Polymers in Circular Economy: A Comprehensive Approach to Sustainability. An overview.

FRANCISCA L. ARANDA[1,2], MARTINA ZÚÑIGA[2], BERNABÉ L. RIVAS[3]*

1. Departamento de Materiales, Facultad de Ingeniería, Universidad de Concepción. Edmundo Larenas 315, Concepción. Chile.
2. Departamento de Polímeros, Facultad de Ciencias Químicas, Universidad de Concepción, Edmundo Larenas 129, Concepción, Chile.
3.Universidad San Sebastián, Concepción. Chile.

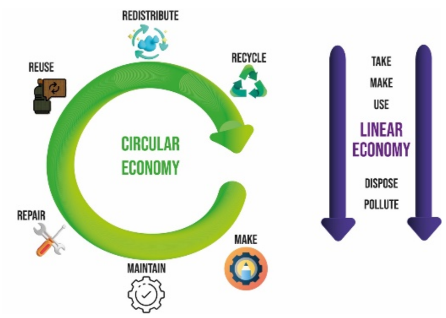
ABSTRACT

The circular economy has emerged as a fundamental paradigm in the search for sustainable solutions in the global economic context, as an innovative approach that seeks to transform the way we consume and produce goods and services. Its fundamental principles are based on the reduction, reuse and recycling of resources, promoting sustainability and minimizing waste. This new way of thinking has applications in a variety of sectors, from manufacturing to waste management. The implementation of government policies and regulations play an important role in promoting the circular economy by setting standards and requirements for responsible resource management. However, there are challenges and barriers that need to be overcome, such as resistance to change and the need for upfront investments. Despite these obstacles, there are successful examples of circular economy around the world, demonstrating the tangible benefits of this approach in terms of waste reduction. This paper presents an exploration and analysis of the circular economy, providing a vision of its foundation, applications and challenges in promoting a more sustainable management of resources and products globally.

Keywords: *Circular Economy, Sustainable transition, Polymers, Renewable resource, Environmental.*

1. INTRODUCTION

Figure 1. Graphical Abstract**.**



The Society, since the industrial revolution, has remained in a constant linear economy [1, 2], where the production and use of resources has been extremely endangered due to the excessive use of fossil fuels and other conventional non-renewable energies. It has been estimated that natural resources are consumed at twice the rate they are produced and that by 2050 [3] it could increase to threefold. This growth in resource use is closely associated with the increase in the world's population, which is expected to reach 8.5 billion by 2030, resulting in unprecedented exploitation of natural resources [4]. In this way, waste management has set the international standard in terms of the use and application of resources [5], as well as the promotion of clean energies with low environmental impact, as well as systems in which the carbon [6] and water footprint is minimal.

However, globally, natural resource depletion coupled with greenhouse gas emissions [7], have increased and continue to accelerate. With this it is considered that a focus on the circular economy could be one of the most efficient ways to reduce environmental impact. The circular economy corresponds to an economic and systemic approach that aims to redefine the way we produce, consume, and manage resources, as well as, maximize efficiency in the use of resources and minimize waste, and the time that environmental sustainability is promoted [8,9]. It is based on the principle of closing the life cycles of products, materials and resources, so as to minimize the use of natural resources, encourage reuse and recovery of products and different materials at the end of their useful life [10].

Unlike the traditional economic model, which is based on a linear economy, the circular economy seeks to create a regenerative system in which products and materials maintain their value for as long as possible. This involves designing products with greater durability, facilitating their repair and refurbishment, promoting reuse and exchange, encouraging recycling and recovery of materials for reintroduction into the supply chain [11]. The circular economy not only focuses on environmental aspects, but also considers economic [12] and social [2] aspects and benefits.

From an economic point of view, closing the life cycles of products and materials generates opportunities for job creation, technological innovation, cost reduction and the promotion of economic resilience. At the same time, by reducing dependence on natural resource extraction, the negative environmental impact associated with production is minimized and biodiversity is protected. From the social aspect, the circular economy can foster inclusion and equity [13] by promoting business models based on collaboration and community participation [14]. It can also increase environmental awareness and education, encouraging communities to adopt more sustainable and responsible behavior. Thus, in 2002, the concept of "Cradle to Cradle", C2C, was introduced, which involves the recycling of waste and transformation into new products [15].

In this sense, the current practices of generation and disposal of different materials has become an unsustainable practice, one of the best examples correspond to synthetic polymers where their production has increased from 15 million tons in the sixties to 311 million tons by 2014 and this value is expected to triple by 2050 [16,17]. Thus, the world production of plastics, excluding polyethyleneterephtalate (PET) and polyamides (PA) fibers in 2019, China was awarded 51% of total production, while the United States 19%, Europe 16% and Latin America 4% [18].

The importance of replacing petroleum-based polymers, a resource that is rapidly depleted and generates high pollution [19] is becoming increasingly apparent. In the traditional linear economy, these polymers are usually treated as single-use products, which leads to the accumulation of a significant amount of plastic waste that alarmingly pollutes our environment. These materials, designed to offer high performance and durability, persist for long periods in the environment, causing impacts on all aspects of ecosystems. Whether in their original form or after undergoing processes that release micro or nano plastic

*Corresponding author email:bernabe.rivas@uss.cl

particles, derived from oxidative, hydrolytic, thermal or microbial processes [20] and these polymers are incorporated into the trophic chain, affecting the health of various organisms [21,22].

However, in the context of the circular economy, a different vision is promoted, the extending the useful life of polymers through reuse and recycling [23]. The polymer recycling process involves several stages. It starts with the meticulous collection and separation of plastic materials. The polymers are then washed, crushed, and melted, resulting in granules or pellets. These granules become the raw material for the manufacture of new plastic products. In this way, polymer recycling becomes a cornerstone of the circular economy, substantially reducing the amount of plastic waste that ends up in landfills and minimizing the need to extract natural resources [24].

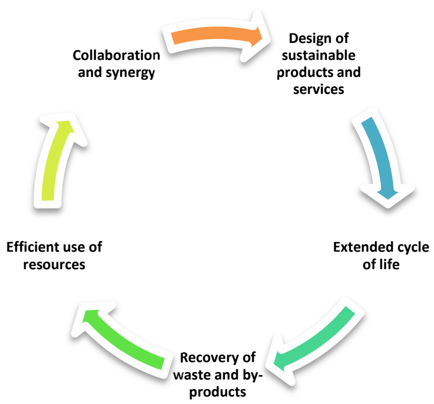
However, despite the clear benefits offered by polymer recycling, we cannot overlook the challenges facing this process [25]. One of the main challenges lies in the contamination of recycled polymers, since impurities such as labels, inks or food debris can affect the quality of the recycled material. In addition, some polymers present complications in their efficient separation and recycling due to their chemical and physical properties. The lack of adequate recycling infrastructure and the lack of economic incentives are significant barriers to the expansion of polymer recycling [26, 27].

In short, replacing petroleum-based polymers with more sustainable alternatives is imperative, and circular economy emerges as a crucial approach in this regard. Through reuse and recycling, we can significantly reduce the environmental footprint of polymers and mitigate the negative impacts that have characterized the traditional linear economy. However, it is essential to address the present challenges in polymer recycling to achieve an effective transition to a more sustainable future [28,29].

1.1. PRINCIPLES OF THE CIRCULAR ECONOMY

As mentioned above, the circular economy (CE) comprises a concept that has gained high prominence in recent decades as an almost obligatory alternative to the linear model of production and consumption of different products. Unlike this linear model, which is based on the extraction of natural resources, the manufacture of products, their use and subsequent disposal without further treatment, the circular economy seeks to close the cycles of matter and energy by minimizing waste and maximizing the value of different resources, demonstrating that it requires the creation of organizational competencies and dynamic capacities [30]. In this way, the circular economy presents 5 fundamental principles for long-term sustainability [Figure 1].

Figure 1. Five principles of the circular economy.



Design of sustainable products and services:
The first principle of the circular economy is the design of products and services designed to be sustainable throughout their life cycle. This involves considering aspects such as durability, repairability, reuse, and recycling when designing a product. The aim is to maximize the useful life of products and minimize their environmental impact [31], encouraging the transition towards an economy that allows reuse and recycling [32]. The steady growth of the service sector and the shift towards a more sustainable society accounts for the largest share of the global economy. However, there has been little incorporation of sustainability into the design and provision of services until today [33].

Circular business models have been described as new types that use the economic value stored in products for new types of market offerings [34, 35], in order to move towards an increasingly regenerative economy [36,37]. The design of sustainable products and services is based on seven fundamental pillars:

a). Design for durability: Products should be designed for long service life and increased strength. This involves using high-quality materials and manufacturing techniques that reduce wear and allow for repairs [38].

b). Design for reuse: Products must be designed in a modular and standardized manner, allowing easy disassembly and reuse of components in new products or as spare parts [39].

c). Design for recycling: Products must be composed of recyclable and separable materials, facilitating their disassembly and recycling at the end of their useful life [40].

d). Economy of functionality: Instead of selling products, you can offer a service that meets the customer's need. The manufacturer retains ownership of the product and is responsible for its maintenance and updating [41,42].

e). Use of renewable and biodegradable materials: The choice of renewable and biodegradable materials reduces dependence on non-renewable resources and decreases the amount of waste [43].

f). Minimization of packaging: Products should be designed with minimal packaging and preferably reusable or recyclable [44].

g). Collaborative economy: Encourage business models based on exchange, loan and rental, allowing a more efficient use of resources and extending the useful life of products [45].

In this way, the design of sustainable products and services based on the circular economy offers a large number of benefits for both companies and society and the environment, including the following:

- Reduction of environmental impact: By minimizing the extraction of natural resources and the generation of waste, the ecological footprint is reduced and the environment is preserved for future generations [46].

- Stimulus to Innovation: The circular economy allows to promote creativity and innovation in the design of products and services, which drives the development of more sustainable technologies [47].

- Business resilience: Companies that embrace the circular economy can become more resilient to resource scarcity and market fluctuations by relying less on expensive and volatile raw materials [48].

However, there are major challenges in terms of implementing the circular economy, such as the need for changes in business mindset, access to advanced recycling technologies and collaboration between various actors in the value chain.

1.2. Extended cycle of life

The circular economy focuses on extending the life cycle of products and materials as much as possible. This involves promoting the reuse of products and components, as well as repair and maintenance rather than replacing them [49]. By extending the useful life of products, the waste generated is reduced and the demand for new raw materials is reduced. This is why the extended life cycle seeks to extend the useful life of products and maximize their value throughout their existence. This concept goes beyond the traditional concept of "use and dispose" products [50]. Rather than being limited to a single stage of use, this approach seeks to extend the life of products through different strategies, such as designing for durability, repairability and reuse [51]. By extending the life of a product, we are reducing the need to produce new elements frequently and therefore, the demand for natural resources and the generation of waste is reduced [52]. In this way, the concepts of circular economy and extended life cycle are terms that are interconnected and complementary. This cycle is a fundamental component in the circular economy, since it extends the useful life of products, reduces the demand for resources and reduces the amount of waste generated. On the other hand, the circular economy provides the framework and infrastructure for the extended life cycle to be effective and viable at scale [53]. By integrating the extended life cycle within the circular economy, we can see five important aspects:

- **Reduced environmental footprint:** By extending the shelf life of products, the need to produce new elements is reduced, decreasing natural resource extraction and carbon emissions associated with manufacturing [54].

- **Encouragement of sustainable innovation:** The quest to extend the life cycle of products requires innovation in design, materials and processes, which encourages the adoption of more sustainable practices in the industry [55].

- **Job creation:** The circular economy and extended life cycle can create new employment opportunities in sectors related to repair, reuse and recycling [56,57].

- **Reducing dependence on non-renewable resources:** By extending the useful life of products and recycling materials, dependence on non-renewable resources, such as minerals and fossil fuels, is reduced [58, 59].

- **Promoting responsible consumption:** Awareness of durability and the life cycle of products can lead consumers to make more informed and responsible decisions in their purchasing choices [60].

However, despite the great benefits that this model brings, there are three major challenges:

- **Change of mindset:** For both companies and consumers, a change of mentality is necessary to adopt more sustainable practices and value the longevity of products over planned obsolescence [61].

- **Infrastructure and logistics:** A robust infrastructure is needed to collect, repair, and recycle end-of-life products, which may require significant investments [62, 63].

- **Regulation and public policies:** An adequate regulatory framework is needed that encourages and supports the circular economy and the extended life cycle [64].

Recovery of waste and by-products

Instead of considering waste as garbage, the circular economy seeks to valorize it and reintegrate it into new production processes. The premise is that waste from one process can become resources for another. This can be achieved through recycling, composting, energy recovery or the transformation of waste into secondary raw materials [65, 66]. Doing so closes material cycles and reduces dependence on virgin resources. Thus, instead of treating waste as a problem to be eliminated, valorization seeks to make the most of its potential, reintegrating it into the economic and productive value chain [65]. This approach is essential in the context of the circular economy that seeks to minimize the extraction of natural resources and the generation of waste [67], promotes the efficient and sustainable use of natural resources. There are different types of waste and by-products, which can be carried out through various strategies, among which we find:

- Recycling involves collecting, sorting and processing materials into new products or raw materials that can be reused in production [68].

- Reuse consists of using waste and by-products for another purpose without subjecting them to a transformation process, thus prolonging their useful life [39].

- Composting is referred to the biological decomposition of organic materials to produce compost, agricultural areas can be used [69, 70].

- Energy recovery involves the transformation of waste into energy, such as the production of electricity or heat through controlled incineration [71].

- Economy of Functionality, instead of selling products, a service is offered that meets the customer's need, keeping ownership and responsibility of the product in the hands of the manufacturer [72].

The recovery of waste is essential to move towards a circular economy because it allows a reduction of the environmental impact, thus reducing the extraction of new natural resources and preventing waste from accumulating in landfills or being released into the environment [73]. Resource conservation makes it possible to give waste a new use, prolonging its useful life and preserving the intrinsic value of materials, reducing the demand for new resources [74]. Stimulating innovation promotes innovation and the development of new technologies and processes that transform waste into new products and services [75]. The valorization of resources also allows the generation of employment and economic development and thus also allows a reduction in costs associated with the management and disposal of waste [76], benefiting both the company and the communities.

Finally, the valorization of waste and by-products also faces challenges that must be overcome for effective implementation:

- Infrastructure and technology: an adequate infrastructure is needed for the collection, classification and processing of waste efficiently [77,78].

- Public awareness and participation: public education and awareness are essential to promote valorization and encourage more sustainable practices [79, 80].

- Regulation and public policies: at this point, it is considered necessary a solid regulatory framework and policies that encourage valorization and establish standards for its implementation [81].

Efficient use of resources

The circular economy promotes the efficient use of natural resources, minimizing their extraction and maximizing their yield. This is achieved through practices such as eco-efficiency in production, optimization of industrial processes, responsible management of water and energy, as well as the implementation of clean technologies. The objective is to reduce the pressure on ecosystems and reduce the generation of waste.

Collaboration and synergy

The circular economy fosters collaboration and the establishment of synergies between different actors within an economic system. This implies the creation of networks and platforms where companies, governments, non-governmental organizations and society in general can share the knowledge necessary for the optimal development of collaborations [82-84].

*Corresponding author email:bernabe.rivas@uss.cl

1.3. BENEFITS OF THE CIRCULAR ECONOMY

Currently, issues of social scientific importance are focused on the reduction of greenhouse gas emissions, water treatment and environmental pollution [65], so a good optimization of waste is being fundamental to face these problems [86].

Thus, as the EC is primarily concerned with preventing the excessive consumption of resources and optimizing energy and material cycles at all social levels [65,87]. However, the EC is beginning to restructure in line with the modernization of the economic system which is governed by the circulation of different products and energy flows in the natural ecological environment [88, 89]. The predominant approach in the EC improves resource efficiency, reduces inputs and emissions, making it a good strategy to combat climate change [90]. The main objective is to reduce greenhouse gas emissions by achieving a zero-emission economy by 2050 [91] by trying to meet the 1.5°C challenge of temperature reduction to reduce global warming [85, 92].

At the same time, the EC is playing an important role in the agendas of major organizations such as the United Nations Climate Change Conference (COP) [90], the G7, and the World Economic Forum [93]. From this point of view, the EC is representing a framework of solutions to address these problems together with the adequate energy transition, where since COP25 different contributions have begun to be implemented so that countries can achieve emission reductions [90].

A wide variety of benefits have been generated around the implementation of CE in addition to the implementation of new social behaviors in order to favor the objectives promoted. In this sense, it is find the sharing of mobility services, where big data and connectivity [94] have allowed an increase in what is known as the collaborative economy. The electrification or energy transition in vehicles has allowed carbon emissions to decrease greatly [95], as well as the cost of operation and maintenance that can fall between 50 and 70% because these vehicles do not need engine adjustments, oil changes, transmission fluids, in addition to having significantly less wear due to regenerative braking. The improvement of current materials are also a good and promising alternative, an example of this is the implementation of carbon fibers for the manufacture of vehicles or other artifacts, improving aerodynamics, providing greater durability and easy recycling [96, 97].

Another advantage and benefit of the EC refers to the importance of efficient use of different types of resources [98] offers protection and raises awareness towards the environment during all stages of production design and formation of the final product, also restricts pollution, waste and emission of different types of harmful and toxic substances while increasing resource efficiency (99). This also allows entry into the creation of employment opportunities for local communities [100] by bringing different types of investments. At the same time, it has been proven that this path leads to an improvement in public health and, in general, in environmental awareness [101].

In this sense, the EC allows to have a significant opportunity to address both the economic benefits for companies and for society in general, presenting business opportunities addressing the issues of the climate crisis, loss and degradation of biodiversity [102, 104].

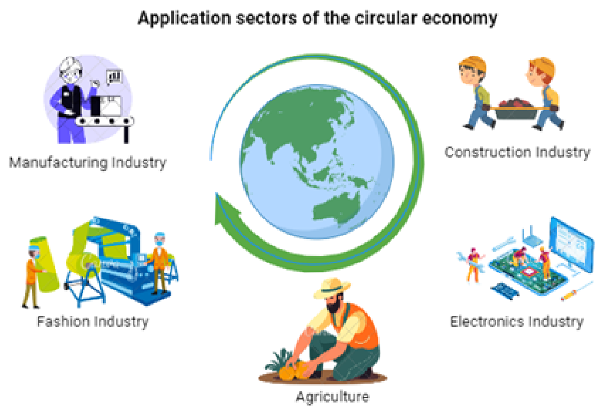
1.4. APPLICATION AREAS

The EC has become a fundamental paradigm that redefines the way in which companies approach sustainability and resource management [105], so in its quest to rethink and revitalize the traditional approach to production and consumption, it spans a diverse spectrum of economic sectors, ranging from manufacturing to agriculture, going through technology, construction and fashion. Each of these sectors finds in the EC an adaptable and effective approach to minimize waste, maximize efficiency and reduce environmental impact, while generating economic opportunities and addressing global challenges more holistically [4, 106, 107].

In this exploration, it will break down how the EC applies in these diverse sectors, highlighting the benefits and opportunities it offers in the pursuit of a more sustainable and prosperous future.

In order to change the traditional linear model of *"take, make, and dispose"*, companies are adopting more sustainable approaches (Figure 2), which also involves designing products that are durable and easy to disassemble, thus facilitating the remanufacturing and recycling of components. As a result, not only are environmental impacts, such as waste generation and pollution, reduced, but opportunities for innovation in design and production are also opened up [108, 109]. In the manufacturing sector, for example, the EC promotes the creation of products designed to last and be easily recycled, which in addition to reducing the amount of waste generated, minimizes the demand and dependence on virgin raw materials [107, 110], promoting the use of recycled materials and the optimization of resource management.

Figure 2. Application sectors of the CE.



In addition, the EC in the manufacturing sector is redefining business-consumer relations. The trend towards reuse and extending the useful life of products is leading to business models based on shared ownership, leasing and service offering rather than merely selling products. This not only encourages resource efficiency, but also creates new revenue streams for businesses and changes the way consumers interact with products [111, 112]. In summary, the EC in the manufacturing sector represents a fundamental shift towards sustainability and efficiency, generating benefits for both businesses and the environment [113].

The construction industry on the other hand has contributed significantly to the economic growth of different countries of the world. However, the adverse effects of construction activities on the environment and social aspects have become a growing concern over the years. In this sector, the EC plays an important role as it promotes the use of sustainable materials, the reuse of existing structures, the extension of the useful life of buildings and materials, in order to drastically reduce the waste generated in construction and demolition projects, the use of energy and the reduction of greenhouse gas emissions, in order to contribute to the reduction of the environmental footprint and boost economic efficiency in this industry [114].

In this context, performance in the construction industry needs a significant shift towards a more regenerative, practical, efficient and sustainable approach, so some of the key CE practices in construction include, the reuse of buildings, rather than demolishing entire structures, the renovation and adaptation of existing buildings is encouraged [115,116]. This not only preserves architectural history and reduces demolition waste, but also saves pristine resources and energy. A clear example of circular economy in construction is the project *"The Buitenschot Land Art Park"* in the Netherlands. A waste dump was transformed into a public park using excavated earth from nearby construction projects, minimizing waste and reducing the need for land transportation. In addition, crushed glass waste was used as material for roads and paths, closing the recycling and reuse cycle, Similar cases have been reported in Pakistan, China, some African countries, and the European Union [117,118].

The use of sustainable building materials and the circularity of construction waste are also promoted in emerging economies, such as certified wood, recycled bricks and bio-based building materials, which have a lower environmental impact in their manufacture and use [119-121]. Modern construction methods such as modular prefabrication, an option to reduce carbon dioxide emotions by up to 40%, which also facilitates the assembly and dismantling of structures, reducing material waste and construction time [122,123]. and green construction as a greening system for buildings, bioretention systems, Biofilters built in building systems can improve the efficiency, sufficiency and coherence of ecological building systems, prioritizing ecological, economic and social impacts on the life cycle of buildings and the environment [124-126].

These approaches to the circular economy in the construction sector not only reduce environmental impacts, but can also generate significant cost savings and create opportunities for innovation in design and construction. The circular economy in construction has become a role model for addressing the environmental and economic challenges of this key sector [127-129].

The CE applied to technology represents a significant transformation in the way we conceive, develop and use electronic devices. Instead of the traditional linear model of production and disposal of technological products, the circular economy introduces a more sustainable and efficient vision, focusing on sustainable design, the reuse of components and the responsible management of electronic waste. This transformative approach not only benefits the environment, but also presents significant economic opportunities and advantages for society as a whole [130,131].

In this context, product design plays a fundamental role. Companies are adopting design approaches that minimize the amount of natural resources needed to manufacture electronic devices. This involves the selection of materials with the lowest environmental impact, as well as the modular design that allows for easy repair and upgrade of components. Durability and ease of disassembly are seen as crucial aspects to ensure that technological products have a longer service life and are easier to recycle at the end of their useful life [132, 133].

Moreover, instead of discarding electronic devices entirely, the circular economy promotes the recovery and refurbishment of valuable components. This includes removing circuit boards, displays, batteries, and other components for reuse in new products or to repair existing devices. These "disassembly and recycling" processes reduce the need to extract new natural resources and decrease the amount of e-waste. It also translates into more responsible management of e-waste. Companies and organizations work together to establish proper collection and recycling systems, ensuring that discarded electronic devices are safely recycled and valuable materials are recovered. In addition, awareness is encouraged among consumers to deliver their obsolete devices to suitable collection points, rather than disposing of them inappropriately [134].

In short, EC in technology is based on a holistic approach ranging from sustainable product design to responsible e-waste management. This approach seeks to transform the technology industry into one that is more environmentally friendly, promoting efficiency in the use of resources and minimizing the negative impact on the planet [135-137].

In a global context marked by growing concern for environmental sustainability and the need to make more efficient use of natural resources, agriculture has also emerged as fertile ground for the implementation of EC principles [138, 139]. Agriculture, as the backbone of our food security and a major player in land and water use, is in a key position to adopt strategies that minimize waste, optimize resource management and reduce environmental impact [140]. In this context, we will explore how the EC is transforming agriculture, promoting innovative practices that go beyond traditional production and contribute to more sustainable and environmentally friendly agricultural production [141].

One of the main pillars of the EC in agriculture is the efficient management of agricultural waste. Instead of considering crop remains, such as stems and leaves, as waste, strategies are being implemented to turn them into valuable resources. This involves composting organic materials to produce natural manure, converting agricultural waste into biogas or bioenergy, and reusing nutrients extracted from crops in the form of organic fertilizers. This intelligent management of agricultural residues not only reduces pollution and waste, but also improves soil quality and reduces dependence on chemical fertilizers [142].

It also encompasses the use of advanced technologies to optimize production and resource use. Precision agriculture, which includes data farming and the use of sensors, enables farmers to make more informed decisions about planting, irrigation, and fertilizer application [138]. This reduces the excessive use of resources, such as water and chemicals, while increasing production efficiency. In addition, the adoption of practices such as vertical farming and aquaponics contribute to the circular economy by using space and resources more efficiently and sustainably [143].

Another important facet in agriculture is the promotion of short supply circuits, which involve reducing the distance between producer and consumer. These more local distribution systems reduce the need for long-distance transportation, which decreases carbon emissions and food waste [144]. In addition, they promote greater transparency in the supply chain and a more direct connection between farmers and consumers, which can increase demand for fresh and seasonal produce [145].

In this sense, the EC in agriculture focuses on optimizing the use of resources, reducing waste and promoting more sustainable practices throughout the food chain, from production to consumption. These strategies not only have environmental benefits, but can also improve the productivity and profitability of agriculture in the long run [146, 147].

Meanwhile, in fashion, an industry known for its speed and focus on ephemeral trends is undergoing a fundamental transformation in its approach thanks to the EC encouraging the production and consumption of sustainable garments, along with reuse through second-hand purchase and textile recycling (148). This revolutionary approach seeks to change the way we conceive, produce and consume clothing, encouraging sustainability, reuse and waste reduction along the entire fashion value chain [149-151].

Sustainable design has become the essential starting point. Designers are taking a conscious approach that considers the durability of garments and the choice of environmentally friendly materials [152]. This involves the use of recycled, organic and sustainable fabrics, as well as the incorporation of features that facilitate the reuse and recycling of garments [153, 154].

One of the main pillars of the EC in fashion is the recycling and reuse of garments. Instead of discarding used clothes, companies are promoting the collection and recycling of garments, as well as the transformation of old garments into new ones through *"upcycling"* [155]. Not only does this reduce the amount of clothing sent to landfill, but it also encourages a longer life cycle for clothing [156-158].

CE in fashion not only involves the industry, but also consumers. Through awareness and education campaigns, a more conscious and responsible consumption mentality is being promoted. Consumers are being encouraged to take care of their garments, shop thoughtfully, and consider sustainable options, which is contributing to changing attitudes towards disposable fashion [159-161]. Fashion is revolutionizing the industry by focusing on sustainability, reuse and waste reduction, making it a driver of positive change towards more environmentally and socially responsible fashion [106, 162-164].

*Corresponding author email:bernabe.rivas@uss.cl

These examples represent only part of how the EC is becoming a key approach to addressing environmental and economic challenges in a variety of sectors. As we move towards a more sustainable and prosperous future, the circular economy stands as a fundamental pillar to drive innovation [75], reduce waste and maximize the value of our limited resources.

2. POLICIES AND REGULATIONS

The circular economy, as a systematic approach aimed at minimizing the extraction of natural resources, reducing waste and encouraging the reuse and recycling of materials, has gained increasing prominence on the global agenda in response to growing concerns about environmental sustainability and the need to address challenges related to climate change and natural resource degradation. In this context, policies and regulations play a critical role in the promotion and implementation of the EC. These government measures and regulatory frameworks have evolved to reflect the growing urgency of the transition to a more sustainable and resource-efficient economy, and have encompassed a wide variety of economic sectors and activities (165, 166). This transition is a priority objective worldwide, and as a result, policies and regulations play an essential role in promoting this transformation, seeking to reduce waste, reuse resources and minimize environmental impact, across industries and sectors [167], seeking to reduce waste, reuse resources, and minimize environmental impact, in all industries and sectors [167].

In many jurisdictions, specific laws and regulations have been put in place to address waste management and encourage recycling. These policies set recycling goals, promote waste separation at source, and establish guidelines for the proper handling of end-of-life products. In addition, some regions have implemented extended producer responsibility (EPR) programs, which require manufacturers to be responsible for managing the products they put on the market, even after consumer use [166, 168].

Some examples of waste legislation and policies related to the EC are the European Union (EU) Packaging Waste Directive, where recycling targets are set for different types of packaging, such as plastic, glass and paper, and promotes waste minimization by encouraging the reuse and recycling of packaging. It also imposes responsibilities on packaging producers to ensure proper packaging management [169]. The Extended Producer Responsibility Act (EPR) in Canada, where they state that manufacturers are responsible for the proper management of the products they put on the market, even after consumers discard them. For example, Ontario's EPR Act covers electronics, appliances, packaging and other products [170]. Some examples of waste legislation and policies related to the EC are the European Union (EU) Packaging Waste Directive, where recycling targets are set for different types of packaging, such as plastic, glass and paper, and promotes waste minimization by encouraging the reuse and recycling of packaging. It also imposes responsibilities on packaging producers to ensure proper packaging management [169].

Likewise, the Electronic Products Recycling Act in the United States, where cities like California and New York have enacted specific laws to manage electronic products at the end of their useful life. These laws require manufacturers to establish electronic collection and recycling programs, thereby encouraging the reuse of components and the recovery of valuable materials [171, 172]. The Waste Electrical and Electronic Equipment (WEEE) Directive, as well as the US recycling law establishes specific requirements for the management of electronic waste in the European Union. It obliges manufacturers to assume financial responsibility for the proper management of WEEE, promoting the recovery of materials and the minimization of environmental and health risks [173].

On the other hand, the ENERGY STAR Environmental Labeling program in the United States awards environmental labels to products that meet established energy efficiency standards. This allows consumers to identify products that are more energy efficient, thus encouraging the purchase of more sustainable devices [174]. The National Solid Waste Management Policy in India has implemented guidelines for proper solid waste management and promotes source segregation and selective waste collection, with the aim of reducing the amount of waste sent to landfill and encouraging reuse and recycling [175].
Several countries in Latin America are implementing policies and regulations oriented towards EC and sustainable waste management such as the REP (Extended Producer Responsibility) Law in Chile implemented in 2016, which establishes the responsibility of producers in the management of waste of priority products, such as packaging and electronic products. This legislation seeks to encourage reuse and recycling, and has led to the creation of producer-funded collection and recycling systems [176]. In the city of Buenos Aires, the Zero Waste Program has been implemented, which aims to reduce the amount of waste sent to landfills and promote the selective collection of recyclable materials. This initiative includes the promotion of composting, material recovery, and reuse [177].

Brazil approved the National Solid Waste Policy in 2010, which establishes guidelines for proper waste management and promotes the circular economy. The Act includes provisions on e-waste management and shared responsibility between manufacturers, importers and distributors for the management of end-of-life products [178]. While Colombia has launched a Circular Economy Program that seeks to promote sustainability and efficient resource management in various sectors, including waste management. This program aims to reduce waste generation, encourage recycling and support the transition towards a more circular economy [179]. These examples illustrate how circular economy legislation and policies can address a variety of products and sectors, setting recycling goals, producer responsibilities and requirements for proper waste management, all with the aim of promoting sustainability and reducing environmental impact.

Ecodesign policies seek to encourage manufacturers to produce more sustainable products from the outset. These regulations establish environmental and energy efficiency criteria for products, which encourages resource reduction and durability, this coupled with environmental labeling, such as ecolabels, helps consumers make informed decisions when identifying products that meet certain sustainability standards [180]. Some governments have introduced taxes on pollution and natural resources, while offering subsidies and tax breaks to companies that adopt more sustainable practices. These economic mechanisms aim to encourage the adoption of more environmentally friendly processes and products. At the regional level, the European Union has been a pioneer in the implementation of ambitious circular policies, such as the Circular Economy Action Plan. At the global level, the Paris Agreement on climate change and the United Nations Sustainable Development Goals also include aspects related to the EC, promoting international cooperation in this area [181,182].

In summary, circular economy policies and regulations are fundamental to drive the transition towards a more sustainable and responsible economic model. These governmental measures and international agreements play a crucial role in promoting business and consumer practices that reduce waste, encourage reuse and minimize environmental impact [183].

3. CHALLENGES AND BARRIERS

Different classifications have been reported on issues of barriers to the implementation of the EC, one of these being hard factors, covering technical and economic, and soft, institutional and social [184]. Other authors have classified barriers into four levels corresponding to institutional market, value chain, organization and employee levels [185]. The classification of the five categories includes economic, structural, operational, attitudinal, and technological [186, 187].

These barriers can be found in different sectors, one of them is in the construction sector where there is lack of commercial subsidies [188-190], lack of financial aid [191,194], lack of research, education and information [188, 195], lack of strategic vision and collaboration platforms [196, 197] lack of regulatory instruments [198], lack of fiscal actions [199], lack of circular vision lack of integrated CDW processes, tools and practices [200], lack of an information management system (201). We can also find economic barriers, since the lack of a group of subsidies is related to the lack of market investments, in addition to the lack of marketing strategies for the reinsertion of secondary materials.

Among other important barriers, we find the information barriers, where the lack of awareness, knowledge and dissemination of information have generated a strong barrier to the implementation of the EC institutional (202), which focus mainly on cultural barriers associated with slow generation and implementation of changes and supply lines (189), policies, in which the lack of legislative regulations have led to failures in issues of integrated management), as well as the lack of groups with a circular economy vision are lack of government funding for research, innovation, development and investment (196). The lack of information management systems is closely related to the availability and transparency of data and processes in general (203).

In general, a circular plan could be obtained that allows intersectorial integration, where solutions to face and overcome existing challenges and barriers range from the impartiality of governments, working together with academic and business institutions, as well as the allocation and reallocation of funds to sustainable solutions.

However, the main challenges and barriers are classified into 10 aspects:
1. Cultural change: it is established as one of the greatest challenges in CE issues from the social and business point of view, since the linear form of operation is the one that has predominated until now [204]. As already mentioned, the EC requires a transition towards valuing reuse and recycling rather than common practices of disposing of different products [205].

2. Initial investment: the adoption of practices and technologies based on the EC can mean different significant investments from public or private companies, which can mean a great barrier especially for those that are small and medium-sized (206).

3. Rules and regulations: the current regulations, in the different countries, do not allow a favoring towards the circular economy. These laws should be adapted to promote the reuse and recycling of products (207).

4. Complexity in the supply chain: the reconfiguration of the supply chain is a crucial point because the implementation of the EC in them may require significant changes in everything related to logistics and management [208, 209].

5. Lack of adequate infrastructure: for the adoption of recycling and reuse processes, adequate infrastructure is necessary, such as recycling plants and complete and selective collection systems, where it has been seen that many countries have already begun to implement them, however, due to their high costs it is being seen as a major obstacle for the EC.

6. Product design and planned obsolescence: many of the products on the market are designed to have a limited useful life or with components that are not easy to repair or recycle [210], however, planned obsolescence must be worked on in order to give the products a longer life, and thus avoid greater production and disposal of articles [211].

7. Education and public awareness: this aspect is fundamental in terms of the benefits we can acquire from the EC. However, a lack of public understanding and support is creating significant barriers. Currently, knowledge of sustainable design or purely of the EC is not mandatory within the profession [212]. The importance of CE education must be integrated into curricula so that students can understand and recognize that these principles are fundamental for better development. Some examples are the design of the longevity of products, where these can be repaired and updated. Design of materials to reduce environmental impact and increase working efficiency [213].

8. Access to financing: at this point, companies wishing to implement CE practices may be hampered by poor access to finance as investors may be limited to new initiatives [214, 215].

9. Uncertainty about profitability: in the absence of a policy to incentivize EC or education in this regard, companies may be reluctant to adopt new practices since the perception may be less profitable in the short term [216], without considering that the implementation of this model can generate long-term savings as well as a wide variety of competitive advantages [217].

10. Complexity of materials and products: many of the materials and products are difficult to recycle and/or reuse or suitable technologies do not exist, limiting the applicability of the EC in a wide variety of industries [218,219].

4. Polymers in the Circular Economy

In the EC context, polymer recycling plays a key role in the transition to a more sustainable economy. A prominent example of polymer recycling is PET (polyethylene terephthalate) used in beverage packaging. These plastic bottles are collected, washed, shredded, and melted to produce recycled PET granules, which are then used to make new bottles, textile fibres, and other products [220]. This process reduces the demand for virgin raw materials and decreases the amount of plastic waste in landfills and oceans [221].

Another example is the recycling of polypropylene (PP), a widely used polymer that recycled is used in the manufacture of automotive components, such as bumpers and interior panels, coatings, among others, which reduces the resource consumption and carbon footprint of the automotive and construction industry [106]. In the field of fashion, the recycling of polyester makes it possible to convert used plastic bottles into textile fibers. This decreases pressure on natural resources and helps address the problem of textile waste in the fashion industry [217].

These examples illustrate how polymer recycling has a positive impact on a wide range of industries, from packaging and automotive to construction and fashion. However, this process goes beyond the mere reuse of existing plastic materials. It also involves the constant search for innovative approaches to improve the properties of recycled polymers. An outstanding strategy in this regard is the integration of natural polymers, such as cellulose, chitosan and starch, in the composition of these recycled materials [Figure 3], [222,224]. Synergy between the circular economy and the incorporation of natural polymers not only reduces the consumption of natural resources and minimizes waste generation, but also offers exciting opportunities to improve the sustainability and performance of final products in a wide range of industrial applications this due to the characteristics of these polymers such as their high abundance, biocompatibility, versatility for different types of reactions, high biodegradability, which allow obtaining a wide variety of materials [225].

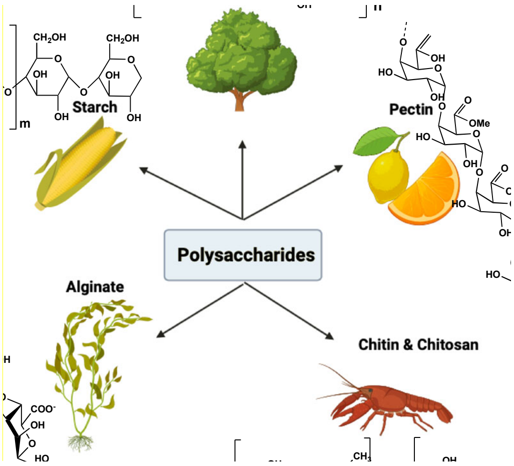
For example, in the packaging industry, the trend has been adopted to combine recycled polymers with natural polymers such as cellulose. This not only reduces the amount of virgin plastic used in packaging, but also improves the biodegradability and mechanical strength of the resulting products. Cellulose films coated with recycled polymers offer an excellent barrier against moisture and oxygen, making them ideal for food packaging [226-228].
In construction, recycled polymers mixed with cornstarch are being used to create more sustainable building materials. Made from recycled polymers and starch, composite boards are strong, lightweight and biodegradable, making them an attractive option for furniture and structural element manufacturing [22,230].

In fashion, the combination of recycled polymers with natural fibers such as organic cotton or hemp is being explored. This not only reduces reliance on virgin synthetic fibres, but also results in more environmentally friendly and comfortable garments for sustainability-conscious consumers [231].

*Corresponding author email:bernabe.rivas@uss.cl

Another of the materials that are beginning to be used in the agricultural and environmental remediation area are artificial polymer hydrogels from cellulose like carboxymethylcellulose, since their active groups are available along the polymer chain [232], allowing hydrogels like poly (2-hydroxyethyl-metha-crylate (PHEMA) to be set aside, polyacrylamide (PA), polyethylene glycol (PEG), and polyvinyl alcohol (PVA) [223,224]. The carboxy-methylcellulose hydrogels have a wide range of uses, where the most prominent are in the agricultural area to help preserve the quality of fruits and vegetables, remediation of agricultural soils, preserve water sources and encapsulation of bioactive molecules [226].

Figure 3. Natural polymers most abundant in nature with potential use as materials.



Another of its applications is in the medical area where it is used to prevent the reappearance of tumors. Thus carboxymethylcellulose-based hydrogels have been used to transport drugs and prevent the recurrence of postoperative tumors [232]. In general, materials based on "green polymers" help prevent and partially reduce waste and contribute to more sustainable life cycles and a lower carbon footprint [235].

These examples highlight how the introduction of natural polymers into the recycled polymer matrix can improve the properties of final products, while promoting sustainability in various industries. This synergy between recycled and natural materials represents an innovative strategy to address environmental challenges and maximize the value of polymers in the circular economy [236].

5. CONCLUSIONS

The circular economy represents an essential and promising approach to addressing the economic and environmental challenges of our time. By following the principles of resource reduction, reuse and recycling, we can achieve greater efficiency in the use of natural resources, reduce negative impacts on the environment and at the same time generate significant economic benefits. The sectors of application are diverse and policies and regulations play a fundamental role in their promotion.

Although there are challenges and barriers on the way to a fully implemented circular economy, the examples demonstrate that it is possible and beneficial for businesses, society and the planet. By embracing this approach and working together to overcome obstacles, we can move towards a more sustainable and equitable future, where the life cycle of products and resources is managed responsibly, thus contributing to a more sustainable and resilient world.

Recycled polymers and natural polymers become fundamental pillars of this transition towards a more sustainable economic model. Recycled polymers extend the life of existing plastic materials, reducing the need to extract finite natural resources and minimizing the accumulation of plastic waste. At the same time, natural polymers offer eco-friendly alternatives to synthetic polymers, contributing to the sustainability and biocompatibility of final products.

In summary, the importance of polymers in the circular economy lies in their ability to optimize the use of resources, reduce waste generation and promote sustainability in various sectors. These materials are not only essential components of the circular economy, but are also concrete examples of how adopting this approach can be beneficial for businesses, societies and the natural environment. Thus, the responsible management of polymers becomes a crucial factor to move towards a more equitable, resilient and sustainable world, where the circular economy is the norm.

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REFERENCES

1. Di Vaio A, Hasan S, Palladino R, Hassan R. The transition towards circular economy and waste within accounting and accountability models: a systematic literature review and conceptual framework. *Environment, Development and Sustainability*. 2023;25(1):734-810.
2. Mies A, Gold S. Mapping the social dimension of the circular economy. *Journal of Cleaner Production.* 2021;321:128960.
3. MacArthur E. Towards the circular economy. *Journal of Industrial Ecology*. 2013;2(1):23-44.
4. Akhimien NG, Latif E, Hou SS. Application of circular economy principles in buildings: A systematic review. *Journal of Building Engineering*. 2021;38:102041.
5. Rahman MM, Yap YH, Ramli N, Dullah M, Shamsuddin M, editors. Causes of shortage and delay in material supply: a preliminary study. *IOP Conference Series: Materials Science and Engineering*; 2017.
6. Müller LJ, Kätelhön A, Bringezu S, McCoy S, Suh S, Edwards R, et al. The carbon footprint of the carbon feedstock CO 2. *Energy & Environmental Science*. 2020;13(9):2979-92.
7. Velenturf AP, Purnell P. Resource recovery from waste: Restoring the balance between resource scarcity and waste overload. *Sustainability*. 2017;9(9):1603.
8. Busu M, Trica CL. Sustainability of Circular Economy Indicators and Their Impact on Economic Growth of the European Union. Sustainability. 2019;11(19):5481.
9. Hysa E, Kruja A, Rehman NU, Laurenti R. Circular Economy Innovation and Environmental Sustainability Impact on Economic Growth: An Integrated Model for Sustainable Development. *Sustainability*. 2020;12(12):4831.
10. Chen Z, Chen S, Liu C, Nguyen LT, Hasan A. The effects of circular economy on economic growth: A quasi-natural experiment in China. *Journal of Cleaner Production.* 2020; 271:122558.
11. Braungart M, McDonough W. Cradle to cradle: Random House; 2009.
12. George DAR, Lin BC-a, Chen Y. A circular economy model of economic growth. Environmental Modelling & Software. 2015;73:60-3.
13. Souza Piao R, de Vincenzi TB, da Silva ALF, de Oliveira MCC, Vazquez-Brust D, Monteiro Carvalho M. How is the circular economy embracing social inclusion? *Journal of Cleaner Production*. 2023;411:137340.
14. Luthin A, Traverso M, Crawford RH. Assessing the social life cycle impacts of circular economy. Journal of Cleaner Production. 2023; 386:135725.
15. McDonough W, Braungart M. Cradle to cradle: Remaking the way we make things: North point press; 2010.

16. Mumladze T, Sleiniute A, Denafas G, editors. The possibility of recycling of multilayer packaging waste: Reducing Environmental impacts. Proceedings of the 16th International Conference on Environmental Science and Technology, *Rhodes,* Greece; 2019.
17. MacArthur DE, Waughray D, Stuchtey MR, editors. The new plastics economy, rethinking the future of plastics. World Economic Forum; 2016: Ellen MacArthur Foundation and McKinsey & Company London, UK.
18. Collias DI, James MI, Layman JM. Introduction—Circular Economy of Polymers and Recycling Technologies. Circular Economy of Polymers: Topics in Recycling Technologies. ACS Symposium Series. 1391: *American Chemical Society*; 2021.
19. Gandini A, Lacerda TM, Carvalho AJF, Trovatti E. Progress of Polymers from Renewable Resources: Furans, Vegetable Oils, and Polysaccharides. *Chemical Reviews.* 2016;116(3):1637-69.
20. Hinsken H, Moss S, Pauquet J-R, Zweifel H. Degradation of polyolefins during melt processing. *Polymer degradation and stability.* 1991;34(1-3):279-93.
21. Aranda FL, Rivas BL. Microplastics: formation, disposition, and associated dangers. An overview. *Journal of the Chilean Chemical Society*. 2023; 68:5755-61.
22. Sharma S, Bhardwaj A, Thakur M, Saini A. Understanding microplastic pollution of marine ecosystem: a review. *Environmental Science and Pollution Research.* 2023:1-44.
23. Voicu SI, Thakur VK. Green polymers-based membranes for water reuse in a circular economy context. *Current Opinion in Green and Sustainable Chemistry.* 2023;43:100852.
24. Hussain A, Podgursky V, Viljus M, Awan MR. The role of paradigms and technical strategies for implementation of the circular economy in the polymer and composite recycling industries. *Advanced Industrial and Engineering Polymer Research.* 2023;6(1):1-12.
25. Neto RT, Santos SAO, Oliveira J, Silvestre AJD. Biorefinery of high polymerization degree proanthocyanidins in the context of circular economy. *Industrial Crops and Products.* 2020;151:112450.
26. Braskem offers bio-based polymers to promote the circular economy. *Focus on Catalysts.* 2019;2019(7):5.
27. Asif I, Rafique U. Synthesis & fabrication of O-linked polymeric hybrids for recovery of textile dyes: Closed loop economy. *Environmental Research*. 2023;236:116780.
28. Bardoquillo EIM, Firman JMB, Montecastro DB, Basilio AM. Chemical recycling of waste polyethylene terephthalate (PET) bottles via recovery and polymerization of terephthalic acid (TPA) and ethylene glycol (EG). *Materials Today: Proceedings*. 2023.
29. Gupta RK, Guha P, Srivastav PP. Natural polymers in bio-degradable/edible film: A review on environmental concerns, cold plasma technology and nanotechnology application on food packaging- A recent trends. *Food Chemistry Advances.* 2022;1:100135.
30. Erdiaw-Kwasie MO, Abunyewah M, Yusif S, Erdiaw-Kwasie A. Does circular economy knowledge matter in sustainable service provision? A moderation analysis. *Journal of Cleaner Production.* 2023;383:135429.
31. Webster K. The circular economy: A wealth of flows. (No Title). 2015.
32. Hailemariam A, Erdiaw-Kwasie MO. Towards a circular economy: Implications for emission reduction and environmental sustainability. *Business Strategy and the Environment*. 2023;32(4):1951-65.
33. Field JM, Fotheringham D, Subramony M, Gustafsson A, Ostrom AL, Lemon KN, et al. Service research priorities: designing sustainable service ecosystems*. Journal of Service Research.* 2021;24(4):462-79.
34. Tukker A. Product services for a resource-efficient and circular economy–a review*. Journal of cleaner production.* 2015;97:76-91.
35. Aranda-Usón A, Portillo-Tarragona P, Scarpellini S, Llena-Macarulla F. The progressive adoption of a circular economy by businesses for cleaner production: An approach from a regional study in Spain. *Journal of Cleaner Production.* 2020;247:119648.
36. Rosa P, Sassanelli C, Terzi S. Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes. *Journal of cleaner production.* 2019;236:117696.
37. Urbinati A, Rosa P, Sassanelli C, Chiaroni D, Terzi S. Circular business models in the European manufacturing industry: A multiple case study analysis. *Journal of cleaner production.* 2020;274:122964.
38. Fuchs M, Hovemann G. The circular economy concept in the outdoor sporting goods industry: challenges and enablers of current practices among brands and retailers. *Sustainability.* 2022;14(13):7771.
39. Kokkinomagoulos E, Kandylis P. Grape pomace, an undervalued by-product: industrial reutilization within a circular economy vision. *Reviews in Environmental Science and Bio/Technology.* 2023:1-35.
40. Zhu Z, Liu W, Ye S, Batista L. Packaging design for the circular economy: A systematic review. *Sustainable production and consumption*. 2022;32:817-32.
41. Donaghy KP. A circular economy model of economic growth with circular and cumulative causation and trade. *Networks and Spatial Economics*. 2022;22(3):461-88.
42. Dey PK, Malesios C, Chowdhury S, Saha K, Budhwar P, De D. Adoption of circular economy practices in small and medium-sized enterprises: Evidence from Europe. *International Journal of Production Economics*. 2022;248:108496.
43. Kalita NK, Hakkarainen M. Integrating biodegradable polyesters in a circular economy. *Current Opinion in Green and Sustainable Chemistry.* 2022:100751.
44. Prajapati D, Zhou F, Dwivedi A, Singh T, Lakshay L, Pratap S. Sustainable agro-food supply chain in e-commerce: Towards the circular economy. *Sustainability.* 2022;14(14):8698.
45. Köhler J, Sönnichsen SD, Beske-Jansen P. Towards a collaboration framework for circular economy: The role of dynamic capabilities and open innovation. *Business Strategy and the Environment. 2022*;31(6):2700-13.
46. Khan SAR, Razzaq A, Yu Z, Miller S. Industry 4.0 and circular economy practices: A new era business strategies for environmental sustainability. *Business Strategy and the Environment.* 2021;30(8):4001-14.
47. Sehnem S, de Queiroz AAFS, Pereira SCF, dos Santos Correia G, Kuzma E. Circular economy and innovation: A look from the perspective of organizational capabilities. *Business Strategy and the Environment*. 2022;31(1):236-50.
48. Kennedy S, Linnenluecke MK. Circular economy and resilience: A research agenda. *Business Strategy and the Environment*. 2022;31(6):2754-65.
49. Fontana A, Barni A, Leone D, Spirito M, Tringale A, Ferraris M, et al. Circular economy strategies for equipment lifetime extension: A systematic review. *Sustainability.* 2021;13(3):1117.
50. Milios L. Overarching policy framework for product life extension in a circular economy—A bottom-up business perspective. *Environmental Policy and Governance*. 2021;31(4):330-46.
51. Ertz M, Leblanc-Proulx S, Sarigöllü E, Morin V. Advancing quantitative rigor in the circular economy literature: New methodology for product lifetime extension business models. *Resources, conservation and recycling*. 2019;150:104437.
52. Roleders V, Oriekhova T, Zaharieva G. Circular Economy as a Model of Achieving Sustainable Development. *Problemy Ekorozwoju*. 2022;17(2).
53. Kristensen HS, Mosgaard MA. A review of micro level indicators for a circular economy–moving away from the three dimensions of sustainability? *Journal of Cleaner Production.* 2020;243:118531.
54. Haupt M, Hellweg S. Measuring the environmental sustainability of a circular economy. *Environmental and Sustainability Indicators.* 2019;1:100005.
55. Stenton M, Houghton JA, Kapsali V, Blackburn RS. The potential for regenerated protein fibres within a circular economy: Lessons from the past can inform sustainable innovation in the textiles industry*. Sustainability*. 2021;13(4):2328.
56. Horbach J, Rennings K, Sommerfeld K, editors. *Circular economy and employment*. 3rd IZA Workshop: Labor Market Effects of Environmental Policies; 2015.
57. Horbach J, Rammer C. Circular economy innovations, growth and employment at the firm level: Empirical evidence from Germany. *Journal of industrial ecology.* 2020;24(3):615-25.
58. Chojnacka K, Moustakas K, Witek-Krowiak A. Bio-based fertilizers: A practical approach towards circular economy. *Bioresource Technology*. 2020;295:122223.
59. Mutezo G, Mulopo J. A review of Africa's transition from fossil fuels to renewable energy using circular economy principles. *Renewable and Sustainable Energy Reviews.* 2021;137:110609.
60. Testa F, Iovino R, Iraldo F. The circular economy and consumer behaviour: The mediating role of information seeking in buying circular packaging. *Business Strategy and the Environment*. 2020;29(8):3435-48.
61. Leipold S, Weldner K, Hohl M. Do we need a 'circular society'? Competing narratives of the circular economy in the French food sector. *Ecological Economics.* 2021;187:107086.

**Corresponding author email:bernabe.rivas@uss.cl*

62. Mignacca B, Locatelli G, Velenturf A. Modularisation as enabler of circular economy in energy infrastructure. *Energy Policy.* 2020;139:111371.
63. Pactwa K, Konieczna-Fuławka M, Fuławka K, Aro P, Jaśkiewicz-Proć I, Kozłowska-Woszczycka A. Second life of post-mining infrastructure in light of the circular economy and sustainable development—recent advances and perspectives. *Energies.* 2021;14(22):7551.
64. Valenzuela F, Böhm S. Against wasted politics: A critique of the circular economy. *Ephemera: theory & politics in organization*. 2017;17 (1):23-60.
65. Geissdoerfer M, Savaget P, Bocken NM, Hultink EJ. The Circular Economy–A new sustainability paradigm? *Journal of cleaner production.* 2017;143:757-68.
66. Lüdeke-Freund F, Gold S, Bocken NM. A review and typology of circular economy business model patterns. *Journal of Industrial Ecology.* 2019;23(1):36-61.
67. Kuzior A, Arefiev S, Poberezhna Z. Informatization of innovative technologies for ensuring macroeconomic trends in the conditions of a circular economy. *Journal of Open Innovation: Technology, Market, and Complexity.* 2023;9(1):100001.
68. Sheth RP, Ranawat NS, Chakraborty A, Mishra RP, Khandelwal M. The Lithium-Ion Battery Recycling Process from a Circular Economy Perspective—A Review and Future Directions. *Energies.* 2023;16(7):3228.
69. Mihai F-C, Plana R, Arizmendiarrieta JS, Irigoyen I. Business models of composting for a circular economy. Current Developments in Biotechnology and Bioengineering: *Elsevier;* 2023.
70. Chamorro F, Carpena M, Fraga-Corral M, Echave J, Riaz Rajoka MS, Barba FJ, et al. Valorization of kiwi agricultural waste and industry by-products by recovering bioactive compounds and applications as food additives: A circular economy model. *Food Chemistry.* 2022;370:131315.
71. Bernardo M, Lapa N, Pinto F, Nogueira M, Matos I, Ventura M, et al. Valorisation of spent tire rubber as carbon adsorbents for Pb (II) and W (VI) in the framework of a Circular Economy. *Environmental Science and Pollution Research.* 2023:1-18.
72. Valencia M, Solíz MF, Yépez M. Waste picking as social provisioning: the case for a fair transition to a circular economy. *Journal of Cleaner Production.* 2023;398:136646.
73. Caruso G. Fishery wastes and by-products: A resource to be valorised. *J Fish Sci.* 2015;9(4):080-3.
74. Cooney R, de Sousa DB, Fernández-Ríos A, Mellett S, Rowan N, Morse AP, et al. A circular economy framework for seafood waste valorisation to meet challenges and opportunities for intensive production and sustainability. *Journal of Cleaner Production.* 2023;392:136283.
75. Jesus GMK, Jugend D. How can open innovation contribute to circular economy adoption? Insights from a literature review. *European Journal of Innovation Management*. 2023;26(1):65-98.
76. Rudan E. Circular Economy of Cultural Heritage—Possibility to Create a New Tourism Product through Adaptive Reuse. *Journal of Risk and Financial Management.* 2023;16(3):196.
77. Khan K, Khurshid A. Are technology innovation and circular economy remedy for emissions? Evidence from the Netherlands. *Environment, Development and Sustainability.* 2022:1-15.
78. Reuter MA. Digitalizing the circular economy: Circular economy engineering defined by the metallurgical internet of things. *Metallurgical and Materials transactions B.* 2016;47:3194-220.
79. Dyer M, Wu S, Weng M-H. Convergence of public participation, participatory design and NLP to co-develop circular economy. *Circular Economy and Sustainability. 2021*;1:917-34.
80. Ahmed Z, Mahmud S, Acet H. Circular economy model for developing countries: evidence from Bangladesh. *Heliyon.* 2022.
81. Marsh AT, Velenturf AP, Bernal SA. Circular Economy strategies for concrete: implementation and integration. *Journal of Cleaner Production.* 2022;362:132486.
82. Tavera Romero CA, Castro DF, Ortiz JH, Khalaf OI, Vargas MA. Synergy between circular economy and industry 4.0: A literature review. *Sustainability.* 2021;13(8):4331.
83. Morales ME, Batlles-delaFuente A, Cortés-García FJ, Belmonte-Ureña LJ. Theoretical research on circular economy and sustainability trade-offs and synergies. *Sustainability.* 2021;13(21):11636.
84. Geipele I, Plotka K, Wirzhbitskis Y, Zvirgzdins J, editors. *The Synergy in Circular Economy.* 2018.
85. Yang M, Chen L, Wang J, Msigwa G, Osman AI, Fawzy S, et al. Circular economy strategies for combating climate change and other environmentalissues. Environmental Chemistry Letters. 2023;21(1):55-80.
86. Dantas TET, de-Souza ED, Destro IR, Hammes G, Rodriguez CMT, Soares SR. How the combination of Circular Economy and Industry 4.0 can contribute towards achieving the Sustainable Development Goals. *Sustainable Production and Consumption.* 2021;26:213-27.
87. Rincón-Moreno J, Ormazábal M, Álvarez M, Jaca C. Advancing circular economy performance indicators and their application in Spanish companies. *Journal of Cleaner Production.* 2021;279:123605.
88. Shen K-w, Li L, Wang J-Q. Circular economy model for recycling waste resources under government participation: a case study in industrial waste water circulation in China. *Technological and Economic Development of Economy.* 2020;26(1):21-47.
89. Nikolaou IE, Jones N, Stefanakis A. Circular economy and sustainability: the past, the present and the future directions. *Circular Economy and Sustainability.* 2021;1:1-20.
90. Macarthur E, heading H. How the circular economy tackles climate change. *Ellen MacArthur Found.* 2019;1:1-71.
91. Durán-Romero G, López AM, Beliaeva T, Ferasso M, Garonne C, Jones P. Bridging the gap between circular economy and climate change mitigation policies through eco-innovations and Quintuple Helix Model. *Technological Forecasting and Social Change.* 2020;160:120246.
92. Fawzy S, Osman AI, Yang H, Doran J, Rooney DW. Industrial biochar systems for atmospheric carbon removal: a review. *Environmental Chemistry Letters.* 2021;19:3023-55.
93. Sarfraz M, Ivascu L, Artene AE, Bobitan N, Dumitrescu D, Bogdan O, et al. The relationship between firms' financial performance and performance measures of circular economy sustainability: an investigation of the G7 countries. *Economic Research-Ekonomska Istraživanja.* 2023;36(1): 2101019.
94. Gupta S, Chen H, Hazen BT, Kaur S, Gonzalez EDS. Circular economy and big data analytics: A stakeholder perspective. *Technological Forecasting and Social Change.* 2019;144:466-74.
95. Deng S, Kpodzro E, Maani T, Li Z, Huang A, Yih Y, et al. Planning a circular economy system for electric vehicles using network simulation. *Journal of Manufacturing Systems.* 2022;63:95-106.
96. da Silva ER, Lohmer J, Rohla M, Angelis J. Unleashing the circular economy in the electric vehicle battery supply chain: A case study on data sharing and blockchain potential. *Resources, Conservation and Recycling*. 2023;193:106969.
97. Garcia LV, Ho Y-C, Myo Thant MM, Han DS, Lim JW. Lithium in a sustainable circular economy: A comprehensive review. *Processes.* 2023;11(2):418.
98. Su B, Heshmati A, Geng Y, Yu X. A review of the circular economy in China: moving from rhetoric to implementation. *Journal of cleaner production.* 2013;42:215-27.
99. Zhijun F, Nailing Y. Putting a circular economy into practice in China. *Sustainability Science.* 2007;2(1):95-101.
100. Park J, Sarkis J, Wu Z. Creating integrated business and environmental value within the context of China's circular economy and ecological modernization. *Journal of Cleaner Production.* 2010;18(15):1494-501.
101. Kumar V, Sezersan I, Garza-Reyes JA, Gonzalez ED, Al-Shboul MdA. Circular economy in the manufacturing sector: benefits, opportunities and barriers. *Management Decision.* 2019;57(4):1067-86.
102. Bhatia MS, Srivastava RK, Jakhar SK, Kumar S. What's critical for closed-loop supply chain operations? Findings from the Indian small and medium manufacturing enterprises. *Journal of Cleaner Production.* 2022;372: 133791.
103. Suhandi V, Chen P-S. Closed-loop supply chain inventory model in the pharmaceutical industry toward a circular economy. *Journal of Cleaner Production.* 2023;383:135474.
104. Okorie O, Russell J, Cherrington R, Fisher O, Charnley F. Digital transformation and the circular economy: Creating a competitive advantage from the transition towards Net Zero Manufacturing. *Resources, Conservation and Recycling.* 2023;189:106756.
105. Bag S, Gupta S, Foropon C. Examining the role of dynamic remanufacturing capability on supply chain resilience in circular economy. *Management Decision.* 2019;57(4):863-85.
106. James AT, Kumar G, James J, Asjad M. Development of a micro-level circular economy performance measurement framework for automobile maintenance garages. *Journal of Cleaner Production*. 2023;417:138025.

107. Ahmad F, Bask A, Laari S, Robinson CV. Business management perspectives on the circular economy: Present state and future directions. *Technological Forecasting and Social Change.* 2023;187:122182.
108. Singhal D, Tripathy S, Jena SK. Remanufacturing for the circular economy: Study and evaluation of critical factors. *Resources, Conservation and Recycling*. 2020;156:104681.
109. Hazen BT, Mollenkopf DA, Wang Y. Remanufacturing for the Circular Economy: An Examination of Consumer Switching Behavior. *Business Strategy and the Environment*. 2017;26(4):451-64.
110. Wei S, Tang O, Sundin E. Core (product) Acquisition Management for remanufacturing: a review. *Journal of Remanufacturing.* 2015;5(1):4.
111. Kalverkamp M, Raabe T. Automotive Remanufacturing in the Circular Economy in Europe:Marketing System Challenges. *Journal of Macro-marketing.* 2018;38(1):112-30.
112. Hunka AD, Linder M, Habibi S. Determinants of consumer demand for circular economy products. A case for reuse and remanufacturing for sustainable development. *Business Strategy and the Environment.* 2021;30(1):535-50.
113. Okorie O, Obi M, Russell J, Charnley F, Salonitis K. A triple bottom line examination of product cannibalisation and remanufacturing: A review and research agenda. *Sustainable Product and Consumption.* 2021;27:958-74.
114. Illankoon C, Vithanage SC. Closing the loop in the construction industry: A systematic literature review on the development of circular economy. *Journal of Building Engineering.* 2023;76:107362.
115. Yang Y, Chen B, Chen Y, Liu F, Xie X, Guo W, et al. Development of a high strength cementitious grout for filling the joints of UHPC permanent formwork. *Developments in the Built Environment.* 2023;13:100120.
116. Dewagoda KG, Ng ST, Chen J. Driving systematic circular economy implementation in the construction industry: A construction value chain perspective. *Journal of Cleaner Production.* 2022;381:135197.
117. Walker AM, Opferkuch K, Roos Lindgreen E, Simboli A, Vermeulen WJV, Raggi A. Assessing the social sustainability of circular economy practices: Industry perspectives from Italy and the Netherlands. *Sustainable Production and Consumption.* 2021;27:831-44.
118. Genovese PV, Zoure AN. Architecture trends and challenges in sub-Saharan Africa's construction industry: A theoretical guideline of a bioclimatic architecture evolution based on the multi-scale approach and circular economy. *Renewable and Sustainable Energy Reviews.* 2023;184:113593.
119. Bao Z. Developing circularity of construction waste for a sustainable built environment in emerging economies: New insights from China. Developments in the Built Environment. 2023;13:100107.
120. Ding Z, Wang X, Zou PXW. Barriers and countermeasures of construction and demolition waste recycling enterprises under circular economy. *Journal of Cleaner Production.* 2023;420:138235.
121. Ahmed N. Utilizing plastic waste in the building and construction industry: A pathway towards the circular economy. *Construction and Building Materials.* 2023;383:131311.
122. Ghobadi M, Sepasgozar SME. Circular economy strategies in modern timber construction as a potential response to climate change. *Journal of Building Engineering.* 2023;77:107229.
123. Quale J, Eckelman MJ, Williams KW, Sloditskie G, Zimmerman JB. Construction matters: Comparing environmental impacts of building modular and conventional homes in the United States. *Journal of industrial ecology.* 2012;16(2):243-53.
124. Pearlmutter D, Theochari D, Nehls T, Pinho P, Piro P, Korolova A, et al. Enhancing the circular economy with nature-based solutions in the built urban environment: green building materials, systems and sites. *Blue-Green Systems.* 2019;2(1):46-72.
125. Ossio F, Salinas C, Hernández H. Circular economy in the built environment: A systematic literature review and definition of the circular construction concept. *Journal of Cleaner Production.* 2023;414:137738.
126. Hassan MS, Ali Y, Petrillo A, De Felice F. Risk assessment of circular economy practices in construction industry of Pakistan. *Science of The Total Environment.* 2023;868:161418.
127. Ma W, Liu T, Hao JL, Wu W, Gu X. Towards a circular economy for construction and demolition waste management in China: Critical success factors. *Sustainable Chemistry and Pharmacy.* 2023;35:101226.
128. Almokdad M, Zentar R. Characterization of recycled dredged Sediments: Toward circular economy in road construction. *Construction and Building Materials.* 2023;402:132974.
129. Khadim N, Agliata R, Thaheem MJ, Mollo L. Whole building circularity indicator: A circular economy assessment framework for promoting circularity and sustainability in buildings and construction. *Building and Environment.* 2023;241:110498.
130. Wu D, Pi Y. Digital technologies and product-service systems: A synergistic approach for manufacturing firms under a circular economy. *Journal of Digital Economy.* 2023;2:37-49.
131. Heyes G, Sharmina M, Mendoza JMF, Gallego-Schmid A, Azapagic A. Developing and implementing circular economy business models in service-oriented technology companies. *Journal of Cleaner Production.* 2018;177:621-32.
132. Ren Y, Wu K-J, Lim MK, Tseng M-L. Technology transfer adoption to achieve a circular economy model under resource-based view: A high-tech firm. *International Journal of Production Economics.* 2023;264:108983.
133. Khan SAR, Zia-ul-haq HM, Umar M, Yu Z. Digital technology and circular economy practices: An strategy to improve organizational performance. *Business Strategy & Development*. 2021;4(4):482-90.
134. Demestichas K, Daskalakis E. Information and Communication Tech-nology Solutions for the Circular Economy. *Sustainability.* 2020;12(18): 7272.
135. Upadhyay A, Mukhuty S, Kumar V, Kazancoglu Y. Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of Cleaner Production*. 2021;293:126130.
136. Pagoropoulos A, Pigosso DCA, McAloone TC. The Emergent Role of Digital Technologies in the Circular Economy: A Review. *Procedia CIRP.* 2017;64:19-24.
137. Khan SAR, Piprani AZ, Yu Z. Digital technology and circular economy practices: future of supply chains. *Operations Management Research*. 2022;15(3):676-88.
138. Rótolo GC, Vassillo C, Rodriguez AA, Magnano L, Milo Vaccaro M, Civit BM, et al. Perception and awareness of circular economy options within sectors related to agriculture in Argentina. *Journal of Cleaner Production*. 2022;373:133805.
139. Velasco-Muñoz JF, Mendoza JMF, Aznar-Sánchez JA, Gallego-Schmid A. Circular economy implementation in the agricultural sector: Definition, strategies and indicators. *Resources, Conservation and Recycling*. 2021;170:105618.
140. Barros MV, Salvador R, de Francisco AC, Piekarski CM. Mapping of research lines on circular economy practices in agriculture: From waste to energy. *Renewable and Sustainable Energy Reviews*. 2020;131:109958.
141. Haque F, Fan C, Lee Y-Y. From waste to value: Addressing the relevance of waste recovery to agricultural sector in line with circular economy. *Journal of Cleaner Production.* 2023;415:137873.
142. 142. Nordin SM, Zolkepli IA, Ahmad Rizal AR, Tariq R, Mannan S, Ramayah T. Paving the way to paddy food security: A multigroup analysis of agricultural education on Circular Economy Adoption. *Journal of Cleaner Production*. 2022;375:134089.
143. Velasco-Muñoz JF, Aznar-Sánchez JA, López-Felices B, Román-Sánchez IM. Circular economy in agriculture. An analysis of the state of research based on the life cycle. *Sustainable Production and Consumption.* 2022;34:257-70.
144. Khan F, Ali Y. Moving towards a sustainable circular bio-economy in the agriculture sector of a developing country. *Ecological Economics.* 2022;196:107402.
145. Cavicchi C, Oppi C, Vagnoni E. Energy management to foster circular economy business model for sustainable development in an agricultural SME. *Journal of Cleaner Production.* 2022;368:133188.
146. Mujtaba M, Fernandes Fraceto L, Fazeli M, Mukherjee S, Savassa SM, Araujo de Medeiros G, et al. Lignocellulosic biomass from agricultural waste to the circular economy: a review with focus on biofuels, biocomposites and bioplastics. *Journal of Cleaner Production.* 2023;402:136815.
147. Rodríguez-Espinosa T, Papamichael I, Voukkali I, Gimeno AP, Candel MBA, Navarro-Pedreño J, et al. Nitrogen management in farming systems under the use of agricultural wastes and circular economy. *Science of The Total Environment.* 2023;876:162666.
148. Papamichael I, Voukkali I, Loizia P, Rodrıguez-Espinosa T, Pedreño JN, Zorpas AA. Textile waste in the concept of circularity. *Sustainable Chemistry and Pharmacy.* 2023;32:100993.

*Corresponding author email:bernabe.rivas@uss.cl

149. Saccani N, Bressanelli G, Visintin F. Circular supply chain orchestration to overcome Circular Economy challenges: An empirical investigation in the textile and fashion industries. *Sustainable Production and Consumption*. 2023;35:469-82.
150. Tsironis G, Tsagarakis KP. Global online networking for circular economy companies in fashion, apparel, and textiles industries, the LinkedIn platform. Current Opinion in Green and Sustainable Chemistry. 2023;41:100809.
151. Hultberg E, Pal R. Lessons on business model scalability for circular economy in the fashion retail value chain: Towards a conceptual model. *Sustainable Production and Consumption.* 2021;28:686-98.
152. Islam MT, Jabber MA, Sakib MN. Application of revised theory of planned behavior model to assess the readiness of circular economy in the RMG sector of Bangladesh. *Journal of Cleaner Production.* 2023;420:138428.
153. Galatti LG, Baruque-Ramos J. Circular economy indicators for measuring social innovation in the Brazilian textile and fashion industry. *Journal of Cleaner Production.* 2022;363:132485.
154. Colasante A, D'Adamo I. The circular economy and bioeconomy in the fashion sector: Emergence of a "sustainability bias*". Journal of Cleaner Production*. 2021;329:129774.
155. Zúñiga M, Aranda FL, Rivas BL. Polymers recycling: upcycling techniques. An overview. *Journal of the Chilean Chemical Society.* 2023;68(2):5876-86.
156. D'Adamo I, Colasante A. Survey data to assess consumers' attitudes towards circular economy and bioeconomy practices: A focus on the fashion industry. *Data in Brief.* 2022;43:108385.
157. Provin AP, Dutra ARdA, de Sousa e Silva Gouveia ICA, Cubas eALV. Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles. *Technological Forecasting and Social Change*. 2021;169:120858.
158. Gupta R, Kushwaha A, Dave D, Mahanta NR. Chapter 10 - Waste management in fashion and textile industry: Recent advances and trends, life-cycle assessment, and circular economy. In: Hussain CM, Singh S, Goswami L. *Elsevier;* 2022.
159. Abdelmeguid A, Afy-Shararah M, Salonitis K. Investigating the challenges of applying the principles of the circular economy in the fashion industry: A systematic review. *Sustainable Production and Consumption.* 2022; 32:505-18.
160. Brydges T. Closing the loop on take, make, waste: Investigating circular economy practices in the Swedish fashion industry. Journal of Cleaner Production. 2021;293:126245.
161. Koszewska M. 9 - Circular economy in textiles and fashion—the role of a consumer. In: Muthu SS, editor. Circular Economy in Textiles and Apparel: *Woodhead Publishing*; 2019.
162. Morone P, D'Adamo I, Yilan G. Editorial overview: The fashion industry wears the circular economy and sustainability. *Current Opinion in Green and Sustainable Chemistry.* 2023;42:100815.
163. Shirvanimoghaddam K, Motamed B, Ramakrishna S, Naebe M. Death by waste: Fashion and textile circular economy case. *Science of The Total Environment.* 2020;718:137317.
164. Chopra SS, Dong L, Kaur G, Len C, Ki Lin CS. Sustainable process design for circular fashion: Advances in sustainable chemistry for textile waste valorisation. *Current Opinion in Green and Sustainable Chemistry*. 2023;39:100747.
165. Barkhausen R, Fick K, Durand A, Rohde C. Analysing policy change towards the circular economy at the example of EU battery legislation. *Renewable and Sustainable Energy Reviews.* 2023;186:113665.
166. Koseoglu-Imer DY, Oral HV, Coutinho Calheiros CS, Krzeminski P, Güçlü S, Pereira SA, et al. Current challenges and future perspectives for the full circular economy of water in European countries. *Journal of Environmental Management.* 2023;345:118627.
167. Ziegler R, Bauwens T, Roy MJ, Teasdale S, Fourrier A, Raufflet E. Embedding circularity: Theorizing the social economy, its potential, and its challenges. *Ecological Economics.* 2023;214:107970.
168. Shang Y, Song M, Zhao X. The development of China's Circular Economy: From the perspective of environmental regulation. *Waste Management.* 2022;149:186-98.
169. Niero M. Implementation of the European Union´s packaging and packaging waste regulation: A decision support framework combining quantitative environmental sustainability assessment methods and socio-technical approaches. *Cleaner Waste Systems.* 2023;6:100112.
170. Lifset R, Kalimo H, Jukka A, Kautto P, Miettinen M. Restoring the incentives for eco-design in extended producer responsibility: The challenges for eco-modulation. *Waste Management.* 2023;168:189-201.
171. Namias J. The future of electronic waste recycling in the United States: obstacles and domestic solutions. *Columbia University.* 2013.
172. Arain A, Pummill R, Adu-Brimpong J, Becker S, Green M, Ilardi M, et al. Analysis of e-waste recycling behavior based on survey at a Midwestern US University. *Waste Management.* 2020;105:119-27.
173. Goodship V, Stevels A, Huisman J. Waste electrical and electronic equipment (WEEE) handbook: *Woodhead Publishing;* 2019.
174. Sanchez MC, Brown RE, Webber C, Homan GK. Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program. *Energy Policy.* 2008;36(6):2098-108.
175. Sharma KD, Jain S. Overview of municipal solid waste generation, composition, and management in India. *Journal of Environmental Engineering.* 2019;145(3):04018143.
176. Abril Ortiz A, Sucozhañay D, Vanegas P, Martínez-Moscoso A. A regional response to a global problem: single use plastics regulation in the countries of the Pacific Alliance. *Sustainability.* 2020;12(19):8093.
177. Pierini VI, Mazzeo N, Cazenave M, Semmartin M. Waste generation and pro-environmental behaviors at household level: A citizen science study in Buenos Aires (Argentina). *Resources, Conservation and Recycling*. 2021;170:105560.
178. Fidelis R, Marco-Ferreira A, Antunes LC, Komatsu AK. Socio-productive inclusion of scavengers in municipal solid waste management in Brazil: Practices, paradigms and future prospects. *Resources, Conservation and Recycling.* 2020;154:104594.
179. Márquez AJC, Rutkowski EW. Waste management drivers towards a circular economy in the global south–The Colombian case. *Waste Management.* 2020;110:53-65.
180. Chembessi C, Beaurain C, Cloutier G. Understanding the scaling-up of a circular economy (CE) through a strategic niche management (SNM) theory: A socio-political perspective from Quebec. *Environmental Challenges.* 2021;5:100362.
181. McLaren D, Niskanen J, Anshelm J. Reconfiguring repair: Contested politics and values of repair challenge instrumental discourses found in circular economies literature. *Resources, Conservation & Recycling: X.* 2020;8:100046.
182. seyyedi Sr, Kowsari E, Ramakrishna S, Gheibi M, Chinnappan A. Marine plastics, circular economy, and artificial intelligence: A comprehensive review of challenges, solutions, and policies. *Journal of Environmental Management.* 2023;345:118591.
183. Marks D, Miller MA, Vassanadumrongdee S. Closing the loop or widening the gap? The unequal politics of Thailand's circular economy in addressing marine plastic pollution. *Journal of Cleaner Production.* 2023;391:136218.
184. De Jesus A, Mendonça S. Lost in transition? Drivers and barriers in the eco-innovation road to the circular economy. *Ecological economics.* 2018;145:75-89.
185. Guldmann E, Huulgaard RD. Barriers to circular business model innovation: A multiple-case study. *Journal of cleaner production*. 2020;243:118160.
186. Kirchherr J, Piscicelli L, Bour R, Kostense-Smit E, Muller J, Huibrechtse-Truijens A, et al. Barriers to the circular economy: Evidence from the European Union (EU). *Ecological economics.* 2018;150:264-72.
187. Govindan K, Hasanagic M. A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective. *Int J of Producn Res.*2018;56(1-2):278-311.
188. Ghisellini P, Ji X, Liu G, Ulgiati S. Evaluating the transition towards cleaner production in the construction and demolition sector of China: A review. *Journal of Cleaner Production.* 2018;195:418-34.
189. Aslam MS, Huang B, Cui L. Review of construction and demolition waste management in China and USA. *Journal of Environmental Management.* 2020;264:110445.
190. Selman AD, Gade AN, editors. Barriers of incorporating circular economy in building design in a Danish context. *Association of Researchers in Construction Management (ARCOM) Annual Conference*; 2020.
191. Hart J, Adams K, Giesekam J, Tingley DD, Pomponi F. Barriers and drivers in a circular economy: The case of the built environment. *Procedia Cirp.* 2019;80:619-24.

192. Charef R, Emmitt S. Uses of building information modelling for overcoming barriers to a circular economy. *Journal of cleaner production.* 2021;285:124854.
193. Andersen SC, Larsen H, Raffnsøe L, Melvang C, editors. Environmental product declarations (EPDs) as a competitive parameter within sustainable buildings and building materials. *IOP Conference Series: Earth and Environmental Science;* 2019.
194. Tomaszewska J. Polish transition towards circular economy: Materials management and implications for the construction sector. *Materials.* 2020;13(22):5228.
195. Williams J. Circular cities: Challenges to implementing looping actions. *Sustainability.* 2019;11(2):423.
196. Al Hosni IS, Amoudi O, Callaghan N. An exploratory study on challenges of circular economy in the built environment in Oman. *Proceedings of the Institution of Civil Engineers-Management, Procurement and Law.* 2020;173(3):104-13.
197. Cruz-Rios F, Grau D, editors. Design for disassembly: an analysis of the practice (or lack thereof) in the United States. *Construction Research Congress 2020;* 2020.
198. Kanters J. Circular building design: An analysis of barriers and drivers for a circular building sector. *Buildings*. 2020;10(4):77.
199. Ajayi SO, Oyedele LO, Bilal M, Akinade OO, Alaka HA, Owolabi HA, et al. Waste effectiveness of the construction industry: Understanding the impediments and requisites for improvements. *Resources, Conservation and Recycling.* 2015;102:101-12.
200. Finch G, Marriage G, Pelosi A, Gjerde M. Building envelope systems for the circular economy; Evaluation parameters, current performance and key challenges. *Sustainable Cities and Society.* 2021;64:102561.
201. Van Bueren B, Leenders M, Nordling T, editors. Case Study: Taiwan's pathway into a circular future for buildings. IOP Conference Series: Earth and Environmental Science; 2019: *IOP Publishing*.
202. Campbell-Johnston K, ten Cate J, Elfering-Petrovic M, Gupta J. City level circular transitions: Barriers and limits in Amsterdam, Utrecht and The Hague. *Journal of cleaner production.* 2019;235:1232-9.
203. Munaro MR, Tavares SF. A review on barriers, drivers, and stakeholders towards the circular economy: The construction sector perspective. *Cleaner and Responsible Consumption.* 2023;8:100107.
204. Mauss N-A, Bühner D, Fottner J. Applicability and limitations of change management for circular economy in manufacturing companies. *Procedia Computer Science.* 2023;217:998-1007.
205. Pitkänen K, Karppinen T, Kautto P, Pirtonen H, Salmenperä H, Savolahti H, et al. How to measure the social sustainability of the circular economy? Developing and piloting social circular economy indicators in Finland. *Journal of Cleaner Production.* 2023;392:136238.
206. D'Angelo V, Cappa F, Peruffo E. Walking the tightrope: Circular economy breadth and firm economic performance. *Corporate Social Responsibility and Environmental Management.* 2023.
207. Blok V. The Normative and Social Dimensions of the Transition towards a Responsible*, Circular Bio-Based Economy.* 2023.
208. de Vasconcelos DC, Viana FLE, de Souza AL. Circular economy and sustainability in the fresh fruit supply chain: a study across Brazil and the UK. *Latin American Business Review.* 2021;22(4):393-421.
209. Seroka-Stolka O, Ociepa-Kubicka A. Green logistics and circular economy. *Transportation Research Procedia.* 2019;39:471-9.
210. Malinauskaite J, Erdem FB. Planned obsolescence in the context of a holistic legal sphere and the circular economy. *Oxford Journal of Legal Studies.* 2021;41(3):719-49.
211. Wieser H. Beyond planned obsolescence: Product lifespans and the challenges to a circular economy. *GAIA-Ecological Perspectives for Science and Society.* 2016;25(3):156-60.
212. Adamson G, Stevens B. Industrial strength design: how Brooks Stevens shaped your world. (No Title). 2003.
213. Andrews D. The circular economy, design thinking and education for sustainability. *Local economy.* 2015;30(3):305-15.
214. Gonçalves BdSM, Carvalho FLd, Fiorini PdC. Circular economy and financial aspects: A systematic review of the literature. *Sustainability.* 2022;14(5):3023.
215. Ozili PK. Circular economy, banks, and other financial institutions: what's in it for them? *Circular Economy and Sustainability*. 2021;1(3):787-98.
216. Viana FC. A case study about circular economy and sustainability in a small business. *Design ecovisions.* 2021:45.
217. Soto M, Uarac F, Doussoulin JP. Rentabilidad económica del reciclaje de desechos de la moda en el sur de Chile. *Revista Venezolana de Gerencia: RVG.* 2022;27(8):1182-95.
218. Ragossnig AM, Schneider DR. Circular economy, recycling and end-of-waste. SAGE Publications Sage UK: London, England; 2019. p. 109-11.
219. Jacobs C, Soulliere K, Sawyer-Beaulieu S, Sabzwari A, Tam E. Challenges to the circular economy: Recovering wastes from simple versus complex products. *Sustainability.* 2022;14(5):2576.
220. Jehanno C, Demarteau J, Mantione D, Arno MC, Ruipérez F, Hedrick JL, et al. Synthesis of Functionalized Cyclic Carbonates through Commodity Polymer Upcycling. *ACS Macro Letters.* 2020;9(4):443-7.
221. Chen X, Wang Y, Zhang L. Recent Progress in the Chemical Upcycling of Plastic Wastes. *ChemSusChem.* 2021;14(19):4137-51.
222. Amor IB, Hemmami H, Laouini SE, Abdelaziz AG, Barhoum A. Influence of chitosan source and degree of deacetylation on antibacterial activity and adsorption of AZO dye from water. *Biomass Conversion and Biorefinery.* 2023:1-11.
223. Yin J, Fang K, Li J, Du N, Hu D, Cao D, et al. Competitive adsorption mechanisms of pigments in sugarcane juice on starch-based magnetic nanocomposites. *International Journal of Biological Macromolecules.* 2023;231:123134.
224. Zhu J-L, Wang M-L, Shi S-C, Ren J-X, Huang H-D, Lin W, et al. In-situ constructing robust cellulose nanocomposite hydrogel network with well-dispersed dual catalysts for the efficient, stable and recyclable photo-Fenton degradation. Cellulose. 2022;29(3):1929-42.
225. Voicu SI, Thakur VK. Green polymers-based membranes for water reuse in a circular economy context. *Current Opinion in Green and Sustainable Chemistry.* 2023:100852.
226. Saberi Riseh R, Gholizadeh Vazvani M, Hassanisaadi M, Skorik YA. Micro-/nano-carboxymethyl cellulose as a promising biopolymer with prospects in the agriculture sector: a review. *Polymers.* 2023;15(2):440.
227. Jia P, Li Z, Wang X, Xu F, You M, Feng S. Performance improvement of lateral flow assay using heterogeneous nitrocellulose membrane with nonuniform pore size. *International Communications in Heat and Mass Transfer.* 2023;143:106729.
228. Abu-Zurayk R, Alnairat N, Khalaf A, Ibrahim AA, Halaweh G. Cellulose acetate membranes: Fouling types and antifouling strategies—A brief review. *Processes.* 2023;11(2):489.
229. Oldal DG, Topuz F, Holtzl T, Szekely G. Green electrospinning of biodegradable cellulose acetate nanofibrous membranes with tunable porosity. *ACS Sustainable Chemistry & Engineering.* 2023;11(3):994-1005.
230. 230. Oprea M, Voicu SI. Cellulose Acetate-Based Materials for Water Treatment in the Context of Circular Economy. Water. 2023;15(10):1860.
231. McAllister HP, Kalow JA. Tandem triumphs in PVC upcycling. *Chem Catalysis.* 2023;3(3):100578.
232. Zhu Y, Zhang Y, Wu H, Wang S, Li X. An oxidative polymerized carboxymethyl cellulose hydrogel for the combined anti-tumor recurrence. *Journal of Materials Science.* 2023;58(1):369-82.
233. Bashir S, Hina M, Iqbal J, Rajpar A, Mujtaba M, Alghamdi N, et al. Fundamental concepts of hydrogels: Synthesis, properties, and their applications. *Polymers.* 2020;12(11):2702.
234. Kaur P, Bohidar HB, Nisbet DR, Pfeffer FM, Rifai A, Williams R, et al. Waste to high-value products: The performance and potential of carboxymethylcellulose hydrogels via the circular economy. *Cellulose.* 2023;30(5):2713-30.
235. Maranghi S, Tosti L, Domiński A, Rydz J. Life cycle assessment of (bio) degradable polymers as a tool to achieve the goals of the circular economy. *Packaging Review*. 2023.
236. Tavares T, Leon F, Vaswani J, Peñate B, Ramos-Martín A. Study for Recycling Water Treatment Membranes and Compnents towards a Circular Economy & mdash; Case of Macaronesia Area. *Membranes.* 2022;12(10):970.

**Corresponding author email:bernabe.rivas@uss.cl*