0		
	S2-Electricity	39,801.0		
Total		36,801.0	710	51.8
2018	S1-(none)	0		
	S2-Electricity	32,872.3		
Total		32,872.3	670	49.1
2019	S1-(none)			
	S2-Electricity	24,279.1		
Total		24,279.1	442	54.9

13.6 Discussion and Conclusions

This article has provided an answer to one of the barriers mentioned by Rampasso et al. (2019), "Difficulty in determining the energy baseline and energy performance indicators", it has been shown that it is not so complicated and that with little effort positive results can be obtained. This helps to promote the circular economy, having less energy dependence and emitting fewer gases into the atmosphere. Likewise, it has been ratified that the implementation of an EnMS with little investment has a direct influence on R1 (inputs) and R5 (outputs) as defined by Laskurain-Iturbe et al. (2021). Furthermore, according to future estimates and in line with Therkelsen et al. (2018), the payback on investments is less than 1.5 years. In this line, with a little help and few resources in terms of investments, satisfactory energy efficiency results were obtained (around 10% energy savings). First actions may be done with no investments at all or those that cost a few hours of both employees and analysts (the so-called 'low hanging fruits). It has also been shown that the implementation of an EnMS should not be the work of a sole employee, but the performance of the whole company. Nevertheless, this situation may arise in case an industry attempts to adopt an EnMS based on ISO 50001 and lacks competent personnel. The interpretation of "competent" is defined by the organization, as top management must evaluate the suitability of the company's resources and manages to acquire the necessary competence. In this case, an external consultant might help to optimize resources as he/she/they would be dedicated to guiding the process of implementation. This consultant may be a lead or internal auditor on ISO 50001 and/or an energy manager.

In addition, the organization must evaluate how many resources will they provide for this adoption. The organization might hire an external consultant; however, plant personnel is suggested to be trained in ISO 50001 to gain knowledge of the implementation process and to accomplish energy objectives. Even though there are guides on the Internet that may help with a step-by-step implementation, the whole process relies on the commitment of top management.

At first sight, the statistical knowledge for the calculation of the EnB may seem profound. However, this sophistication is defined by the organization, as the process of certifying assessment conformity to the ISO 50001 standard, not only the EnB and EnPI calculation. A rough EnB may help to calculate energy savings during the first implementation, and this EnB can be improved according to data monitoring. ISO 50006 guides how to meet the requirements of ISO 50001 related to the establishment, use and maintenance of EnPI and EnB. ISO 50015 develops a common set of principles and guidelines to be used for a Measurement & Verification (M&V) plan. The external consultant may assist in this process as well.

Regarding the metering plan, a frequent misinterpretation is that organizations must meter each variable related to energy. This is not right, as the plan is defined by the organization. Data obtained through the metering plan must also be analyzed and used in conjunction with the Energy Review. Hence, through this analysis, only a few variables will be set to be metered. ISO 50015 also provides principles related to the metering plan as it plays a key role in measuring and verifying energy savings.

A frequent situation regarding energy savings is that organizations already know what measures should or must be taken, especially within the first years in case an EnMS is being implemented. This might be due to the organization already knowing which processes can and/or must be improved, and the implementation of ISO 50001 helps to substantiate them. Gap analysis by an external consultant and dialogues with top management help to acknowledge the actual starting point, thus describing more accurately the needs for resources. Contrary to what Kanneganti et al. (2017) stated, this article casts doubt that an intensive energy assessment process is necessary to identify significant energy uses (SEUs) and EnPIs for targeted energy reductions. Since it has been demonstrated that can be done with energy bills and without a large investment in consumption monitoring.

Also, the methodology to calculate the carbon footprint in an SME has been complimented. It should serve as an example for more and more companies to measure these values to know how they are contributing to slowing down climate change and supporting the circular economy. Taking into consideration the obtained results, the article has implications for SMEs and governments. This real case was fostered by a public subsidy, ratifying the comments of Fuchs et al. (2020), regulations or government incentives are important factors in encouraging the implementation of an EnMS based on ISO 50001. Therefore, it is very important that public policies, apart from encouraging recycling, reuse or reuse of materials, also include subsidies for SMEs to implement EnMS to encourage the circular economy. Sometimes, because they do not have enough resources or simply because they have not considered it and this real case can be used as a reference for other SMEs located in developed and developing countries because it contributed to an increase in their competitiveness. SMEs have an example to know that they should not only adopt EnMS for environmental reasons, but the economic benefits can become their main motivation because savings in energy costs go directly to the economic profit and loss account. For governments, this article is proof that supporting the adoption of EnMS can be a tool to help improve the country's economic competitiveness and to improve the country's environmental position. Another mechanism available to the institutions is to promote Learning Energy Efficiency Network (LEEN) for the development of EnMS in industrial SMEs. A LEEN "is a network that usually consists of 10 to 15 participants from different sectors, which together determine a network target for increasing energy efficiency" (Odyssee-Mure 2020).

The main limitations of this research are related to the methodology used. An exploratory case study can be illustrative and relevant in an under-researched area such as this. The evidence has to cover practices that have not been previously researched in the literature. As in other qualitative studies, it is unwise to attempt to generalize the results too far.

Author Contributions All authors contributed to the study conception and design. Marco Agustín Massacesi carried out the statistical analysis and all authors conducted the rest of the article. Likewise, all authors have read and approved the final manuscript.

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Chapter 14
Energy Decarbonization via Material-Based Circular Economy

Achintya Das and Ananya Roy Chowdhury

Abstract This chapter explores the concept of energy decarbonization and its practical implementation through the adoption of a circular economy (CE) founded on materials. It emphasizes the role of CE principles in mitigating environmental impacts as it analyzes the crucial interplay between energy transition and resource management. In pursuance of decarbonized energy systems, the focus of the discussion is on how CE strategies can mitigate resource scarcity issues. Important considerations include end-of-life management, tradeoffs, and the incorporation of principles of environmental justice. The chapter emphasizes waste reduction and repurposing of abandoned industrial sites as opportunities to reduce environmental costs. It also investigates the potential for technological innovations such as automation and artificial intelligence to improve recycling processes. Policymaking, regulation, and research and development efforts are discussed as essential catalysts for the realization of a CE-focused energy decarbonization strategy. This chapter highlights the global and cross-sector nature of this initiative, as well as its potential to revolutionize resource management while advancing sustainability objectives.

Keywords Energy decarbonization · Material-based circular economy · Sustainable solutions · Greenhouse gas emissions · Circular economy approach · Resource efficiency · Waste reduction · Low-carbon energy system · Carbon–neutral future

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14.1 Introduction

The Industrial Revolution boosted velocity, productivity, and pollution and waste (Smil 2000). Some of the worst waste and pollution operations were reduced by government legislation, but the majority of remedies remained "end-of-pipe" solutions. In the 1960s and 1970s, there was an upsurge in recycling, air and water pollution, and wilderness conservation (Commoner 1971). Renewable energy (RE) technologies have a lower life-cycle carbon footprint than fossil-fuel generation because of fossil-fuel emissions (Gallagher et al. 2019; Hertwich et al. 2015; Kleijn et al. 2011). The recent expansion of the global renewable energy (RE) sector has increased energy security by decreasing dependence on fossil fuels and mitigating climate change. Significant investments are required to enhance the production of renewable energy by 2035 (IEA 2014). Sustained investment has been spurred by technological advancements, savings through lean product manufacturing, and government incentives (IRENA 2015). RE deployment results from a resolve to address climate change by reducing greenhouse gas emissions (EEA 2015). Green energy will thus continue to grow for the remainder of this century. As the RE sector expands, more energy and raw materials will be required to create and maintain these systems. Compared to fossil-fuel systems, RE technologies (iron/steel, copper, etc.) need considerable input materials (Hertwich et al. 2015; Kleijn et al. 2011). Rare earth elements are sometimes required in large quantities (Elshkaki and Graedel 2013).

Circular economy (CE), industrial ecology, and the environmental accounting model Life Cycle Assessment (LCA) increasingly gained traction (Ehrenfeld 2004). LCA study confirms attempts to decarbonize energy and transportation but reveals little progress toward a circular economy in extractives, which might benefit socio-ecological systems.

This study focuses on advancing photovoltaics, wind, tidal energy, and lithium-ion batteries (LIB) toward a circular economy. Research challenges, accomplishments, and future directions for the circular economy should be analyzed, beginning with extraction and continuing through disposal or recovery. The circular economy models ignore these solutions for the transition to renewable energy and reducing carbon emissions. This review contains steel, aluminium, copper, quartz, cobalt, lithium, rare earth elements (REEs), and precious metals and minerals. We wish to highlight low-impact extraction, zero-waste, and circular economy policies and practices and areas requiring greater study and cooperation to achieve circular economy and sustainability objectives. The technique identified leading practitioners, researchers, research gaps, and challenges in the solar, wind turbine, and battery sectors. This mix of renewable energy issues, best practices, and recovery options will aid in advancing material circularity and industrial ecology. A century ago, Robert Ayres termed resource exploitation the "cowboy economy" (Ayres 1997). Between 1985 and 1995, 90 countries enacted new mining legislation (Naito et al. 1999). Basel Convention prohibits the export of hazardous wastes, although distinguishing them from recyclables is difficult (Alter 1997). Mining techniques and national restrictions vary, resulting in diverse social and environmental repercussions (Kuan et al.

2020). In 2010, non-metallic minerals accounted for 44% of global resource extraction, followed by biomass (24%), fossil energy carriers (18%), and metal ores (13%). Increasing material extraction will need resource recovery for a circular economy that is intended to be restorative. “cradle-to-grave” industrial operations squander natural resources. The global circularity of energy and materials decreased from 9.1 to 8.6% (CE 2020). The majority of natural resources are used and discarded. In a circular economy, recovery and restoration substitute disposal. The circular economy reuses byproducts. Renewable energy, avoiding hazardous compounds that impede reuse, eco-friendly design, and systems thinking may minimize waste (EMF 2013). To diminish waste through cyclical and regenerative innovation, these sustainability strategies have shifted from exploitative innovation to restorative innovation (Hofstra and Huisingh 2014). Optimization of industrial waste is hard for several reasons. Industrial facilities may function regardless of other waste streams (heat, water, or material). The sporadic construction of industrial facilities makes intersectoral collaboration problematic. Ferrous (iron, manganese, nickel, chromium, cobalt, molybdenum), non-ferrous (aluminium, lead, zinc, copper, tin), precious and rare metals and minerals, energy, and specialized minerals are in greater demand. There may be more metal in waste than in ore, presenting economic potential. There may be more indium in end-of-life (EoL) flat-panel display panels than in ores and tailings. EoL waste streams may create a circular basis for natural resources. Recycled metals lessen threats to national security (Dussaux and Glachant 2019). Plastics are used in wind turbines, photovoltaics, batteries, and electric vehicles, making them essential to a circular economy. Three hundred million tons of plastic are thrown annually (UNEP 2018). Garbage is either buried or burned for energy. Biopolymers or more recyclable plastics may be able to tackle plastics-related issues. Industry and location influence recycling. Due to trade restrictions, growing composites, and tougher quality requirements, the recycling business has stagnated for almost a decade (ISRI 2019). Although processing recycled or reused materials may increase profit margins, manufacturers seldom justify doing so (CE 2020). A circular economy reduces waste by reuse and recycling. The waste hierarchy guides commercial and industrial choices on waste reduction. Such as bagasse, molasses, and alcohol are managed by Nanning Sugar Company (Yang and Feng 2008). Extraction, production, and recovery are included in the circular economy. If resources can be moved or reverse logistics are performed, outputs may become inputs. “Cradle-to-Cradle” is fundamental to a circular economy (Braungart et al. 2007). “Biomimicry” by Benyus encourages natural designs to decrease waste and enhance green design (Benyus 2007). “Performance Economy” stresses eco-efficiency and material circularity (Stahel 2016), but “Industrial Ecology” constructs industrial processes as ecological systems in which wastes become inputs (Graedel 1994). Investing in the circular economy is influenced by resources, availability, competencies, and demand (Kiefer et al. 2019; Horbach 2008). Auditing may assist firms in identifying internal obstacles to circular economy programs. The government’s policies and financial aid will accelerate investments, concentrate businesses, and restore capital (Hofstra and Huisingh 2014).

14.2 Minimizing Environmental Deterioration

Environment degradation has developed into a "shared concern" for people in the current situation. Human actions are a greater contributor to such calamities than natural occurrences. The primary causes of the issue are the industrial revolution, population increase, and rising demand for luxury goods. Currently, nature and its resources are degraded due to a lack of sufficient education, awareness, understanding, and attitude toward the environment on the part of humans. Consumption and economic expansion have led to the devastation of the environment. Increasingly, automobile emissions, the discharge of effluents, the production of garbage, and inadequate waste management are driving the fast depletion of landscapes and the resulting massive environmental degradation. According to a survey, 90 billion tons of natural resources are produced annually, and according to specific forecasts, this number might quadruple by 2050 (Maurya et al. 2020). Environmental degradation is a global issue that encompasses a broad range of problems, such as pollution, biodiversity loss, animal extinction, deforestation and desertification, global warming, and many more (Brown et al. 1987; Maurya et al. 2020; Tian et al. 2004). Environmental degradation is the deterioration of the environment as a result of the depletion of its resources, which include all the biotic and abiotic components that make up our surroundings, i.e., air, water, soil, plants, animals, etc. (Bourque et al. 2005; Malcolm and Pitelka 2000). Minimizing environmental deterioration necessitates a waste management system that includes the valorization of mine waste, including leftover metals from the ore matrix. For sustainability and environmental security, building a robust environmental education (EE) system that fosters human sensitivity to nature is of utmost importance. In this regard, the United Nations and a number of nations are actively pursuing engagement with society. In this regard, various awareness campaigns and community development programs are now underway in several nations worldwide. The bulk of India's natural resources, particularly the environment, are in a dire state of degradation. Environmental education (EE) programs are necessary to increase students, researchers, politicians, and society's environmental sensitivity and understanding. Success stories depend on public engagement, awareness, and education to achieve environmental security and circularity. Local and industry-specific policy and planning are essential.

14.2.1 Mining

Here, we briefly explore the environmental devastation caused by mining some metals crucial to the renewable energy industry.

Copper mining generates a substantial amount of waste. Copper consumption is mostly driven by China's production needs, whereas sixty per cent of the world's copper deposits are located in Chile, Australia, Peru, Russia, Indonesia, Mexico, and the United States (Liu et al. 2020). Copper mining yields several valuable metals, including cobalt, tellurium, indium, gallium, silver, molybdenum, and germanium (Sverdrup et al. 2019).

Indium, especially indium tin oxide, is an essential metal for photovoltaics and flat panel displays. The element is also used in copper indium gallium selenide solar cells. China has over 70% of the world's indium deposits, typically found in copper, zinc, or lead mines (Sverdrup et al. 2019).

Aluminium generated from bauxite is typically found in the tropics, with substantial production in Brazil, Australia, and India (Norgate and Haque 2010). Typically, the Bayer process consumes huge quantities of lime and caustic soda and generates red mud, a corrosive byproduct that may pollute groundwater (Ayres 1997). Additionally, red mud is regularly linked to large pollution incidents, such as tailings dam failures, which result in severe soil and water contamination (Ruyters et al. 2011).

Iron ore deposits are plentiful. Despite this, Brazil, China, Malaysia, and Australia dominate iron ore output for steel. Similar to other mining operations, land use change, tailings, and spoils may cause heavy metal contamination of water sources and riparian habitats (Zabowski et al. 2001). These activities' pollution contributes to a rise in ecological deterioration and health concerns for residents (Diami et al. 2016).

Cobalt mining has a rich history spanning several decades, with over half of the world's cobalt production originating in the Democratic Republic of Congo (DRC) and subsequently refined in China (Brink et al. 2020). The majority of cobalt extraction occurs in the African copper belt, with a significant portion being carried out through artisanal methods (Geenen and Radley 2014). To comprehend the environmental impact of cobalt mining, it's essential to consider the various phases involved. Older mining operations may exhibit higher levels of pollution compared to more modern counterparts. One prominent issue plaguing many abandoned cobalt mines is acid leakage, primarily induced by water and air sulfides, leading to acid drainage. Mining and industrial wastewater often contain trace metals, some of which can be hazardous at elevated concentrations. Of note, the environmental repercussions of mining are more pronounced in water bodies than in the air. Mines are a source of dust emissions, which can contaminate soils, detrimentally affecting plant and animal life. Pollutants, particularly metals, may pose health risks. Overall, cobalt mining has left a notable environmental footprint, emphasizing the significance of responsible mine construction practices. Mining operations involve crucial steps, including pattern drilling to fracture rock before blasting, ultimately breaking down the mined rock. These activities have associated environmental concerns, such as water discharge and the disposal of mining waste. Mining can take various forms, including open-pit, surface, and underground mining, each with its set of environmental considerations. The mined ore comprises both valuable minerals and waste materials, often containing silver alongside cobalt. Extraction processes typically involve flotation to isolate minerals, with gold and silver further recovered using cyanide. Nevertheless, mining and processing inevitably generate tailings, which can have adverse effects on water bodies and often contain cyanide residues. Additionally, mining activities contribute to environmental issues like dust emissions, noise pollution, and ground vibration. The historical development of cobalt mining, particularly its association with silver extraction, has significantly influenced mining practices. While the environmental impacts of mining are well-documented, efforts can be made to mitigate these effects and promote more sustainable mining practices.

Gold mining is one of the most destructive industries in the world. It may lead to population shifts, tainted water supplies, injuries among workers, and the destruction of pristine ecosystems. Mercury and cyanide are released into the environment and endanger human and environmental health. Twenty tons of waste are produced when enough gold is mined to make one wedding ring. Gold mining might have catastrophic effects on nearby water sources. Arsenic, lead, mercury, petroleum byproducts, and cyanide are just a few of the 30 dangerous substances that may be found in toxic mining waste. Mining companies annually discharge 180 million tons of toxic waste into waterways. However, when tailings dams containing mining waste fail, these pollutants may enter waterways. These have caused the deaths of hundreds, the relocation of thousands, and the contamination of the drinking water of millions of people throughout the globe. The resulting polluted water, known as acid mine drainage (AMD), is extremely toxic to aquatic life (Brink et al. 2020). The effects of AMD, such as mercury and heavy metals, infiltrate the food chain and sicken people and animals for decades, poisoning drinking water.

Sand, or silica, is one of the most abundant materials on earth, but silica deposits with the right composition, shape, and size are relatively rare. For example, desert sands are unsuitable for most applications because of their smooth shape and composition. Most high-purity applications for decarbonization (e.g., high-quality glass, silicon, and window glass) require silica sourced from quartz. Quartz is essential for semiconductor-grade silicon for electronics and photovoltaics, solar quality glass—with low iron and aluminium content, window glass for buildings, homes, and the silicon-aluminium alloys used in vehicles. Lower purity quartz is used as an input to concrete for buildings, wind farms, and nearly every major piece of infrastructure. Silicon metal for aluminium alloys, semiconductors, and glass makes high-purity quartz an important ingredient in decarbonization, given future demands for photovoltaics, windows, and lightweight vehicles (Mulvaney et al. 2021). The world's largest industrial quartz resources are in Brazil, with China, Madagascar, South Africa, Canada, the U.S., and Venezuela playing major roles. However, industrial quartz is rarely pure enough for glass and silicon manufacturing. High-purity quartz is usually sourced from crystal, vein quartz, metamorphic quartzite, and pegmatite. Most high-purity quartz mining occurs in open pits, where high-purity quartz veins can be mined. The high purity supplies are from operations in the Spruce Pine mining district, North Carolina, considered the world's largest deposit (Zhou and Yang 2018). Another major supplier is Norway, with a processing sector to upgrade high-purity quartz (Zhou and Yang 2018). Advances in quartz processing are being made to remove impurities, but semiconductors and clear glass generally require ultra-high purity quartz (Banza et al. 2006). Many countries have banned the export of high purity and ultra-high purity quartz, ostensibly to develop domestic high-tech, value-added industries. Glass requires numerous inputs in addition to quartz, including soda ash, sodium sulfate, dolomite, limestone, and coke (Badino et al. 1995). Lower quality quartz is widely used as the proppant in natural gas and oil extraction by hydraulic fracturing.

Boron and phosphorous are often found in high-purity quartz but are undesired dopants in semiconductor-grade silicon (Si), silicon carbide (SiC). Undesired dopants in semiconductors can disrupt electrical properties, leading to conductivity and charge carrier problems, potentially causing device failure (Das and Duttagupta 2015).

14.2.2 Wastewater

Municipal wastewater, agricultural waste, industrial waste, medical waste, and electronic waste are only some of the byproducts of a rapidly expanding human population (Bhatia et al. 2018; Duan et al. 2020; Saratale et al. 2020). Human health and environmental viability depend on effective waste management (Arora et al. 2021; Bhatia et al. 2020). Different technologies have been shown to successfully process various waste streams and produce valuable byproducts (Ginni et al. 2021; Bhatia et al. 2021a, b; Kumar et al. 2019). Households and commercial establishments in the textile, municipal, dairy, and pharmaceutical industries and mining industries all contribute to wastewater production (Bhatia et al. 2021c). Wastewater is difficult to handle due to its high nutrient content; its release may cause eutrophication and poses environmental risks. Wastewater is often treated using a combination of physical and chemical techniques, but this may be costly and lead to unwanted side effects such as sludge production and secondary water pollution. Biowaste-to-bioenergy conversion technology based on microbes might provide a low-cost strategy for handling wastewater and creating bioenergy. Several microbially mediated processes may accomplish resource recovery and energy production from wastewater. These include anaerobic digestion (AD), microbiological fuel cells (MFC), dark fermentation, etc. Many books and articles have been published on turning wastewater into bioenergy, and that number keeps rising.

14.2.3 Solid Waste

Extraction activities generate many types of solid waste, including rock mass, tailings, wastewater, hazardous waste, and end-of-life (EoL) machinery. Recycling waste saves energy (Mackey et al. 2019). 50% of a mine's energy goes towards comminution, or crushing and grinding rock (Fuerstestenau 1981), equivalent to 4% of global electricity (Jeswiet and Szekeres 2016). Grinding mills are expensive to run. Semi-autonomous grinding reduces ore particle size. Finer media enhances particle and grinding medium collisions in agitated mills like the Isamill (Burford and Clark 2007). Modernizing mining equipment might save energy and reduce rock waste. Existing mills may be retrofitted to capture wasted heat if large-scale changes aren't feasible. Heat transfer or thermal conversion device research is essential for mining energy management. Energy audits and mill improvements save energy. By rerouting overflows and increasing grinding ball size, the African Barrick Gold mine saved 40% energy (Lopez-Pacheco 2012). Copper, lead, nickel, and gold ore grades have declined for 30 years, requiring more grinding for concentration, energy, and GHG emissions, which needed more water. Acid mine drainage (AMD) may discharge with a low pH and heavy metal concentrations after mining stops in the water. AMD is difficult to cure, with neutralization or diversion being the best alternatives (Akcil and Koldas 2006). Recent sustainable methods include using liquid membrane emulsion to remove metal from wastewater and converting AMD to purified water and metal and sulfate ion by-products.

14.2.4 Greenhouse Gas (GHG)

The metals and mining industry accounts for between 4 and 7% of worldwide greenhouse gas emissions. CO_2, methane, and NO_x are produced by fuel usage, local energy, and other sources. Scope 1, Scope 2, and Scope 3 emissions are typical subcategories for greenhouse gas (GHG) emissions. Scope 1 emissions include gasoline usage, industrial operations, and other modest sources. Scope 2 (Indirect greenhouse gas emissions) covers electricity purchases. Scope 3 encompasses indirect emissions from the company's value chain, including transportation, business travel, product consumption, and leased equipment downstream. By 2050, the International Council on Mining and Metals (ICMM) has committed to achieving zero Scope 1 and 2 emissions (ICMM 2021).

Many firms must cut their greenhouse gas emissions to satisfy global climate goals. Decarbonizing and reusing embodied energy will reduce carbon emissions from extractive industries. The production of aluminium may be energy-intensive and create greenhouse gases. However, some operations are located near hydroelectric power. Each kilogram of steel scrap recycled at EoL saves 1.5 kg of carbon dioxide equivalent, 13.4 megajoules of primary energy (Broadbent 2016). Most of bauxite and iron ore processing's embodied energy, and greenhouse gas emissions come from loading and shipping (Mackey et al. 2019). Mining companies are acquiring and generating renewable energy to minimize greenhouse gas emissions (McLellan et al. 2012). Boosting product lifetimes, dematerializing goods, increasing manufacturing yields, replacing products, and recovering materials from waste streams can decrease industrial energy use and emissions (Olivetti and Cullen 2018).

14.2.5 Land Use, Biodiversity, and Reclamation

The relationships between mining and biodiversity are complex and cover several scales. To successfully manage biodiversity in mining zones, the complete magnitude and distribution of risks must be identified and incorporated into conservation planning and decision-making. The current study focuses on direct consequences at the mine site level. Nevertheless, knowledge across all sizes and contexts is necessary to comprehend how these factors affect biodiversity problems. Here are three locations where new information and perspectives might be enormous (Sonter et al. 2018).

First is understanding whether conservation strategies (national rules, certification programs, and industry performance standards) apply in mining scenarios. Few site-level case studies have evaluated the benefits (and limitations) of conservation strategies to counteract mining consequences (ICMM 2010) and the feasibility of using an ecosystem services strategy to meet social, economic, and biodiversity conservation goals (World Bank 2015). We need both spatial and temporal evidence. Mining may learn what works from other extractive industries (forestry, fishing). Agricultural supply chain activities (Lambin et al. 2018) may differ in a mining context where industry organizations exist, and influencing the behaviour of a single firm may be an effective lever for industry-wide change.

Second, we must comprehend the purpose of technology. This explains how future mining enhancements will impact biodiversity and how to incorporate them into conservation programs and objectives. New technologies will provide new ecological threats and conservation opportunities (Sonter et al. 2018; Souza et al. 2015). Inventions in engineering enhance the efficiency of mineral extraction, enabling the exploitation of formerly unprofitable resources and resulting in wider, deeper trenches (Mudd 2010). Increasing ecological vulnerabilities need an extraction, processing, and maintenance that are environmentally sound. Phytomining and phytoremediation might reduce the need for chemically intensive metal extraction (Ali et al. 2013; Whiting et al. 2004); however, it is difficult to scale up these methods.

Thirdly, estimating the global impact of mining requires scenario modelling to account for all possible causal pathways and estimate all probable geographical and temporal consequences. This necessitates that mining projects account for all connected infrastructure, natural resource use, and human behaviour changes and study and manage each consequence within the mitigation hierarchy. Despite data and methodological limitations (Souza et al. 2015), spatial life cycle analyses have the potential to capture the indirect effects of mining, mineral processing supply networks, and commerce (Odeh and Cockerill 2008), despite data and methodological limits (Souza et al. 2015). Models and scenario evaluations may be used to predict future threats to biodiversity (Sonter et al. 2014a, 2018) and examine policy impacts (Sonter et al. 2014b). Such modelling is also very uncertain (e.g., 5% probability of a tailings dam collapse, 10% chance of a significant demographic change in a small town); research on adding uncertainty into the mitigation hierarchy would be advantageous. Regional planning is required to reduce death by a thousand cuts and increase productivity (Sonter et al. 2013; Ten et al. 2004; Whitehead et al. 2017). This increases scenario planning to the regional level but requires explicit uncertainty management. Existing international organizations may aid in bridging research gaps and shedding light on where mining and conservation can coexist and where exclusive conservation is necessary (ICMM 2016). Convention on Biological Diversity and Intergovernmental Platform on Biodiversity and Ecosystem Services has given mining problems little thought, despite being in a position to do so. The International Forum on Mining Metals and Sustainable Development (IGF) has the potential to become an essential arena for governments and businesses to debate mining and biodiversity and develop policy action plans. The high-level political conference on sustainable development should include mining in its biodiversity preservation objectives. To benefit biodiversity, these high-level efforts must influence how mining is planned and carried out on the ground and foster a constructive, coordinated engagement between the mining industry, policymakers, and conservation organizations.

14.3 Make Use of Trash from Factories

Industrial activity is booming due to rising market demand. To adapt, enterprises must continually create, which increases resource consumption, raw material usage, and industrial waste. Industrial waste is one of the greatest concerns facing the earth. To overcome this obstacle, further efforts are being made to transform the current linear economic model into a circular one in which waste reuse will be favoured above virgin raw materials. Industrial waste is waste resulting from industrial processes. Industrial waste is generated by manufacturing, converting, utilizing, consuming, cleaning, and maintaining industrial activities. The manufacturer is responsible for disposing of any industrial waste. The circular economic model aims to repurpose as much waste as possible to reduce its environmental impact and future raw material use. Businesses concerned about the environment are altering their manufacturing processes to use waste as a resource. This dynamic is essential in all industries. Depending on the characteristics of the trash (physical condition, composition, or volume), there are various reuse or recovery options. Companies and organizations are taking increased measures to identify each sector's optimal waste recovery routes.

This must be the primary recovery option if waste can be recycled in a different industrial process. No waste transformation is required to adapt trash to a new technique or purpose. Environmental, economic, and energy impacts are reduced.

In another form of recovery, components are extracted from industrial waste. These compounds are reclaimed in a novel industrial procedure to replace fresh raw materials. This approach reduces the environmental impact, but the cost and energy consumption depends on the transformation required to create the chemicals of interest. There are several methods for converting garbage into valuable substances or preparing it for a new process. Common chemical and physical processes include drying, crushing, and separation.

Another option is the creation of energy from waste. Energy is the primary objective of waste incinerator recovery (Damgaard et al. 2010). Industrial waste may be categorized based on its generation method, chemicals, physical condition, and risk. To reuse the garbage or the elements it contains, we've categorized it by its key components:

Composting: As the name implies, these wastes are mostly organic chemicals from agri-food or other operations. Agri-food waste is the most abundant. Agri-food waste can contain high-value compounds. Fruit waste from juice production is a good example. These leftovers are low-value garbage that must be dried or transformed. From these leftovers, high-value cosmetics and cleaning products may be made. Many methods were created to use biowaste to make biofuels; however, they aren't always accessible or cost-effective, particularly on a small scale. Closed looping might be a solution (Paladino and Neviani 2018). An experimental facility is being investigated to produce biofuels from used cooking oil, organic waste, and algal biomass. Cetane ranged between 47.7 and 58.4 and LHVs between 36,080 and 36,992 kJ/kg. The addition of glycerol enhanced the quality of syngas (Paladino and Neviani 2018).

Plastics: Plastics are a widely used material. Because of their cheap cost, new plastics have been preferred above reuse until now. Plastic garbage and microplastic pollution might be used for clean and renewable energy devices and infrastructures. 14% of 300 million tons of plastic garbage is recycled. Identifying the main plastic, separation processes, and final goal is crucial. Not all plastics are simple to recycle, but newer transformation processes give this trash new life. Reusing plastics or recovering energy might result in energy savings and environmental benefits for manufacturing energy devices. Different recovery techniques must be employed depending on the kind of plastic or its additives. Low-density polyethene (HDPE), polypropylene (PP), and low-density polyethene (LDPE) have calorific values exceeding 40 MJ/kg. Recycling polyolefin conserves ten quadrillions Btu or 1.7 billion barrels of oil. GHG emissions from the plastics industry may triple to 6.5 gigatons per year or 15% of global GHG emissions. Recycling decreases energy and emissions (Zheng and Suh 2019). Mechanical recycling preserves the chemistry of trash. This method contaminates the materials. Polymer cost and quality are inferior to the original. Sorting and shipping costs make mechanical recycling unattractive in developing countries. PET and HDPE plastics are more easily recyclable than other polymers, which account for 24% of the world's plastic waste (UNEP 2018). EoL plastic must be sufficiently large. Plastics with temperature-sensitive composite structures or thermoset properties are difficult to recycle mechanically (Zheng and Suh 2019). Chemical recycling processes may convert polymeric polymer into monomer/feedstock. The decomposition of polymers is thermal, catalytic, and biological. Sorting is an expensive requirement of industrialized chemical recycling. Prioritizing recycling in low-income areas and building mixed-waste recycling systems may be less costly than separating plastics. The most effective approach for dealing with mixed waste is pyrolysis. Although burning plastic removes sorting, the energy released is less than the plastic's potential energy (Gutowski et al. 2013; Rahimi and Garcia 2017). Recyclable and degradable plastics support renewable energy (Garcia and Robertson

2017). To increase plastic recovery and recycling rates, there must be a competitive resale market, consumer-based recycling incentives, consistent markings on end-of-life (EoL) products and packaging to indicate how and where to recycle, and policies that hold manufacturers accountable for increasing recycled content and managing EoL waste. Better recovery and recycling may minimize plastic waste and environmental costs, but they cannot remove them entirely. Companies that reduce virgin plastic derived from petroleum and recycle plastic trash are gaining popularity due to the waste hierarchy. Materials derived from bio-based feedstocks are advantageous. Tires made from biodegradable materials would minimize plastic waste. Biodegradable plastic is preferable for packaging (textiles, single-use items, and food packaging). At EoL, recyclable plastic is resilient, simple to remove, and rebuildable. Microbes may degrade biodegradable polymers (UNEP 2015). Variable biodegradation conditions may yield nano-sized pieces (Lambert et al. 2013). Bioplastics used in batteries and photovoltaics must resist temperature, humidity, microorganisms, sun radiation, and atmospheric conditions (Azarabadi et al. 2017). Bioplastics might be used to make turbine blades (Corona et al. 2015). Most manufacturers create polymers by combining virgin and recycled plastics. Companies are developing bioplastics derived from seaweed (Ferrero et al. 2015). Almost all energy devices are electrical (Bilo et al. 2018). Plastics are present in nearly all technologies and gadgets. Therefore innovations in recovery, recycling, and manufacturing are essential for decarbonizing a circular economy.

Metal: Metals aren't as inexpensive as plastics; therefore, they're often recycled for new uses. Electronic trash is the best example of metal recovery since it includes high-value precious metals. The worldwide steel industry has seen a tremendous transformation over the last four decades, resulting in major increases in energy efficiency. Most scrap metal is being remelted in electric arc furnaces (EAF) to produce steel. Steel from automobiles was recycled at a rate of 106% in 2014, demonstrating more metal recovery than is required for the construction of new domestic vehicles (USGS 2020). There is a significant difference when comparing the energy necessary to generate virgin aluminium by electrolysis of bauxite to the energy required to recycle aluminium. Automobile and beverage industries create the bulk of recyclable aluminium alloy scrap.

In lieu of coal, electric arc furnaces, which are used to melt scrap metal, may be fed with waste plastics to manufacture steel. The steel industry's use of plastics as a reductant or chemical energy exemplifies synergy between scrap streams from diverse industries. Corrosion may limit the lifetime of both steel and zinc, but hot-dip galvanized zinc coatings may preserve it for much longer. Chinese tariffs on imported scrap metal and a tax on a wide variety of American-made items, including automobiles, motorcycles, and scrap metal, may have reduced recycling rates in 2019 (Lasky 2018).

Fabric scraps: This waste is expanding due to short-lived garments or frequent trend changes. Because of this, we must deal with textile waste. This form of garbage may be recovered or reused. Interior panels using textile waste are one example.

Mine rubbish: This industry generates plenty of garbage. These often have a relatively low value and a very high weight. Using the wastes' properties, we've made low-cost counterweights.

Reusing garbage or recovering it doesn't only reduce environmental effects, as we've said before. Less waste means less money spent on trash collection and disposal. Recovering waste and byproducts is essential from an economic standpoint. Utilizing recovered resources from the process or other activities decreases expenses compared to purchasing new raw materials. Reducing waste management may increase the profitability of any operation. As industry and society embrace waste recovery, more businesses will need the associated employment. New firms are focused on waste recovery. Companies that take steps to lessen their environmental impact are held in high esteem by society and customers.

14.4 Low-Carbon and Renewable Energy Circular Economies

Renewable energy must unquestionably be a part of the answer to climate change. As a result of several nations' commitments at (COP26) to achieve net-zero carbon emissions by 2050, the infrastructure for renewable energy will expand significantly. Solar photovoltaics (PV) is the most cost-effective energy source in history for projects that have benefited from low-cost financing and used high-quality resources. In the last decade, the capacity of a single wind turbine has more than doubled, decreasing the cost of wind energy. However, although essential for achieving a net-zero goal, the renewable energy sector faces obstacles. It is anticipated that by 2050 there will be 43 million tonnes of wind turbine blade debris, and the Wyoming blades will not be the only renewable energy industry garbage entering the environment. Lithium-ion battery trash is expected to reach 2 million tonnes yearly by 2030, while the International Renewable Energy Agency (IRENA) predicts that solar panel waste will reach 78 million tonnes by 2050. This waste is unavoidable due to design and material decisions focusing on two primary factors: energy production and price.

This is excellent news for businesses and countries seeking to decrease carbon emissions. However, these same design decisions have rendered it difficult and uneconomical to reuse and recycle components, such as wind turbine blades built from low-value fibreglass composites. Thus they are bound to landfills or incinerators. These traditional design decisions hinder the renewable energy industry's ability to compete with the fossil fuel industry.

The renewable energy industry is very material-intensive. Each wind turbine, for instance, is constructed from vast amounts of steel, iron, fibreglass, copper, and aluminium and is mounted on a concrete foundation. Similarly, a tidal turbine is made from mild steel, stainless steel, iron, etc. Significant negative effects may result from these material requirements as the sector expands.

The increasing need for industrial resources by the renewable energy sector might set it against other economic sectors. The demand for materials such as steel, cement, aluminium, and plastics is projected to triple by 2050, while the market for minerals (including metals for renewable energy infrastructure) is projected to grow fivefold. This might result in supply and pricing difficulties. As a result of the transition to a carbon–neutral economy, it is anticipated that shortages would cause prices to increase and persist. Materials used in renewable energy technology in lesser amounts may significantly harm the environment. For instance, the nacelle of a wind turbine generator is packed with rare earth metals such as neodymium and dysprosium. According to research conducted at MIT, a 2-megawatt wind turbine includes around 340 kilos of rare earth. Although this is a minor fraction of the wind turbine's weight, the techniques required to extract rare earth damage the environment since they are chemical-intensive and contaminate the air, soil, and groundwater. The extraction of lithium and cobalt for batteries and silicon and zinc for solar panels has detrimental environmental effects. Intensifying geopolitical and environmental problems and restrictions may also limit the availability and disrupt supply systems. In addition to these obstacles, the extraction and manufacturing of essential industrial materials and components have substantial environmental and social implications.

This requires a fundamental rethinking of the architecture of renewable energy infrastructure, the policy mechanisms that inform use-lifetimes and end-of-use actions, and the business models upon which the industry is based to avoid the creation of waste and significantly reduce the need for virgin materials as well as the negative climate, biodiversity, and societal impacts associated with their extraction. Circular economy principles provide a future-proof method for addressing climate change.

14.4.1 Metals and Mineral Demands

Future decades may need 3 billion tonnes of metals for the clean energy transition, necessary to escape catastrophic climate change effects.

The battery pack of a typical electric vehicle needs 8 kg (18 lb) of lithium, 35 kg of nickel, 20 kg of manganese, and 14 kg of cobalt while charging stations require copper. Wind and tidal turbines need iron ore, copper, and aluminium, whereas solar panels use copper, silicon, silver, and zinc. In recent years, supply chain issues have surrounded lithium and cobalt, although many other metals are utilised.

Lithium, a soft, silvery-white metal, is used in lithium-ion batteries. Smartphones and electric cars (EVs) are their greatest consumers. Tesla, BMW, Ford, and Nissan use lithium-ion batteries.

Cobalt, a silver-grey byproduct of copper and nickel mining, can be another lithium-ion battery cathode component. It has industrial and military purposes.

Nickel is another battery element that will become more common. Nickel is already extensively utilised, especially in stainless steel manufacture, and mines are spread throughout several nations, so its supply isn't a worry.

Manganese is utilised in batteries, steel, and animal feed.

Copper is used for wind power, wiring, motors, and coinage.

Rare-earth metals are 17 chemically related elements. Each has distinct qualities, making them crucial for low-energy lighting, catalytic converters, wind turbines, EVs, and computer hard-drive magnets.

Neodymium and praseodymium, known as "NdPr," are utilized in electric motor magnets. Their soaring demand and cost have made headlines recently.

Cobalt, lithium, and copper costs have risen in recent years, causing worries about low-carbon technologies. Even if metal stockpiles are ample for the foreseeable future, shortages are conceivable. Metal depletion might affect renewable energy output. Metal shortage problems and price volatility may raise the economic relevance of recycling and remanufacture.

Increasing metal recovery rates is a multifaceted challenge made more difficult by poor collection and processing of metallic EoL commodities and the cheap availability of specific metal deposits (Ayres 1997). Ideally, electronic trash should be considered a resource for raw materials. A kilogram of mobile phones contains 100 times as much gold as a kilogram of gold ore. The carbon footprint of electronic equipment recycling is far smaller than that of mining. The value of functional electronic devices and their constituent parts surpasses the value of the materials they contain.

A recent study shows global average EoL recovery rates of over 50% for 18 of 60 metals, including silver, aluminium, gold, chromium, cobalt, copper, iron, manganese, nickel, lead, and zinc. Indium and REEs have EoL recovery rates below 1%, while lithium-ion batteries are below 5%. Permanent magnets, nickel metal hydride batteries, and lamp phosphors may enhance REE recovery rates, although collection and extraction challenges remain (Binnemans et al. 2013). Cobalt recycling rates are 35%, and platinum group metals are 11%, according to the European Commission Joint Research Centre (Mathieux et al. 2017). Indium and gallium have 0% rates. The complexity of current technology, the small number of minor metals, and the lack of an economic base make it difficult to recover them. Despite this, it is possible to construct a CE in which resources are capitalized and reused to generate decent and sustainable employment rather than being extracted, consumed, and discarded. CE is a system in which all resources and components are constantly maintained at their maximum value, and waste is removed. Recovering and recycling important metals, including platinum group metals in PCBs, through closed-loop systems is financially viable. Automation may be needed for specific occupational safety issues, such as pulmonary health problems from indium tin oxide exposure (Hawley Blackley et al. 2020). Photovoltaics, lithium-ion batteries, wind turbines, and electric cars will extract, manufacture, and create waste. Synergies between the recycling and remanufacturing sectors may boost the CE's efficacy and efficiency in low-carbon systems.

14.4.2 In Wind Energy, the Circular Economy

Wind energy generation is essential to the renewables and electrification agenda and climate change mitigation. The International Renewable Energy Agency (IRENA) REmap scenario predicts that by 2050, renewable energy would account for 86% of the world's power production, with the wind as the primary generating source (35%) and installed capacity topping 6000 gigawatts (GW) (IRENA 2019; Hao et al. 2020). As the wind turbine business evolves and turbine sizes increase dramatically, more equipment will be decommissioned for various reasons, such as age, damage, or repowering with higher power, more efficient equipment that generates more energy. Regardless of the reason, substantial amounts of end-of-life (EoL) wind turbine waste will be generated in the future. The tower, gearbox, main shaft, generator, castings, bearings, and other nacelle and hub components make up 94% of the weight of wind turbines, excluding the base. The remaining 6%, composed of polymer composites, plastic, rubber, power electronics, lubricant, and cooling components, is either difficult to recycle or unattainable (Fraisse et al. 2016; Hao et al. 2020). More than ninety per cent of the weight of the blades consists of polymer composites reinforced with glass or carbon fibre. The trend toward longer blades has increased the use of carbon fibre, and glass-carbon hybrid reinforced composites, significantly reducing blade weight while maintaining blade strength and stiffness. The moderate growth rate and 'Central' scenarios presented by Liu and Barlow predict that global waste from wind turbine blades will reach 15,000 t in 2018, over 50,000 t in 2022, and 43 million tons in 2050.

Here, our main focus is how carbon fibre may rejoin the circular economy system with the highest quality, either as a product (reuse/repurpose or resize/reshape) or as a recycled "raw" or intermediate material (recycle, recovery, and conversion). Since many countries restrict the disposal of composite waste in landfills, sending wind turbine blades to landfills is not a viable long-term alternative (Pickering 2006). Therefore, Asmatulu et al. (2014) explored the feasibility of recycling these materials as structural components in bridges, buildings, and artificial reefs. Other ideas for recycling blades include bridges and urban furniture; however, ensuring structural integrity remains the largest challenge in reusing composites in infrastructure for public amenities. In composite blade recycling, viable output streams include fibre, filler, resin, and recovered energy (Liu et al. 2019). Jaw cutters are often used to segment blades before crushing or shredding. Shredding reduces fibre length and strength, while hammer milling generates noise and dust while breaking the composite into smaller pieces. The recyclates still include polymer residue, and their quality varies; therefore, their applications are limited to low-grade structures. The material loop must be completed from the CE's perspective, which largely depends on the quality of the recovered carbon fibre and the technical factors involved (Hahladakis and Iacovidou 2018; Kasprzyk and Gajewska 2019; Hao et al. 2020).

14.4.3 In Bioenergy, the Circular Economy

In an age of increasing change, the need to establish energy systems that provide a secure, cheap energy supply worldwide while conserving the environment is bolstering the impetus for a global energy transition. This change entails shifting away from fossil fuels and toward renewable energy sources, backed by greater energy efficiency and decreased total energy use. Bioenergy will play crucial roles in all energy transition sectors and in developing a climate-friendly, circular carbon economy that provides economic and social advantages. Bioenergy is today's greatest renewable energy source, accounting for 70% of the renewable energy supply and 10% of the overall primary energy supply worldwide in 2017 (IRENA 2020). Implementing a CE model to get the greatest benefit from waste to achieve zero landfilling and reintroduce trash into productive processes might be a potential strategy for enhancing municipal waste management. Bioenergy has important responsibilities as an energy source and a feedstock that can replace fossil fuels in end-use sectors (industry, transportation, and buildings). It can help balance an electrical grid with many variable renewables, such as solar photovoltaic and wind. Bioenergy technologies are advancing quickly and have substantial expansion potential by 2050. In 2050, the proportion of primary energy met by modern bioenergy might grow from 5 to 23%.

Meanwhile, conventional bioenergy applications must be phased out, which account for most of the bioenergy demand today. In sectors that are especially difficult to decarbonize, such as long-haul or heavy freight transport and some industrial sectors (i.e. iron and steel, cement and lime, aluminium, and chemicals and petrochemicals), biomass utilization will be substantial. As an alternative to fossil fuels, biofuels might play a significant role in the transportation industry, complementing the increased use of electrification.

In a circular carbon economy, bioenergy is a subset of the larger biomass system that satisfies fundamental human needs by producing food, feed, fibre, fine chemicals, fertilizer, and fuels. Nonetheless, bioenergy may boost the whole biomass system by establishing income streams for residues and wastes created throughout supply chains that would otherwise be burnt on-site, discarded, or squandered. Bioenergy may assist reduce environmental issues caused by leftovers and wastes, such as methane emissions while increasing the economics of agriculture and forest management. If properly controlled and regulated, the use of biomass may reduce atmospheric CO_2 concentrations. Considered across its whole life cycle, biomass utilisation for energy purposes results in a net reduction in CO_2 emissions (D'Adamo et al. 2021; Leong et al. 2021).

Similarly, when biomass is incorporated into bio-based materials (e.g., construction, furniture, and plastics), it increases the biogenic carbon stored in materials throughout the products' lifetimes and, under certain conditions, may have the beneficial effect of sequestering CO_2 over the medium to long term. If bioenergy is combined with carbon capture and storage (BECCS), then the carbon is not released into the atmosphere, resulting in a net decrease in CO_2 emissions (i.e. negative emissions). BECCS is not yet implemented on an industrial scale, although the technology might be utilized for applications such as bioethanol production, waste-to-energy facilities, electricity generation, and pulp and cement manufacturing. Biomass has the potential to contribute to energy and environmental goals significantly, but its production must be ecologically, socially, and economically sustainable. The environmental, social, and economic advantages of biomass energy usage depend on several variables and may vary by area. Indeed, waste recovery and its transformation into clean energy may help to counteract the impact of fossil-carbon-based fuels on climate change (Pellegrini et al. 2018). In this approach, the development of biomethane plants might serve as an illustration of progress toward CE. Concurrently, a double-green transition might be accomplished by (i) increasing the proportion of renewable energy in the transportation sector (RES-T); and (ii) enhancing waste management methods. Citizens are vested in increasing the pace of separated garbage collection to decrease unsorted waste and convert organic waste into a valuable resource (Ingrao et al. 2019). The advantages to agricultural output from using fermentate must also be emphasized, as must the aesthetic and economic benefits to the tourist industry from an effective, clean, and correct management of municipal solid waste (Moretto et al. 2019). Bioenergy's broad adoption requires a high level of assurance in its long-term viability, which necessitates the conduct of sustainability evaluations that analyze the risks associated with each bioenergy method. Despite significant motivations for the worldwide adoption of bioenergy, several obstacles impede its continued growth. Depending on various markets and renewable energy technology, they differ.

14.4.4 In Photovoltaics, the Circular Economy

In recent decades, photovoltaic (PV) solar electricity has expanded dramatically. In the near future, it is anticipated that the number of End-of-Life (EoL) PVs will increase significantly. To limit hazardous waste disposal in landfills, it is necessary to create and implement EoL management practices. Recoverable materials include glass cullet, silicon wafers and granulates, silver, indium, tin, molybdenum, nickel, zinc, copper, aluminium, steel, tellurium, cadmium, gallium, and ruthenium (Mulvaney et al. 2021). In the long term, photovoltaics recycling may save the U.S. $150 billion in raw materials by 2050 (IREA 2016a, b). Some EoL modules are disposed of at landfills, hazardous waste sites, and materials recovery facilities. Since the 1990s, First Solar has recycled its thin-film CdTe modules. France constructed its first photovoltaic recycling facility in 2018. A take-back and collection system may aid in developing a secondary market for obsolete solar modules. In 2017, the United States imported 92% of its demand for crystalline silicon (c-Si) and thin-film modules and relied completely on foreign wafers.

As the demand for photovoltaics (PV) increases, more virgin materials (silicon, indium, silver, tellurium, and copper) will be required to manufacture new goods. The principles of a circular economy go from a linear “take-make-consume-throw-away” system to one that allows for prolonged life, high performance, and reuse/recovery of products and resources. Recycling PV manufacturing detritus and equipment diverts precious resources from landfills and lessens the dependency on mining resources. Extending the usable life of PV equipment via repair and reuse and recovering PV components through recycling reduces environmental consequences throughout the lifetime of the equipment. Private investment in product and process innovation, as well as the utilization and recovery of PV production waste, modules, and balance of system (BOS) equipment, is stimulated by cost reductions, increased profitability, and increased competitiveness. Research and development and analysis aimed at enhancing the cost-effective recovery of high-purity materials at high recovery rates might facilitate private investment by making recycling more economically feasible.

According to the IRENA (2016) research and a paper by Gautam et al. (2021, 2022), between 2020 and 2047, India may anticipate 295 million tonnes of trash from EOL solar PV and its BOS. This waste is worth 645 billion dollars, and 70% of it could be recovered (452 billion dollars). A lack of infrastructure for the coordinated collection and reverse supply chain of EOL e-waste (Lahane et al. 2020; Prajapati et al. 2019; Shukla et al. 2010). CE mishandling is partly attributable to the prevalence of the informal sector in collecting e-waste. In India, e-waste management remains a big challenge; just 4% of all e-waste produced in the nation is recycled (Arora et al. 2018). For the effective circular economy-based management of created e-waste, it is necessary to locate SMEs doing remanufacturing, refurbishment, and central recycling so that crucial and rare earth metal-containing e-waste may be submitted for recovery from all e-waste rather than being exported (Ravi and Shankar 2015; Shaw et al. 2016; Shukla et al. 2010). This would create a reverse CSC for solar PV e-waste in India and optimize the placement of RRR facilities for maximum recovery by giving the optimal coordinates of dismantling and recycling facilities (Baidya et al. 2020; Fontana et al. 2019; Wang et al. 2018). According to the research, plant size and location are crucial determinants of the economic viability of solar PV e-waste recycling (Cucchiella et al. 2015).

14.4.5 In Tidal Energy, the Circular Economy

The development of tidal stream power is at an earlier stage than that of more prevalent renewable energy sources like wind power, and a wide variety of designs exist, albeit many of the most successful devices are of the three-blade horizontal axis kind (Walker et al. 2018). Due to the differing densities of water and air, a tidal turbine’s rotor diameter is much less than that of a similarly-rated wind turbine. Generally, these devices are seabed-mounted, although several designs superficially resemble wind turbines. Typically rated at 1–2 MW, tidal turbines are envisioned to be deployed in arrays conceptually comparable to wind farms on 100 s MW. In general, it is separated into three different sections: a “device” part including the steel turbine body, internal electrical components, and yaw rotation mechanism; a “support” section containing the support structure, mounting system, and foundations; and the composite turbine blades (‘blades’). In this instance, the support structure was made completely of steel, and the mounting mechanism consisted of steel and concrete piles. The turbine device is around 52% mild steel, 35% stainless steel, 11% iron, and 2% other materials by mass. The support comprises 60% mild steel and 40% cementitious materials, while the blades are built completely of an epoxy resin reinforced with glass fibres (Walker et al. 2018).

14.4.6 In Energy Storage, the Circular Economy

The increased use of lithium-ion batteries (LIB) in renewable energy systems would hasten the depletion of cobalt and lithium. Li is mostly extracted by roasting and leaching from igneous rocks in China and South Africa (Mossali et al. 2020; Meshram et al. 2014). In reality, brine extraction is hampered by technical limitations: One ton of lithium requires 20,000 t of water (Katwala 2018). Unless 90% of LIBs are recycled, lithium demand will surpass the mining supply in the near future (Sonoc and Jesweit 2014). Co used to manufacture LIBs is sourced from the Democratic Republic of the Congo, which is sanctioned for human rights violations. Ni extraction will need 170 times the existing capacity. Since repetitive cycling affects battery performance and some cell chemistries deteriorate more quickly than others (Pellow et al. 2020), these two factors influence LIB lifetimes simultaneously. Most LIB failures may be attributable to thermal runaway induced by extrusions in the manufacturing process, overheating, improper charging, or electrolyte or separator damage. Nickel, zinc, cobalt, lithium, manganese, copper, aluminium, steel, plastic components (PP, PET), slag for building materials, graphite carbon, solvent/electrolyte (sulfuric acid), fibreglass, and coolant/battery management system are examples of LIB waste (Mulvaney et al. 2021; Pellow et al. 2020). Recycling LIBs, among other benefits, may minimize our environmental impact, save money, and decrease waste by decreasing the need to mine and import virgin components (Bankole et al. 2013). Globally, fewer than 3% of LIBs are now recycled, despite projections that metals recycling may cut LIBs’ cost per kWh by 13%. (Sonoc et al. 2015). Care must be taken as electrical and chemical hazards exist during deinstallation, collection, reverse logistics, reclamation, recycling, and remanufacturing LIBs.

14.5 Policies in the Circular Economy

14.5.1 Corporate Policy

Corporate environmental management entails the implementation of strategic, operational, and tactical choices across all corporate operations to avoid negative environmental impacts. Companies incorporated environmental management methods into their business strategy (Boffelli et al. 2019; Cramer 1998; Resta et al. 2015). CE, which emphasizes resource and energy efficiency, decreases the flow of resources along the whole value chain (Kazancoglu et al. 2021; Aranda-Usón et al. 2020). The CE also attempts to prevent the waste of natural resources and broadly safeguard the environment (climate change, protection of biodiversity) (Stewart and Niero 2018). To maintain a consistent output level, the CE model uses fewer resources owing to decreased resources or the utilization of recycled raw materials (Figge et al. 2018). CE principles include reduction, reuse, recycling, refurbishment, remanufacturing, and recovery (Prieto-Sandoval et al. 2019). A CE necessitates a change in the economic and political framework and a shift inside individual businesses. Strong linkages exist between the CE and environmental sustainability practices of companies, including enhanced energy efficiency, use of renewable energy and waste recovery, and use of recycled or renewable resources in raw material supply (Lieder and Rashid 2016; Kazancoglu et al. 2021; Moreno et al. 2016).

Thus, implementing CE requires modifications to company business structures (Pieroni et al. 2019). In the circular business model, the objective of enterprises is not just to generate economic value but also to promote sustainable development by addressing social and environmental concerns. However, many companies' current corporate environmental management strategy is to reduce the company's short-term environmental effects (Korhonen et al. 2018; Lozano 2020; Robèrt et al. 2002). CE involves extending current corporate environmental management systems to generate high economic value from the material life cycles of organizations (Bocken et al. 2016; Stahel 2016).

Companies must create goods and services that adhere to CE's social and environmental standards. Consequently, CE endorses both internal and inter-organizational sustainable management (Korhonen et al. 2018). At the micro level, ecological rules and public incentives have moulded the company's sustainable CE practices (Aranda-Usón et al. 2020; Kazancoglu et al. 2021; Ghisellini et al. 2016).

14.5.2 Policy of the Government and Transition to CE in Supply Chains

The legislative requirements that governments should have established for the CE should be pertinent to recycling and trash management and supportive of recyclable product monitoring, collection, and sorting mechanisms at each level of the supply chain (Jia et al. 2020; Lazarevic and Valve 2017). Government has a significant role in encouraging environmental management in the company. Government policies, norms, and laws play a vital role in establishing CE practices in developing nations during the transition from linear to CE. During the transition to the CE, government policies, corporate procedures, and consumer behaviour will undergo significant changes; therefore, suitable and consistent policies and strategies must be developed to ensure that all stakeholders generate value through cooperation and a shared understanding of the CE. By enacting industry-specific environmental laws, the government may require companies to adopt CE practices (Scupola 2003).

Additionally, the government plays a vital role in increasing public knowledge and understanding of CE ideas (Mathiyazhagan et al. 2013; van Buren et al. 2016). Therefore, the government should include CE legal requirements in its environmental control and legislation system. This law and related procedures must include financial initiatives, technical help, incentive programs, collaboration platforms, and monitoring and auditing criteria for a transparent supply chain structure (Lewandowski 2016). Governments play a crucial role in facilitating the transition of enterprises to CE by providing them with the required technology and infrastructure (Geng and Doberstein 2008; Manninen et al. 2018) and by developing new rules, regulations, and eco-labels (Prieto-Sandoval et al. 2018). Governments may also encourage public procurement based on circularity to advance relevant laws and execute circular commercial activities (Yuan et al. 2008). According to Jia et al. (2018), economic incentives for firms using circular processes may include subsidies and particular exemptions, such as a tax break for ISO 14001-certified enterprises. Environmental taxes are environmental solutions to aid sustainable business (Galvão et al. 2018). Firms must include circular practices into environmental management plans to reach sustainable development goals. According to Dubey et al. (2019), governments play a significant role as external drivers in maintaining the sustainability of supply chains. Governmental green procurement and supply programs may also push companies to use CE standards (Jia et al. 2018).

Moreover, public procurement may help enhance the market for recycled materials. According to Mangla et al. (2018), implementing circular procurement models will benefit from regulations governing government procurement and material handling activities. The government is a coordinator, mediator, and facilitator among different organizations. The government must simultaneously establish laws and regulations, promote economic policies, raise public awareness, and facilitate supply chain cooperation (Lau and Wang 2009). Existing government rules and regulations are based on a linear financial system and lack sufficient circular economy (CE) expertise, which may hinder the transition to a CE (Rathinamoorthy 2019). Due to the lack of government subsidies and financial incentives, businesses cannot get environmental certifications, eco-labels, or training (Jia et al. 2018). However, these certifications are essential for adopting CE and evaluating a company's environmental capabilities (Jaeger and Upadhyay 2020; Scarpellini et al. 2020).

The influence of government control measures is transitive; first, pressure is exerted on producers, and then it is passed to suppliers in the supply chain (Seuring and Müller 2008). Inadequate government support mechanisms are an additional barrier to the adoption of CE. Moreover, governments are uninterested in supporting enterprises' eco-friendly practices (Rizos et al. 2016; Su et al. 2013). Mura et al. (2020) cite bureaucracy as a hindrance to CE practices, particularly for small and medium-sized businesses. Therefore, appropriate methods should be devised to redefine performance criteria, such as recycling standards in accordance with CE regulations. Existing environmental laws should focus on recycling programs and reuse and have difficulty applying CE principles (Kane et al. 2018). Aström and Martin (2018) conducted a thorough literature review on obstacles to CE. The government's lack of ambition and foresight was cited as the largest obstacle to adopting the waste-to-energy supply chain. Pheifer (2017) emphasized the microbarrier, mesobarrier, and macrobarrier as well as the opportunities encountered throughout the shift from the linear economy to the CE using an interview-based methodology. In conversations, the most often mentioned hurdles include product design, lack of reverse supply chain architecture, lack of corporate culture, lack of data, appropriate capital, and existing government laws. Riisgaard et al. (2016) uncovered an additional legal barrier in the form of the extended warranty length for devices, which forbids the use of used components for mobile phone repair in Denmark. Consequently, government rules have a crucial role in regulating the environmental performance of firms in a CE.

Recently in India, the Ministry of Environment, Forest, and Climate Change (MoEFCC) and the Ministry of New and Renewable Energy (MNRE) formed a Task Force to design a policy framework for embracing the circular economy in the solar energy sector. Solar PV modules (panels) and cells were included in the amended proposed E-waste guidelines published in the Gazette on 19 May 2022. India has made a place for itself by joining an exclusive group of nations tackling environmental challenges connected to solar energy.

14.6 Conclusion

A comprehensive, systems-based approach to a circular economy and zero waste necessitates the evaluation of all sectors (Velenturf et al. 2019). We've integrated extractive, manufacturing, and recycling capabilities for companies transitioning to a circular economy. CE-designed new materials, items, and infrastructures are required. This addresses the growing need for critical minerals in renewable energy systems. New paradigms may enhance the recovery of EoL material and embedded energy value. The packaging and design of a product must consider the viability, sustainability, and end-of-life. Multiple-component electronic devices using trace, valuable, or rare metals, as well as the increasing variety of renewable energy materials and products. Difficult to define tradeoffs. Sometimes what seems logical is detrimental to the environment, emphasizing the need to examine material consequences through LCA or contextualizing essential factors such as environmental justice (Olivetti et al. 2010). Environmental expenses may be reduced by reducing garbage and reusing abandoned places by extractive enterprises. Improved scrap sorting and process innovations may increase metal recycling. Utilizing automation, artificial intelligence, teaching producers, organizations, and consumers about payment ramifications, and equalizing and streamlining procedures to promote national consistency, waste management enterprises must boost material recovery rates and energy efficiency. The waste provides the opportunity to transform the economy's material base from extractive sectors and end-of-life product waste to one that restricts extraction and relies on a circular economy approach, converting waste into industrial feedstocks. To encourage society to progress toward CE, new policymaking and regulatory initiatives from supply chains via EoL will require increased R&D investment and assistance, particularly to shift old linear-supply chain processes and business models. Recycling in complex commodity systems, such as decarbonization equipment and infrastructures, is slowed by the absence of a clear commercial reason. To avoid moving or relocating garbage generation and disposal and to make progress toward a circular economy, worldwide and cross-sector efforts must be undertaken to involve trash in clean technology.

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