Environmental Footprints and Eco-design of Products and Processes

Aldo Alvarez-Risco
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Circular Economy

Impact on Carbon and Water Footprint

Springer

Environmental Footprints and Eco-design of Products and Processes

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Preface

Although governments, companies, and citizens have been motivated for years, few efforts have been made to achieve concrete results related to sustainability. Various indicators, programs, laws, initiatives, and other activities have been generated, but little has been achieved. However, the world transformed by the COVID-19 pandemic has increased the interest in environmental issues since it has been possible to understand the need for efficient use of resources due to the profound economic impact caused by the pandemic. Since the signing of the Sustainable Development Goals in 2015, different orientations were created to contribute to environmental content due to the global need, for the eco-efficient use of water, air, land, and other natural resources. With these efforts, the concept of ecological footprint gains much importance.

This book aims to provide the theoretical and practical support needed to implement a circular economy and a footprint linked to water, food, and other sources. These can guide other institutions and policymakers in establishing regulations and implementation and monitoring processes.

Part I presents the circular economy approach, mentioning the strategies, the aspects of deglobalization due to the pandemic, and the necessary leadership needed for the global crisis to be successfully addressed at both the governmental and business levels. Chapter "Measuring Circular Economy" presents various strategies for measuring the circular economy and the progress being made in the world. In Chapter "Better Students, Better Companies, Better Life: Circular Learning", a promising approach to optimizing the education of students in universities is presented so that the improvement of their academic training is accompanied by better results in companies and, ultimately, a better individual and collective life; in other words, the origin of circular learning to build a circular world is proposed. Chapter "Leadership for Sustainability in Crisis Time" shows the global leadership approach needed at different levels, adapted to the current activities of companies, and presents resources for future research in this field and different green certification. The end of this chapter shows the scientific evidence of efforts to comply with the Paris Agreement and recent evidence of the level of compliance in countries. Chapter "Circular Economy for Food Loss Reduction and Water foodprint" discusses that food availability is a critical issue in the world and requires substantial improvement of processes, including the use of new technologies, while at the same time using water efficiently during the food production process. Chapter "3D Print, Circularity and Footprints" presents a very innovative and current topic such as 3D printing, showing the contributions in the saving of resources generated by this technology and the contribution achieved in reducing pollution in the construction sector.

In part II, the applications of footprints in different approaches are presented in more detail. Thus, Chapter "Circular Economy for Packaging and Carbon Footprint" describes the efforts and achievements of the circular economy in product packaging and its relationship with the impact on the carbon footprint through these production processes. Chapter "Circular Economy for Waste Reduction and Carbon Footprint" shows the management of waste in terms of circular economy, detailing the regulation, programs, and impact on carbon footprint. In the case of Chapter "Food Loss Reduction and Carbon Footprint Practices Worldwide: A Benchmarking Approach of Circular Economy", it is described food loss reduction programs because food management is an old and big problem that needs to follow the circular economy guidelines to contribute to global practices and can impact the achievement of better values in the carbon footprint. It is known that the management of clothing manufacturing usually has a great challenge to ensure that it is carried out circularly and that, in addition, waste management is also a necessity that current processes are needed. The description of these contents is seen in Chapter "Fashion and Textile Circularity and Waste Footprint". Chapter "Material Selection for Circularity and Footprints" highlights the need for material selection in companies since more and more new materials have better attributes and are mainly less polluting.

Part III shows substantial efforts and, above all, the innovation of tourist and educational activities. Chapter "Water Footprint in the Textile and Food Supply Chain Management: Trends to Become Circular and Sustainable" describes advances in water management in clothing manufacturing and the food supply chain. These massive products are essential because the ecological management of these production processes has a tremendous global impact. Chapter "Virtual Tourism, Carbon Footprint and Circularity" and Chapter "Virtual Education: Carbon Footprint and Circularity" address how tourism and education have been modified, leading to a global offer via virtual and how a positive impact has been achieved in reducing the ecological footprint on consumers. However, it remains to be discussed whether a more significant benefit can be achieved with these practices and, at the same time, project what else must be planned so that tourist and educational activities in the blended world are successful.

All chapters were reviewed. Some authors assisted in reviewing chapters written by others.

This book shows the experience and knowledge of authors and editors in a highly relevant and timely global change movement: the circular economy and footprint. We expect the book to guide governments, universities, schools, multinational and local companies, and citizens. Finally, the circular economy and footprint are concrete ways to contribute to the UN Sustainable Development Goals, which allow circular international business and contribute with footprint goals.

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Lima, Peru — Shyla Del-Aguila-Arcentales, M.Sc.

About the Authors, Reviewers, Editors, and Their Contributions

This book would not have been possible without the incredible and dedicated efforts and contributions of its many authors, who wrote chapters and often assisted in reviewing the chapters of others.

Camila Almanza-Cruz is the coauthor of Chap "Virtual Education: Carbon Footprint and Circularity".

Aldo Alvarez-Risco is coauthor of Chaps. "Measuring Circular Economy", "Better Students, Better Companies, Better Life: Circular Learning", "Leadership for Sustainability in Crisis Time", "Circular Economy for Food Loss Reduction and Water Foodprint", "3D Print, Circularity and Footprints", "Circular Economy for Packaging and Carbon Footprint", "Circular Economy for Waste Reduction and Carbon Footprint", "Food Loss Reduction and Carbon Footprint Practices Worldwide: A Benchmarking Approach of Circular Economy", "Fashion and Textile Circularity and Waste Footprint", "Material Selection for Circularity and Footprints", "Water Footprint in the Textile and Food Supply Chain Management: Trends to Become Circular and Sustainable", "Virtual Tourism, Carbon Footprint and Circularity", "Virtual Education: Carbon Footprint and Circularity". Also, he is one of the editors and reviewers of the book.

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Circular Economy: Strategies, Deglobalization and Leadership

Measuring Circular Economy

Shyla Del-Aguila-Arcentales, Aldo Alvarez-Risco, and Subramanian Senthilkannan Muthu

Abstract The circular economy seeks its development through various efforts. Specific action guidelines and indicators are required for different levels, types of organizations, regions, etc. Likewise, diverse experiences are required to build indicators for each reality. A review of some indicators is made, and specific evidence is presented for each material or country. Future research is needed to test various indicators for their importance and validity.

Keywords Circular economy · Footprint · Waste · Plastic · Indicators · Index

1 Introduction

Globally, there is a growing trend for organizations to develop projects that enable the shift from linear economy to circular economy-based activities [17, 21]. In organizations based on linear economics, the processes performed by workers are based on the use of materials in one direction only, where the raw materials that enter the process are used to obtain the final product, the resulting waste is thrown away without any further action. However, under the circular economy approach, two fundamental components underpin the circular management approach: recovery and valorization of waste. These approaches imply that particular materials can be reused in the supply chain. Several countries are already initiating the regulation and promotion of circular activities such as Vietnam [25], Canada [9], Russia [78], Latin America

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[85], New Zealand [58], Bolivia [15], Ghana [5], and others. The European Union [99] and China [14] are leading the way to implement the circular economy.

In the scientific literature, there are several reports, ranging from correlational or descriptive models to descriptive [44] or correlational models [2], but there is very little publication associated with measuring circularity, which is critical to monitoring implementation progress.

2 Measure of Circular Economy

When thinking about indicators, one needs to recognize the efforts that can be made to achieve monitoring and eco-efficient use at different levels. The first component that requires monitoring is electricity. Table 1 shows the different indicators that can be applied at different levels. By the eco-innovation action plan of the European Union [13], there are different indicators (Table 1).

Table 1 Indicators based on sustainable resource management, societal behaviors, and business operations

Type of indicators	Source
Sustainable resource management	
Material footprint	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Material_flow_accounts_statistics_-_material_footprints
Resource productivity	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Resource_productivity_statistics
Trends in the repair sector	https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=sbs_na_1a_se_r2&lang=en
Extended producer responsibility	https://circulareconomy.europa.eu/platform/sites/default/files/ecopreneur-circular-economy-update-report-2019.pdf
Recycling rates in Europe by waste stream	https://www.eea.europa.eu/data-and-maps/indicators/waste-recycling-1/assessment-1
Municipal solid waste	https://ec.europa.eu/eurostat/databrowser/view/env_wasmun/default/table?lang=en
Recycling of packaging waste	https://ec.europa.eu/eurostat/web/products-datasets/product?code=ten00063
Recycling of biowaste	https://ec.europa.eu/eurostat/cache/metadata/en/cei_wm030_esmsip2.htm
Recycling of construction	https://ec.europa.eu/eurostat/databrowser/view/cei_wm040/default/table?lang=en

(continued)

Table 1 (continued)

Type of indicators	Source
Municipal waste recycled	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics
Societal behaviors	
Citizens who have chosen alternatives to buying new products	https://data.europa.eu/data/datasets/s1102_388?locale=en
Coverage of circular economy	Scopus
Turnover in repair of computers and personal goods	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Computer_and_personal_and_household_goods_repair_statistics_-_NACE_Rev._2
Number of enterprises and employment in repair of computers	
Number of countries of enterprises and employment in repair of computers	
Business operations	
Difficulties implementing circular economy	https://data.europa.eu/data/datasets/s2110_441_eng?locale=en
Financing sources for circular economy	
Availability of information	
Share of enterprises that facilitated recycling of products	https://ec.europa.eu/eurostat/cache/metadata/en/inn_cis9_esms.htm
Enterprises that extended product life	
Number of eco labeled products and services	https://ec.europa.eu/environment/ecolabel/facts-and-figures.html

3 OECD Indicators

Another indicator relevant to consider is the circular economy indicator proposed by the OECD. The most critical indicators are presented below by category type, sector, indicator, unit of measurement, and source.

Specifically, Moraga et al. [56] described indicators such as self-sufficiency for raw materials, green public procurement, waste generation, food waste, recycling rates, recovery for specific waste streams, the contribution of recycled materials to raw materials demand, trade-in recyclable raw materials, private investments, jobs and gross value added, and patents related to recycling and secondary raw materials. Other authors have proposed different indicators such as Geng et al. [22] (Table 2), Smol et al. [91] (Table 3), and De Pascale et al. [70] (Table 4).

Also, it is recommended to review the proposal of indicators and footprints by Saidani et al. [83], Huysman et al. [31], de Oliveira et al. [65], Padilla-Rivera et al. [66], Rincón-Moreno et al. [79], Avdiushchenko and Zając [4], and Cayzer et al. [8]. More specifically, it is relevant focus on longevity and circularity [16], eight historic port cities [24], indicators in plastic, textile and electro-electronic cases [82], use of energy accounting method [87], material circularity and life cycle indicators [27, 30, 50, 55, 61, 75, 94, 103, 105], manufacturing network [37, 52], product families

Table 2 Indicators based in Geng et al. [22]

Calculation formula	Unit
Output of main mineral resource = GDP/total consumption of main mineral resource	10,000 U/ton
Output of energy = GDP/energy consumption	10,000 U/ton sce
Energy consumption per unit of GDP = energy consumption/GDP (unit: ton sce/10,000 U)	ton sce/10,000 U
Energy consumption per added industrial value = industrial energy consumption AVI	ton sce/10,000 U
Energy consumption of key industrial product = energy consumption of steel (copper, aluminum, cement, fertilizer, paper)/steel production	ton sce/ton
Water withdrawal per unit of GDP = total amount of water withdrawal/GDP	10,000 m^3/U
Water withdrawal per added industrial value = amount of industrial water withdrawal/AVI	10,000 m3/U
Water consumption of key industrial sector product = total amount of fresh water consumption/total amount of steel production	108 m^3/ton
Coefficient of irrigation water utilization = actual amount of irrigation water consumption/total amount of irrigation water consumption	
Recycling rate of industrial solid waste = (industrial solid waste integrated utilization Q/industrial solid waste generation) 100%	

Table 3 Indicators based in Smol et al. [91]

CE–Eco-innovation inputs	*Unit*
Regional authorities environmental and energy R&D for CE appropriations and outlays	% of GDP
Regional total value of green early stage investments	EURO per capita
CE–Eco-innovation activities	*Unit*
Firms having implemented CE–eco-innovation activities aiming at a reduction of material input per unit output	% of total firms in region
Firms having implemented CE–eco-innovation activities aiming at an increase of material recycling	% of total firms in region
CE–Eco-innovation outputs	*Unit*
Generated industrial waste	Amount of waste/person
Generated municipal waste	Amount of waste/person
Recycled industrial waste	Amount of waste/person
Recycled municipal waste	Amount of waste/person
Life cycle assessment of enterprises activity	Amount companies with LCA reports per regions
Number of companies with “zero waste” program	

(continued)

Table 3 (continued)

Resource efficiency outcomes	*Unit*
Material productivity	Regional GDP/domestic material consumption of region
Water productivity	Regional GDP/water footprint of region
Energy productivity	Regional GDP/gross inland energy consumption of region
GHG emissions intensity	CO_2e/regional GDP
Socio-economic outcomes	*Unit*
Employment in eco-industries and circular economy (% of total employment across all companies of region). Revenue in eco-industries and circular economy (% of total revenue across all companies of region)	% of total revenue across all companies of region
GHG emissions intensity	(CO_2e/regional GDP)

Table 4 Indicators based in De Pascale et al. [70]

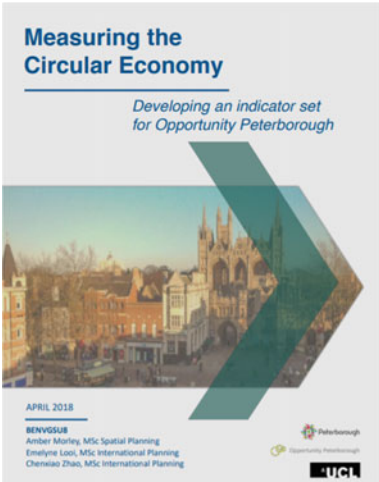
Micro-level	Meso-level	Macro-level
Disassembly Effort Index	Energy-based Indices	Multi-scale integrated analysis of societal metabolism
End-of-Life Index	Resource Productivity	A comprehensive index of circular Economy
Reuse Potential Indicator	MEP Indicators System	Super-efficiency DEA model
Material Circularity Indicator	Best-Worst Method	CE monitoring framework
Recyclability Benefit Rate	Evaluation Index System	Regional indicators of eco-innovation
Longevity Indicator	Resource Productivity Indicator	Index system for evaluating the circular economy development
Material Reutilization Score	Eco-Efficiency Indicator	Circularity indicators based on the MFA approach
Recycling Indices	Wastewater Circonomics Index	The evaluation index system of circular economy development level

[49], cultural heritage buildings [18], BWM-DEMATEL approach [108], levels of innovation [42], waste [53, 54, 74, 77, 86, 92], relation with sustainability [37, 40, 47, 80], standard BS 8001:2017 [71], agriculture [72, 100], city level [1, 26, 39, 60, 67, 68, 88], alternative methods [10, 45, 11, 20, 33, 35, 36, 51, 62–64, 69, 76, 81, 84, 101, 102], in companies [34], plastic [32, 93], mobile phones [19], and supply chain [7]. Also, there is evidence of indicators by regions or countries such as Germany [29], China [14, 23, 48, 95, 106–107], Sweden [28], Croatia [43], and European Union [6, 46, 89, 90, 96, 97, 104] (Table 5).

Table 5 Indicators' contribution according to Kristensen and Mosgaard [41]

Indicator	Contribution
Disassembly Effort Index	Academic
Remanufacturing Product Profiles	Academic
Circular Economy Toolkit	Practical
End-of-life Index	Academic
Reuse Potential Indicator	Academic
Circular Economy Index Material Circularity Indicator	Practical
Circularity Calculator	Practical
Eco-cost/Value Ratio	Academic
Longevity Indicator	Academic
Material Reutilization Score	Practical

Some reports must be reviewed to obtain global information to develop successful strategies.



Source Morley et al. [57]

Source Tully [98]

Source Potting et al. [73]

Source Natural Scotland [59]

Source America's Plastic Makers [3]

Source European Circular Economy Stakeholder Platform [12]

Closing Remarks

In these times of the COVID-19 pandemic, resilience must be based on the eco-efficient use of materials and, therefore, requires building fundamental indicators to help monitor. The book presents the specific development of footprint certifications, focused on different materials. The evidence presented in this chapter should be used as inputs for future research to be carried out, testing the indicators from the governmental, business, and citizen point of view.

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Better Students, Better Companies, Better Life: Circular Learning

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Abstract New education programs related to the circular economy model are being developed and companies applying the circularity model and strategies according to the company and the context in which it is developed. This article aims to know what skills and knowledge new professionals require to minimize the risks in the transition from one model to another and the continuity of circularity. Throughout the literature review, it is shown that the knowledge and application of the circular economy model are focused on engineering careers but not on business careers, which through their acquired knowledge have significant contributions to competitiveness, consumer behavior, supply and demand, costs, and other variables that are important in a decision-making process of a circular economy. In the end, the competencies that are achieved through the different subjects and methodologies suggested are determined and the different actors that should be considered when developing a subject or a circular economy program.

Keywords Circular economy · Education · Circular economy · Circular competencies · Learning outcomes

1 Circularity and Its Application in Economies and Companies

Do you know the Tableau Economique? Many consider the circular economy as new processes, strategies, and ways of life. The circularity was born many years ago [188]. The multiplier effect considered surpluses in the form of income returns and expenditures as essential factors affecting the determination of the scale of the system as the axes of economic growth [50, 139, 151, 162, 188]. Circularity has changed under its different forms as an alternative to the linear model. Some examples include changes in its concept [114], its application [133, 147] or also the political initiatives

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that have been taking place [73], and the different pilot programs to support the change of waste recirculation and for the benefit of climate change [39, 141, 142, 167, 173–174].

In summary, it is said that CE is an alternative model of production and consumption, a growth strategy that allows contributing to sustainable development [90, 92, 134, 151]. These results would be obtained through a cyclical flow for extraction, which allows for transformation, distribution and use and recovery through maintenance, repair of recyclable materials in products, and recovering raw materials from the waste stream [144, 161, 169, 176]. The generation of this economic benefit can coincide with creating social and environmental value, being adopted as a new sustainable economic principle [120], which is how we can say according to Ellen MacArthur Foundation [73] CE is mainly based on three fundamental principles: (1) conserve and optimize non-renewable resource stocks and the balance of renewable resource flows, (2) keep products and materials in use at the maximum in the biological and technical cycles, and (3) design out waste and negative environmental externalities such as pollution [94].

The world was transformed by COVID-19 pandemic (Table 1).

All this leads us to think about how companies and consumers take part in the development, and this is how in recent decades, the circular economy model has been seen as the option to overcome the current model of linear production and consumerism [92]. Thus, China and Japan were the first to adopt the model at the country level. China has been implementing circular economy policies since the 2000s, which has allowed the concept to evolve, becoming flow management and an innovation agenda [183]. It was mainly an industrial ecology program at its inception, being its objective the three "R's": Reduce, Reuse, and Recycle. It is worth noting that China published the Circular Economy Development Plan, integrated into the XIV Five-Year Plan (2021–2025). In 2017, the Circular Economic Policies were published, which contemplate eco-design (as a concept and as a policy) and extended producer responsibility, the latter being a crucial step in implementing the circular economy.

Meanwhile, due to its space and resource constraints, Japan asked itself: how can we better use material flow? As an economy that applies efficient industrialization models (e.g., lean manufacturing), it could visualize models that would improve efficiency by generating change in industrial processes and the application of the three Rs.

Considering the European Union as an economic bloc launched its first EC Action Plan in 2015 [80] and the new EC Action Plan in 2020 [81], it is one of the main blocks that make up the European Green Pact. In Europe, several countries have developed their initiatives, such as the Netherlands [96], France [82], the Energy Transition for Green Growth Act [95], and the Law against waste [97].

Italy is one of the countries that have a high value in the global circularity index, which was regulated by Law 221/2015 to promote green economy and sustainable development, and Law 216/2020 "Waste Decree," which incorporates the four European directives (851/2018 and 852/2018) contained in the EC Package. Other standards applied in Italy include the EMAS standard [76] and the European Union

Table 1 Impact of COVID-19 in different sectors

Education	Ali [9], Allen et al. [10], Alvarez-Risco, Estrada-Merino, et al. [24], Alvarez-Risco, Del-Aguila-Arcentales, Rosen, et al. [15], Alvarez-Risco, Del-Aguila-Arcentales, Yáñez, et al. [16], T. Chen et al. [60], Lackie et al. [119], Lashley et al. [121], Zollinger and DiCindio [187]
Entrepreneurship	Afshan et al. [4], Alvarez-Risco, Mlodzianowska, Zamora-Ramos, et al. [28], Alvarez-Risco, Mlodzianowska, García-Ibarra, et al. [27], Alvarez-Risco and Del-Aguila-Arcentales [16], Belitski et al. [42], Block et al. [45], Brown et al. [52], Bacq and Lumpkin [38], Chafloque-Cespedes et al. [58], Maritz et al. [132], Liguori and Winkler [126]
Health sector	Abiakam et al. [1], Alan et al. [8], Alsairafi et al. [11], Alvarez-Risco, Dawson, et al. [13], Alvarez-Risco, Del-Aguila-Arcentales and Yáñez [20], Barello et al. [40], Bozdağ and Ergün [49], X. Chen et al. [61], Deressa et al. [69], Koetter et al. [116], Raudenská et al. [150], Rojas Román et al. [154], Yáñez, Afshar Jahanshahi, et al. [179], Zhang et al. [185], Zhang et al. [186]
Hospitality	Duarte Alonso et al. [71], Gursoy and Chi [100], Ho et al. [105], Kaushal and Srivastava [111], Yan et al. [178]
Intellectual property	Altindis [12], Alvarez-Risco and Del-Aguila-Arcentales [14], del Castillo [67], Erfani et al. [78], Jecker and Atuire [109], Krishtel and Malpani [118], Okereke [143], Sekalala et al. [158], Zarocostas [184]
Population	Ahsan [6], Alvarez-Risco, Mejia, et al. [25], Cegarra-Navarro et al. [57], Hanzl [102], Lim and Prakash [127], Quispe-Cañari et al. [149], Sánchez-Clavijo et al. [156], Shaw et al. [159], Wen et al. [175], Wu et al. [177], Yáñez, Alvarez-Risco, et al. [179]
Prices	Apcho-Ccencho et al. [36], Chung et al. [62], Galanakis et al. [89], Hepburn et al. [103], Leiva-Martinez et al. [123], Obergassel et al. [140]
Tourism	Assaf and Scuderi [37], Baum and Hai [41], Brouder [51], Carvache-Franco, Alvarez-Risco, Carvache-Franco, Carvache-Franco, Estrada-Merino and Villalobos-Alvarez [54], Fotiadis et al. [88], Carvache-Franco, Alvarez-Risco, Carvache-Franco, Carvache-Franco, Estrada-Merino and Rosen [54], Sigala [160], Carvache-Franco, Carvache-Franco, et al. [56]
Trade	Abudureheman and Nilupaer [2], Acuña-Zegarra et al. [3], Aguirre et al. [5], Alvarez-Risco, Quipuzco-Chicata, et al. [29] Alvarez-Risco, Rosen, et al. [31], Borzée et al. [47], Cruz-Torres et al. [64], Kirk and Rifkin [115], Lopez-Odar et al. [129], Tran [164], Vidya and Prabheesh [171], Yasin Ar [181]
Violence against women	Amarillo [34], Chafloque-Cespedes et al. [59], Dominelli [70], Gulati and Kelly [99], Roesch et al. [152], Sánchez et al. [157], Viero et al. [172]

eco-labels [79]. Germany is a leader in waste management because it has developed policies concerning Sustainable Development Strategies [91], Resource Efficiency Program [85], and the National Program for Sustainable Consumption [86]. In Latin America, Mexico has applied the CE model through waste management [107], and Chile proposed a roadmap, with emphasis on innovation [137] as well as in Peru [72], a roadmap has released that drive and promote the transition from a linear economic model to a circular one in the manufacturing and industrial fish processing industries. Thus, different countries worldwide have been implementing policies, regulations, and the development of the circular economy in search of economic benefit and a better quality of life.

Many countries are applying political plans about the CE, which are gaining strength, and many institutions and people are involved in changing from a linear economy to a circular one. Are the state policies and the different promotion and innovative programs in the new circular economy model enough to achieve a better standard of living in societies?

One of the actors taking part in these state policies is companies, which must modify their resource management and organization practices (energy, water, raw materials) when considering a CE model where they must design, manufacture, distribute, and recover differently from what they have been developing [147]. Under the principles of CE, companies are expected to maintain above all the properties of the products and their components, which allow better management of resources, such as better maintenance [139]. Switching to a CE model implies adopting a new business model and applying new strategies, but these are always appropriate to the CE model applied. The strategies to be followed depend on each company, as shown in Table 2.

Companies must adapt to different organizational processes of the different links of a supply chain and the international physical distribution, seeking to generate value

Table 2 Strategies to be applied by companies in Circular Economy Models

"Resolve" * (2015)	"4R" ** (2017)	"10R" *** (2017)	Based in chain value **** (2018)
Regenerate	Reduce	Refuse	Procurement of materials
Share	Reuse	Rethink	Design
Optimize	Recycle	Reduce	Manufacturing
Make a loop	Retrieve	Reus	Distribution and sales
Virtualize		Repair	Consumption and use
Exchange		Refurbish	Collection and disposal
		Remanufacture	Recycling and recovery
		Repurpose	Remanufacturing
		Recycle	Circular entry
		Recover	

Source Adapted from: *: Ellen MacArthur Foundation [74], **: Kirchherr et al. [114], ***: Potting et al. [146], ****: Kalmykova et al. [110]

along with all the different links. These processes to be adopted seek the efficiency and effectiveness of each of these links for which it requires trained human capital and with the knowledge, skills, and competencies aligned with the EC principles. All areas of the company and the different positions in these different areas should require personnel at different levels who have the skills and competencies that can cope with change in the company and the market and its customer [182]. Thus, another question arises: Do university students receive the necessary training in SC to generate change in small and medium-sized enterprises?

2 Human Resources as a Factor of Change Toward a Circular Economy

As mentioned above, the contribution of companies and private sector organizations is important axis in implementing the new model. Change leads to a new way of seeing, thinking, developing, and doing business. The more significant the change in technological or product innovation, the more complex it is and the greater the knowledge requirements in business models, according to Bocken et al. [46], which enable the identification of strategies for business models that align with resource cycle closure approaches [46, 104]. The changes imply a staff with the required capabilities to take on a new challenge and the risk to change.

The managers of the different areas of the company that assume the change of model must adapt their skills and competencies to the new context. Likewise, organizational functions, such as production, purchasing, marketing and sales, supply chain, design, production, and logistics, are affected by the shift toward a CE model, for which new and updated skills and competencies aligned with the principles of CE are required [93].

The demand for skills and knowledge also varies between sectors and from the stages of circularity in which companies find themselves from the diversification and complexity of tasks, technological advances, reverse processes, and any process in general. Human resources at different levels must change mentality a shift toward greater responsibility about the product or service they offer by establishing an ecologically safe and socially fair operating space for society [63, 98, 101].

According to Burger et al. [53], the study conducted distinguishes 6 levels of competencies to be fulfilled, which are as follows: 1. basic skills (learning ability), 2. problem-solving skills,3. resource management skills (management efficiency skills); 4. social skills (ability to work in teams to achieve objectives); 5. systems skills (ability to understand, monitor, and improve socio-technical systems); and 6. technical skills (developing the ability to design, assemble, operate, and correct difficulties in machine applications or technological systems). It is important to stress the importance of skills to connect and co-create, such as assessing the systemic implications from design decisions until the product reaches the shelf, and then, this goes through a recycling or reuse process [48].

The shift toward a circular economy depends on the skills available, and these likely involve a combination of traditional skills, such as soft skills and service-related skills, and not neglect hard skills [53, 101]. However, it is essential to recognize that CE is a heterogeneous sector composed of different subsectors with different knowledge bases regarding the skills, education, and experience they require, given that activities, duties, and tasks vary across these sectors [170].

The last study conducted by Burger et al. [53] indicates that according to CE jobs, that is, jobs that contribute and are directly related to CE are not only increasing in companies and sectors that develop CE but also in sectors where CE is not applied but that in some way collaborate and support companies that apply CE (provide goods and services). They observed that companies that apply CE processes require more manual and technological skills than companies that support them, requiring more complex cognitive skills.

A company that applies circularity and good CE management generates benefits such as job opportunities and reduces inequality gaps through global redistribution of value. An increasing number of organizations show interest in implementing new goods and services that meet the requirements of a CE model [155], but it is worth highlighting that the application of circular business models is still scarce [128, 165].

3 Without Education, Change Toward a Circular Economy Cannot Be Generated

Education is how a change in values, behaviors, and lifestyles can be generated [43]. It requires leadership on teachers and more knowledge of new tools and approaches [125, 130]. According to Ellen MacArthur Foundation [74] and Kirchherr et al. [113], university professors have not been trained with the latest necessary knowledge as it is a radical innovation. However, universities have incorporated subjects related to sustainability in their curricula since 1990 [35, 173], but it seems that they have not presented an integration between the contents of their curricula and their relationship with sustainability and how to contribute to sustainable societies and the transition to change toward these [87, 106, 117, 131].

Environmentally oriented universities see the need to provide tools and strategies to support, manage, and solve pioneering situations to address urgent issues in waste, renewable energy, and sustainable agriculture [44], which hints that the focus goes toward the improvement of waste management and an improvement an increase in what refers to recycling [92, 161]. At the same time, others relate CE to design thinking and others from a product design perspective [124, 145].

According to Geissdoerfer et al. [90], Türkeli and Schophuizen [166], and Bocken et al. [46], this shift toward a CE model is based on complex tasks and is an integrated process with ecological, social, economic, and political trends. Thus, the circular economy model is not only referred to as waste management and recycling, since the model also allows minimizing risks such as price volatility, improving competitiveness, differentiation of products and services offered, and a reduction in operating costs, which allow a better profit. These points are little studied and are essential factors in the decision-making process of the production and internationalization of a product.

The change from one model to another varies depending on the application and the product. Different teaching methodologies are being applied nowadays, ranging from theory, applied cases, and gamification. However, Türkeli and Schophuizen [166] state that unidirectional education (teacher-students) is no longer competent for teaching CE and even less so if one wishes to raise awareness of the search for tangible solutions for sustainable production and consumption. The change from a linear model to CE is complex due to the lack of knowledge of the processes. For this reason, purely theoretical teaching does not allow the development of competencies and adequate learning for the application of a circular economy in a systemic way.

It is possible to generate a methodology that allows the development of competencies and knowledge to transition change and a circular economy. In this way, a better understanding of its importance can be achieved through CE education, leading students to become factors of change by becoming responsible designers, producers, entrepreneurs, politicians, and consumers.

Unlike other articles, the methodology and knowledge to be developed below are specifically developed for business schools where disciplines other than engineering are taught. Figure 1 shows how the circular economy in its analysis considers the country of destination of the product generated through an innovative eco-friendly model for which it has developed through circular processes to serve a market which

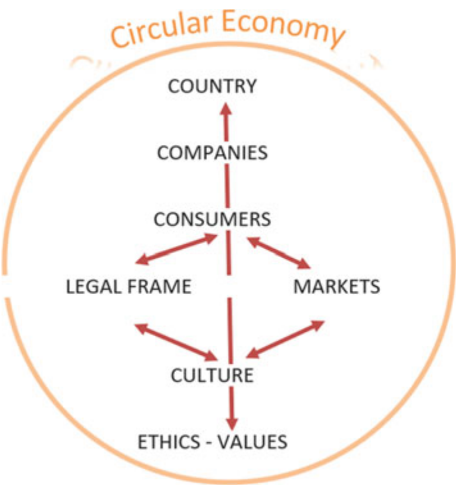

Fig. 1 Macro- and Microstructure analysis when producing with a circular economy model *Source* Adapted from Fang et al. [84], Kirchherr and Piscicelli [112]

is considered by the characteristics of its consumers to be an attractive, necessary, and differentiated product, thus satisfying the needs of the consumer. The rules and regulations, such as certifications requested for entry to the new destination, should be considered the national market existing to achieve the internationalization of the eco-friendly product. Finally, it is essential to consider the ethics and values of the market as those of the company we are dealing with in this operation [112].

Micro- and macro-analysis at the national and international level allows the evaluation of the different objectives either by economic sectors, business models, material flow, long-term results of CE, product life cycle, and CE metrics and indicators [138]. From the management perspective, the analysis of objectives is necessary to generate the required strategies covering national, regional, international, business, and consumer levels [92, 110, 114] and to analyze and verify how the objectives are converted into organizational policies and models [7].

The management of CE needs a redefinition of consumption and production systems that lead to a change in the behaviors of consumers. Therefore, we can say that a mindset change is needed on both the supply and demand sides [122]. Also, entrepreneurs must support their efforts [138].

Considering what has been developed, it can be defined as it is necessary to prepare future professionals, company managers, and create in them a mindset that allows them to develop and apply the appropriate strategies for the generation of change toward a CE that encompasses everything that involves production and consumption and not only the adoption of objectives that allow meeting environmental objectives [138]. Table 3 shows the suggested competencies to be developed by universities to generate a process of change toward a sustainable circular economy model. It should be clarified that it is possible to change toward circularity, but it does not necessarily refer to sustainability.

4 How Do We Achieve These Competencies?

Circular economy is an interdisciplinary discipline and as a subject or topic to be developed is relatively new in university institutions. For this reason, there are no adequate teaching materials, and there is no adequate coordination for its inclusion in the curricula [148]. According to Ellen MacArthur Foundation [75], all undergraduate and graduate students should follow at least one subject, which allows them to know and learn about the circular economy and how unsustainable the linear model is. Regardless of their job placement within the company, making better decisions for society and the environment is essential.

It is essential to consider that the fundamentals of circularity may be the same for all students worldwide. However, its application depends on each economy and

Table 3 Competences to be developed in EC students

Competences required in EC Janssens et al. [108]	**Sustainability competences** UNESCO [168]	**Circular competencies in design** Sumter et al. [163]
a. Competencias técnicas • Professional knowledge and accuracy directed toward sustainability • STEM-skills (Science + Technology + Mathematics) • STEAM-skills (out-of-the-box thinking and creativity	**a.** Systems thinking competency	Systems thinking and holistic thinking
	b. Anticipatory competency	Offering circle products achieve multiple life cycles
	c. Normative competency	• Setting circular criteria • Assessing circular solutions • Analyze and determine the environmental impact (over multiple life cycles)
b. Competencias valorativas • Critically contextualizing of knowledge • Knowledge to engage social, economic, and environmental problems • Transformation of knowledge into action • Environmental awareness and the application of ethical and sustainable principles	**d.** Strategic competency	• Analyze consumer value perception during the design process • Consider circular logistics, inverse logistics, and distribution process
	e. Collaboration competency	
	f. Critical thinking competency	
	g. Self-awareness competency	
c. Competencias transversales • Entrepreneur-ship competences • Collaboration, creative thinking, and flexibility	**h.** Integrated problem-solving competency	

Source Adapted from Janssens et al. [108], UNESCO [168], andSumter et al. [163]

its business sector where the knowledge of CE is transferred and where companies should support with the technical part and experience to participate in the development, organization of the subjects and their evaluation [65]. We can say that there is a clear opportunity for students to learn from experiences in a circular economy, generating little by little an impact on society.

Universities can contribute to the promotion of CE through activities at the university level as well as through their curriculum [148]. Nowadays, despite the progress about the CE message, it is still not enough,what does exist is a comprehensive development in subjects under the term "sustainability," which has been adapted to different curricula and subjects. Table 3 shows the different possible subjects to be part of a curriculum for students studying careers related to business sciences.

The study centers and the different programs evaluate how to initiate CE learning, whether it is through a subject, a group of subjects, a specialization, or postgraduate studies. Table 4 also shows the learning methodologies used throughout the subjects using one more of these throughout the course. The last column shows us the different actors that would participate in virtual or face-to-face visits to inform the students about their experiences and knowledge acquired through the course, depending on the subject related to the theory or the activity in progress.

Considering the list of suggested subjects and depending on the level of learning granted by the university and the competencies developed, a CE manager or strategist could be generated, with knowledge, skills, and competencies different from those acquired in the classic careers of engineering, administration, and economics. The professional specializing in CE can develop policies and business strategies based on CE, mitigate the risks in the transition of change, and be a visionary, detecting business opportunities in CE. Likewise, they see the efficiency of resources and organizational models applied to CE [83].

5 Closing Remarks

The circular economy is gradually gaining importance in different countries where policies, legislation, and standards are being applied to improve society's quality of life and the world. However, it is not enough; the process is prolonged and requires the knowledge and application of the model, for which it is considered that the educational centers are the ones that could develop the knowledge and be through the students to support the transition or continuity of a circular model. The innovative educational approach facilitates the change toward a more sustainable society in CE and allows the development of professionals with new knowledge, attitudes, and competencies to apply and manage the new model.

Table 4 Courses, methodologies, and actors related to circular economy

Courses related to circular economy	**Methodology**	**Actors**
CE for business	Practical workshops on circular economy	Policymakers
Sustainability management	Business Cases	Innovative manufactures
Management	Practical problems	Designers
Efficient resource management	Solve problems collaboratively	Environmental organizations
Design and development	Stimulating critical reflection	EC companies
Implications and opportunities for business and policymakers	Learning to value experience, positive and negative experience	International organizations
The consumer perception and behavior		
Micro- and macroeconomics foundations	Creating opportunities for participatory learning	
Innovation and tech innovation	Workshops on challenges and opportunities	
Marketing	Several lectures of CE	
Sustainable firm	Simulation software, gamming	
Elements for agri-food technology	Learning from errors	
Manufacturing, logistics, and inverse logistics	Written reports that include describing results and decisions taken	
Circular entrepreneurship and business models	Real-life cases using "ideal." Framework principles	
Health and environment	Good and bad practices	
Eco-Innovation as an opportunity	Presentation of group work results	
Circular models of production and consumption		
Risks with the CE transition		
Life cycle thinking		

Source Adapted from Giannoccaro et al. [94], Minguez et al. [136], Lanz et al. [120], Kirchherr and Piscicelli [112]

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Leadership for Sustainability in Crisis Time

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Abstract Leadership has been a crucial topic of moving forward in times of COVID-19, and as can be seen in the chapter, it forces having to address different needs, from the death of workers, providing good teams, maintaining commitment, maintaining leadership image, avoiding harmful habits in closing, and mainly, ensuring smooth and effective communication in all teams locally and globally. Many people have passed away, many companies have remained, and that more than ever should drive the focus of academic and research efforts on leadership in times of crisis. About resilience, there is a need to lead processes that have sustainability at their core, specifically with projects that include sustainable indicators and certifications such as footprinting.

Keywords Circular economy · Leadership · Leader · Sustainable development goals · SDG

1 Introduction

Leadership is an urgent requirement in times of crisis, such as the current COVID-19 pandemic for both face-to-face and remote work [115]. World leaders in each country and global institutions should reflect and ask themselves whether this type of leadership is expected to move a country or the world forward with a pandemic ahead. As of December 31, 2021, 281,808,270 people have been infected worldwide,

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and 5,411,759 have died [203]. When we speak of global leadership in times of crisis, we are talking about the leadership necessary for transnational companies to be able to continue with optimal supply chain management to supply their customers in the world with their products, likewise, leadership is expected from governments to take the most balanced and effective measures to control the pandemic in each country. On the other hand, leadership is expected in the medical environment to feel supported and protect patients. Finally, leadership is expected in education, which by moving to the online format became genuinely global, generating that access to education can be from and to any part of the world. Leadership is required in times of crisis to have a vision of sustainability to achieve sustainable results over time.

We present the leadership actions that have been recognized in the world and reported in the academic literature. We also present a pilot leadership outcome and its effects on job performance, and finally, the pending leadership actions required, emphasizing the communication of information, which is the basis for decision making.

2 Before and Current Situation About COVID-19

The world has changed, and people's habits regarding sustainability have changed forever. The companies and people are working hard to reestablish the world they usually live in. The world has changed and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic time. Sustainable education is the cornerstone for leadership that can guide the companies and habitants for efficient use of sources as water and food. In Table 1, it is presented different sectors that have been damaged by COVID-19.

3 The Employee Needs Sustainable Leadership in Times of Crisis

Today's world is characterized by VUCAT (Volatility, Uncertainty, Complexity, Ambiguity, and Technological). These elements cause workers to need leadership that must be addressed continuously [76]. MNEs have to dedicate efforts to ensure that their employees in all their branches can be led in a homogeneous way to have a strengthened global team [66, 205]. Despite the difficulties that workers of all levels have had to adapt to remote work, based on communication technology, an adaptation has been made in general terms, but in many cases, human resources' typical performance has been altered. It must be considered that remote work is a permanent feature for more organizations and companies, which means that institutional leaders at a global and local level design new rules to safeguard the quality of life of workers and at the same time contribute to their higher performance.

Table 1 Impact of COVID-19 in different sectors

Education	Ali [9], Allen et al. [10], Alvarez-Risco, Estrada-Merino, et al. [20], Alvarez-Risco, Del-Aguila-Arcentales, Rosen, et al. [17], Alvarez-Risco, Del-Aguila-Arcentales, Yáñez, et al. [18], T. Chen et al. [57], Lackie et al. [122], Lashley et al. [123], Zollinger and DiCindio [213]
Entrepreneurship	Afshan et al. [4], Alvarez-Risco, Mlodzianowska, Zamora-Ramos, et al. [23], Alvarez-Risco, Mlodzianowska, García-Ibarra, et al. [22], Alvarez-Risco and Del-Aguila-Arcentales [16], Belitski et al. [34], Block et al. [38], Brown et al. [46], Bacq and Lumpkin [29], Chafloque-Cespedes et al. [54], Maritz et al. [135], Liguori and Winkler [129]
Health sector	Abiakam et al. [1], Alan et al. [8], Alsairafi et al. [12], Alvarez-Risco, Dawson, et al. [14], Alvarez-Risco, Del-Aguila-Arcentales and Yáñez [19], Barello et al. [31], Bozdağ and Ergün [43], X. Chen et al. [58], Deressa et al. [79], Koetter et al. [117], Raudenská et al. [159], Rojas Román et al. [164], Yáñez, Afshar Jahanshahi, et al. [207], Zhang et al. [211], Zhang et al. [212]
Hospitality	Duarte Alonso et al. [85], Gursoy and Chi [97], Ho et al. [103], Kaushal and Srivastava [112], Yan et al. [206]
Intellectual property	Altindis [13], Alvarez-Risco and Del-Aguila-Arcentales [15], del Castillo [77], Erfani et al. [89], Jecker and Atuire [110], Krishtel and Malpani [120], Okereke [144], Sekalala et al. [174], Zarocostas [210]
Population	Ahsan [6], Alvarez-Risco, Mejia, et al. [21], Cegarra-Navarro et al. [53], Hanzl [98], Lim and Prakash [130], Quispe-Cañari et al. [153], Sánchez-Clavijo et al. [169], Shaw et al. [176], Wen et al. [202], Wu et al. [204], Yáñez, Alvarez-Risco, et al. [208]
Prices	Apcho-Ccencho et al. [27], Chung et al. [61], Galanakis et al. [92], Hepburn et al. [101], Leiva-Martinez et al. [127], Obergassel et al. [143]
Tourism	Assaf and Scuderi [28], Baum and Hai [32], Brouder [45], Carvache-Franco et al. [50], Fotiadis et al. [91], Carvache-Franco et al. [51], Sigala [178], Carvache-Franco, Carvache-Franco, et al. [52]
Trade	Abudureheman and Nilupaer [2], Acuña-Zegarra et al. [3], Aguirre et al. [5], Alvarez-Risco, Quipuzco-Chicata, et al. [24] Alvarez-Risco, Rosen, et al. [25], Borzée et al. [40], Cruz-Torres et al. [67], Kirk and Rifkin [116], Lopez-Odar et al. [133], Tran [193], Vidya and Prabheesh [197], Yasin Ar [209]
Violence against women	Amarillo [26], Chafloque-Cespedes et al. [55], Dominelli [82], Gulati and Kelly [96], Roesch et al. [163], Sánchez et al. [170], Viero et al. [198]

For this, mainly in multinationals, the CEO and regional and local managers in the areas of Human Resources, Finance, and IT must propose strategies to take care of the companies' human capital in all their premises. Some of the main components that must be secured include:

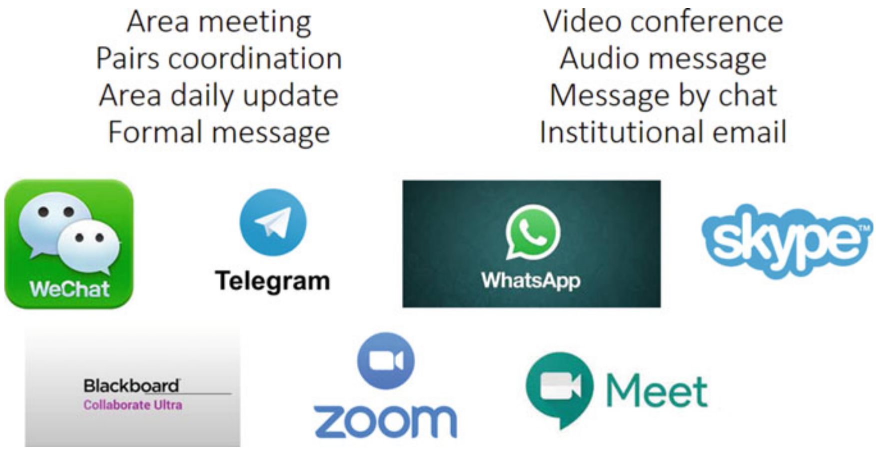

Fig. 1 Activities, type of communication, and alternatives of software

1. Ensure that managers can successfully convey work rules, including annual goals, indicators, activities, and planned schedules. Additionally, it means communication for formal communication [126]. It is relevant that global leadership provides efficient communication in times of pandemic and that it serves after the pandemic to be the efficient way to carry it out [80]. Some concrete examples of standardization of the forms of communication are shown in Fig. 1.

   One example of communication leadership must be the following example:

   a. Do not repeat the myth
   Wrong message
   "It is said that when we are with trusted people in the office, we can stop using masks."
   Correct message
   "You always wear the mask during all the time that I am in contact with people in the office."

2. Ensure everyone has the equipment and the correct connectivity to be carried out at the scheduled times. Everyone is expected to have the same minimal technological tools: webcam, headphones, microphone, monitor, printer, and scanner. Leadership must make workers feel part of the same team with the same weapons. This lack of identification has been a problem in the health field where there have been health workers in the first line of care who have not had the necessary protective equipment for many months and, nevertheless, have continued to save the lives of patients with COVID-19 [71, 125], 131].
3. Evaluate the most suitable descriptions for remote jobs so that effective recruitment can occur for both part-time and full-time workers. Another leadership element that workers tend to manifest is the control they may feel from the company, represented by their bosses, of meeting specific hours in a

manufacturing model. Do people have to be sitting the same hours they were in the office because they are supposed to be productive? Do you think that they should not make the same effort because people are at home? What is the impact of control devices on the image of a leader built in front of the workers? How can a worker feel like a leader, a person who controls them millimetrically through the use of software?

Some current ways to overcontrol employees and do not allow them to create a leadership image include [36]:

- Taking screenshots of employees' screens, making video recordings
- Invisible installs and stealth monitoring features
- Keyloggers
- Instant Messaging app monitoring
- Remote desktop control
- Spying on employees' mobile devices
- Complete communication logs
- VOIP calls spying
- Internet monitoring
- Mobile Keylogger
- Geofencing alerts
- GPS tracking
- Remote control of the infected device along with viewing and blocking specific apps
- Access to the calendar, notes, and reminders
- Surroundings audio recording capability
- Taking over the phone's camera, making screenshots.

4. Ensure that people keep their work, assisting that they can continue to develop their activities despite all the mental effects of the pandemic and also, motivate them to remain focused on institutional objectives [64, 100]. Leadership in the MNE has been reflected in various strategies and commitments, but it is still pending to know what workers expect from their bosses [107]. The urgent need to generate research that allows us to know the impact of leadership and what workers expect from their local and corporate leaders has been recognized [49]. It can be started by conducting studies that link the three main variables: leadership, work environment, and satisfaction. One of the strategies that have been seen throughout the companies is the empowerment of staff skills through the increase and variety of training [86, 166]. The pandemic has also facilitated the global proliferation of Webinars. At a global level, the leaders of companies have understood in most cases that they must retain their talents and must ensure that they can be optimally developed in times of crisis. This distance training also has the advantage of being carried out in the home's comfort, contributing to the work-family balance to achieve employee engagement [56]. Due to all experienced in the global health environment, the urgent need for leadership can be recognized [99, 181]. One aspect that global leaders must prevent and address

is to know the pattern of distraction that employees have due to lockdown. Thus, technostress presence has been recognized [138, 142, 146, 152]. Technostress generates various forms of burnout, which can also lead to increased alcohol consumption at home [182], with all the implications that this entails and an increase in gambling. The institutional leadership must address all these circumstances, achieving that habits are changed, promoting activities in the company that can distract the busy work schedule [44].

Business leadership has responded to the challenge of the pandemic with responsibility and innovation. These attributes are essential for a social actor to operate in an environment of multiple crises: health, economic, environmental, trust, and social. The world continues to undergo rapid transformations. For years, it has faced sustainability-related problems such as biodiversity loss, water scarcity, air pollution, frequent migration crises, and social inequality. When setting these business goals, we often look at the limitations to be overcome, focusing primarily on the profit approach but ignoring the great urgency of addressing environmental, social, and economic issues.

Offering green products and services carries great responsibility as it is expected that the green component of the offer is such. Scientific literature shows that certain companies and individuals have a green expectation of a product when it is not: greenwashing. These previous studies show results from the last 20 years, such as the factors [78], policies [158], evaluation of greenwashing [84], strategies [173], ethical commitment [148], relation with corporate social responsibility [41, 134], impact [74, 149, 185], taxonomy [177], the role of stakeholders [191], the effect of purchase intention [7], and consumer reaction [156]. More recently, a systematic review presented the most recent evidence [73]. Some certifications can help recognize products that deliver on their environmental promise to guide companies and customers. There have been various efforts to encourage companies to obtain sustainable certifications to be standardized. Thus, there are the following certifications:

1. **ENERGY STAR** is the symbol of energy efficiency endorsed by the U.S. government. Thousands of organizations work with the U.S. Environmental Protection Agency (EPA) to deliver energy efficiency solutions that save costs and protect the climate. ENERGY STAR was created in 1992, and over the life of the program, every dollar the EPA has spent on ENERGY STAR has translated into $350 in energy cost savings. A review of the following articles specific to this certification is recommended [42, 47, 105, 147, 155, 160, 184, 201].

2. **Water Sense** is an EPA-sponsored consortia program that seeks to promote efficient water management and bring water-efficient products and services to the marketplace [59, 94, 95, 186, 196].

3. **Cradle to cradle** is a certification that verifies that a product uses safe and environmentally sound materials and is designed for material reuse, recycling, or composting [30, 37, 65, 68, 72, 75, 118–119, 121, 132, 167, 179–180, 192, 200].

4. **Forest Stewardship Council (FSC)** accredits forest managers, manufacturing companies, and controlled wood products that exhibit responsible consumption of forest products. A review of the following articles specific to this certification is recommended [35, 128, 136, 139, 141, 150, 151, 154, 165, 183, 187, 188.

5. **Leadership in Energy and Environmental Design** is a certification that focuses on green buildings. A review of the following articles specific to this certification is recommended [48, 60, 62, 69, 70, 81, 93, 102, 108, 111, 113, 114, 161, 168, 175].

4 Research in Sustainability and Consumers

The development of research that allows management decisions is an urgent issue, given the need for economic reactivation after the COVID-19 pandemic. The authors describe variables that could be part of future studies, which should be quantitative and correlational in order to predict the influence between variables and to be able to organize more efficient strategies. Thus, several studies could be carried out. The following items can be used in Likert scales.

4.1 Behavior of Circular Economy

In Fig. 2, it is presented the items that can be used to test models to explain the behavior of the circular economy.

4.2 Intention of e-commerce

Website Quality

The online purchasing platforms that I use give me detailed information.
The online purchasing platforms that I use give me complete information.
The online purchasing platforms that I use are interesting.
The online purchasing platforms I use have innovative designs.
Information can be easily found on online platforms.

Customer Satisfaction

I enjoy making purchases online.
Interaction is convenient when I use online shopping platforms.
Purchasing online is a good decision to.
Purchasing online is enjoyable.
I am satisfied with the whole experience of purchasing online.

Customer trust

I believe that the companies where I am purchasing online protect their customers.
I consider that the companies that I purchase from online are honest when doing business.
I feel safe when purchasing online.
I believe that the online shopping platforms I use can do business online.
I am sure that the online shopping platforms that I use are reliable.

Attitudes
Recycling plastic waste is good
Recycling plastic waste is useful
Recycling plastic waste is rewarding
Recycling plastic waste is sensible
Recycling plastic waste would give our organization great satisfaction
It is our organization’s responsibility to recycle plastic waste
Subjective Norms
Most people who influence our decisions think that we should recycle plastic waste
Most people inside our organization think that we should participate in recycling plastic waste
Most people outside our organization think that we should participate in recycling plastic waste
Many organizations similar to our organization participate in recycling plastic waste
Our neighboring organizations participate in recycling plastic waste
Perceived Behavioral Control
Our organization knows what items of plastic waste can be recycled
Our organization knows where to take plastic waste for recycling
Our organization knows how to recycle plastic waste
Whether our organization recycles plastic waste is entirely up to us
Whether our organization recycles plastic waste effectively is entirely within our control
Intention of Circular Economy
Our organization intends to recycle plastic waste
Our organization plans to recycle plastic waste
Our organization is willing to put efforts to recycle plastic waste
Our organization is willing to participate or continue plastic recycling
Pressures
International trade regulations
Regional regulations on plastic recycling
Local regulations on plastic recycling
Threat of future environmental regulations
Green strategies of competitors
Environmental awareness of customers
Behavior of Circular Economy
Utilizing eco-friendly packaging
Segregating plastics from other waste
Handing over generated plastic waste to a waste management company
Selling generated plastic waste to other organizations
Reusing generated plastic waste within our organization

Fig. 2 Items to explain Behavior of Circular Economy

Online repurchase intention

When the quarantine ends, I intend to continue purchasing online.
When the quarantine ends, I intend to increase my online purchases.
I intend to buy instead of traditional (physical) purchasing when the quarantine ends.
When the quarantine ends, I intend to use my credit card to make online purchases.

When the quarantine ends, I will recommend my friends/family/acquaintances make online purchases.
When the quarantine ends, if my friends/family/acquaintances ask me for advice, I would recommend purchasing online.
When the quarantine ends, I will not purchase online.

4.3 Intention to Purchase Sustainable Clothing

In Fig. 3, it is presented the items that can be used to test models to explain the intention to purchase sustainable clothing.

Although sustainability professionals have been advocating for years for environmental impact to be integrated into corporate management, with the advent of the pandemic, significant changes have put these issues on the agenda of the CEOs of major companies. Currently, more significant regulatory pressure and activism can be evidenced by an increase in companies' fiduciary responsibility and their leaders.

Perceived environmental knowledge
I know how to behave sustainably
I know how I could lower the ecological harm with my behavior
I understand how I could reduce the negative environmental consequences of my behavior
I understand how to protect the environment in the long-term
Environmental concern
I am concerned about the environmental development
I am concerned about the long-term consequences of unsustainable behavior
I often think about the potential negative development of the environmental situation
I am concerned that humanity will cause lasting damage to the environment
Attitude
Generally, I have a favorable attitude towards the sustainable version of clothes
I am positive-minded towards buying secondhand clothes
I like the idea of buying sustainable clothes instead of conventional clothes to contribute to environmental protection
Subjective norms
My friends expect me to buy sustainable clothes
My family expect me to buy sustainable clothes
People who are important to me expect me to buy sustainable clothes
Purchase intention
I consider purchasing sustainable clothes
I intend to buy sustainable clothes instead of conventional clothes in the future
I might buy sustainable clothes in the future
I would consider buying sustainable clothes if I happen to see them in an online store
Purchase behavior
I choose to buy exclusively sustainable clothes
I buy sustainable clothes instead of conventional clothes if the quality is comparable
I purchase sustainable clothes even if they are more expensive than conventional clothes
When buying clothes, I pay attention that they are sustainable

Fig. 3 Items to explain Intention to purchase sustainable clothing

Fig. 4 Organic recycling process

Globally, leadership is a basis for successful planning. In this period of global resilience, thinking sustainability is the key to making efficient use of the resources available to countries. Various legislative initiatives are being promoted and implemented. Figure 4 shows the organic recycling cycle that must be planned, executed, and monitored. These practices are part of the most recent regulations increasingly demanded by the population.

The regulatory pressure undoubtedly leads to the transformation of sectors and business models that have to comply with their legal obligations and anticipate change to survive in the new paradigm. If sustainability is not made transversal to the business, not only will it be possible for the company to incur non-compliance with the law, but it lose business opportunities, investment, innovation, and competitiveness for the future.

There are several global initiatives to achieve eco-efficient plastic management: the Global Commitment Report [87], the Plastics Pact Network [88], Alliance To End Plastic Waste [11], Commonwealth Clean Ocean Alliance [63], and the UK Plastics Pact [145].

Specifically, the Paris Agreement has been under investigation since 2016, when it was signed [39, 83, 90, 104, 106, 109, 124, 137, 157, 162, 171, 195]. However, recent information shows that the goals set by the Paris Agreement are not being achieved [33, 140, 189, 190, 194, 199] (Fig. 5).

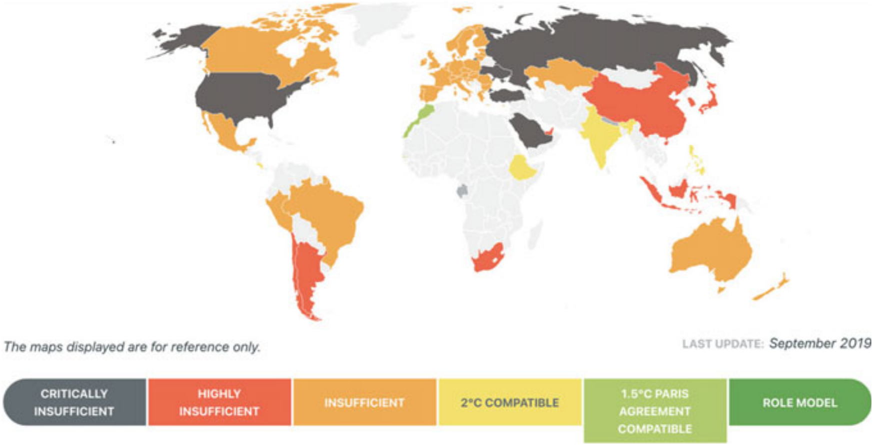

Fig. 5 Compliance with the Paris Agreement

5 Closing Remarks

The current pandemic that is plaguing the world will remain in the memory of each person and company. Each activity developed in this pandemic time is vital because it is the image that remains in the memory of all the people in an organization and is a predictor of the engagement that workers have concerning their leaders. Companies need to work on leadership at all levels so that all the directory measures are reflected in the most peripheral workers since they are direct with direct customers and finished products. Let us look at the future we want to create from global leadership. All the latter shows that leadership is required to achieve the goals set globally.

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Circular Economy for Food Loss Reduction and Water Footprint

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Abstract Food loss is a global problem with significant social, economic, and ecological impacts. According to the Food and Agriculture Organization (FAO), a third of the food produced globally is lost or wasted along the food supply chain (FSC). Food requires water for its production. This water consumption can be measured under the WF indicator's Water Footprint (WF). This indicator makes it possible to measure fresh water's direct and indirect use throughout the food supply chain. Estimates of the water footprint of crop production range between 5,938 and 8,508 km^3/year. The greater the loss or waste of food, the greater the water consumption. Therefore, applying strategies related to the circular economy is an alternative solution. This chapter provides the relationship between food loss and the water footprint to provide alternative solutions under the circular economy model.

Keywords Circular economy · Food loss · Water footprint · Global trends · Impacts

1 Introduction

Globally, firms and citizens try to reestablish the world they usually live in, but it is not possible. Even recent news about new variants of COVID-19 pushes the governments and people to keep their lives according to the protocols. So what has been the damage due to COVID-19? The world has changed and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life [14, 17, 18, 22, 23, 26, 30, 32, 33, 64, 66, 73, 112, 129]. The world has changed and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life.

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Table 1 Impact of COVID-19 in different sectors

Education	[9, 10, 24 19, 20, 59, 103, 104, 166]
Entrepreneurship	[5, 16, 27, 28, 38, 41, 42, 47, 55, 107, 110]
Health sector	[1, 8, 11, 13 21, 39, 44, 60, 67, 99, 125, 130, 157, 163, 164]
Hospitality	[71, 87, 91, 95, 156]
Intellectual property	[12, 15, 65, 74, 94, 100, 122, 135, 162]
Population	[7, 25, 53, 88, 108, 123, 132, 136, 154, 155, 158]
Prices	[35, 62, 82, 90, 105, 121]
Tourism	[36, 40, 46, 50, 51, 52, 80, 137]
Trade	[2, 3, 6, 29, 31, 43, 63, 98, 109, 145, 150, 159]
Violence against women	[34, 56, 70, 86, 128, 133, 151]

Sustainable education is the cornerstone for firms and the population to ensure the efficient use of sources as water and food. In Table 1, it is presented different sectors that have been damaged by COVID-19.

According to the Food Loss and Waste Protocol, a global partnership, FLW refers to the decrease of food during the whole food supply chain. On the one hand, Food Loss (FL) decreases food during the following food supply chain stages: production, post-harvest, and processing. On the other hand, Food Waste (FW) is food in good condition to be consumed, discarded at the end of the food supply chain [152].

As part of the productive process of food harvesting, the water footprint is a factor to consider when talking about the FL and FW; it refers to the quantity of water used for people's consumption in any aspect. Water footprints of nations are the water used by inhabitants as a function of their consumption pattern. A solution to counteract these problems, the concept of circular economy (CE), has become a trend and is increasingly attracting the interest of academics and professionals because it is taken as a form of operationalization for companies to implement the concept of sustainable growth [83, 120]. Information has been compiled on the amount of FL and FW worldwide, information was added on the places where they are primarily generated and the factors surrounding each one, the amount of FL generated by one person per year and what is generated during the production process, distribution, sale, and consumption by people. Moreover, the environmental, social, and economic impacts of FL and FW were analyzed.

2 A Review of Circular Economy

The classic linear model that we have today of extraction-production-use-discharge of material and energy flow of the economic system turns out to be unsustainable [81]. As a complement and to facilitate the reader's understanding, the linear economy model is shown in Fig. 1. The materials cycle initiative has been from the beginning

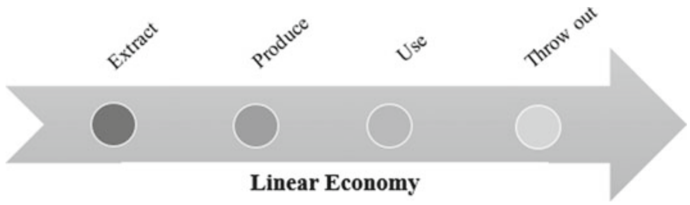


Fig. 1 Linear economy model (*Source* REPSOL [127])

of industrialization and has been put into practice linked to the idea that it reduces the negative impact on the environment and promotes novel trade opportunities throughout the origin of industrialization [68, 69].

However, this linear performance model has established itself in the business world by taking control of general development and causing dangerous damage to the environment. Many people make, use and dispose of the products; in fact, a third of the plastic waste in the world is not collected or managed. Nevertheless, the concern for the ethics and the stability of the resources and the reduction of greenhouse gases begins to be more noticeable and changes the way of seeing the materials. People believe that materials should be preserved rather than constantly consumed and thrown away [138].

According to Keijer et al. [96], awareness of the finite characteristic of many resources and limited environmental tolerance by the chemical industry has increased highly during the last decades. Therefore, they argue that the current linear economy approach of "take, make and dispose of" should be replaced by a new approach to a circular economy (CE). This business-oriented approach emphasizes reusing products, materials, and components, applying remanufacturing, repair, renovation, and improvement processes, and promoting the use of solar, wind, biomass, and other sources derived from waste obtained from the entire product manufacturing process [45, 114, 124]. Zacarías Farah [161] points out that changing the way it is produced and consumed is essential, moving toward the CE model in which production cycles are closed, and an uninterrupted flow of natural resources is maintained.

CE is born primarily in the literature through 3 main "actions," which are called the Principles of the 3Rs: Reduction, Reuse, and Recycling [58, 106, 126, 131, 142, 160, 165].

Charonis [57] establishes his definition of CE based on the vision of the Ellen MacArthur Foundation [72], explaining it as a system made to restore and regenerate. Likewise, it is defined as an economic system that replaces the idea of "end of life" with reduction, the option of reuse, recycling, and recovery of materials in the production, distribution, or consumption processes [97]. According to a current report from the United Nations Environment Program in 2018, titled Re-defining Value—The Manufacturing Revolution, the CE could minimize industrial waste between 80 and 99% in some sectors. In the same way, it would reduce its emissions between 79 and 99%, with optimal results that drive its application [161].

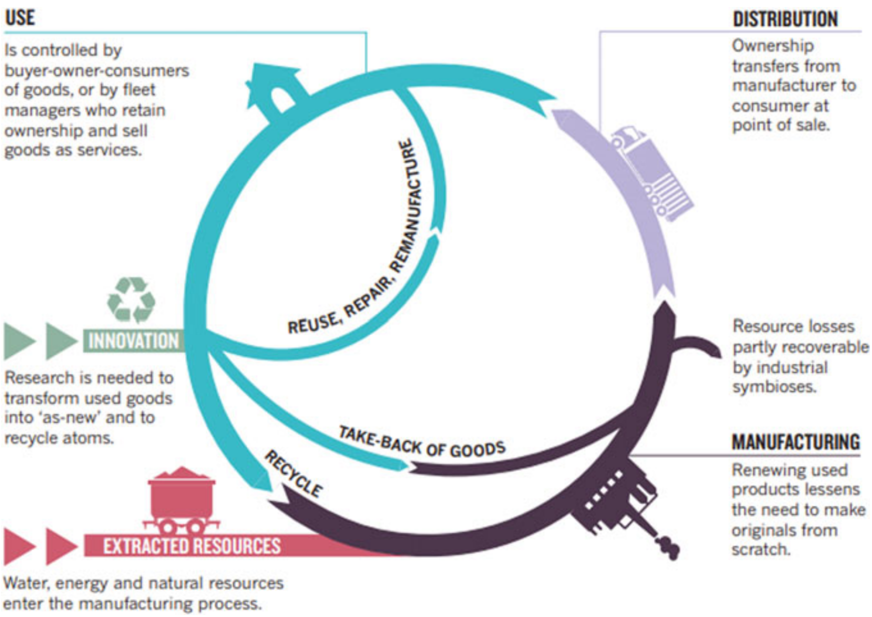


Fig. 2 Closing loops model (*Source* Stahel [138])

A balance would be achieved between the environment, the economy, and society. The CE serves as a tool to develop and create policies related to environmental care and bottom-up stewardship [83]. Thus, by applying this new economic model to achieve sustainable practices, companies contribute to the care and preservation of the environment and cause positive impacts on a social and economic level. Following this line, Fig. 2 shows a CE model called "Closing loops," which applies those above, focusing on transforming the goods in the last stage of their useful life into resources for others, uniting and closing ties in industrial ecosystems decreasing amounts of waste.

3 Food Loss: Data Analysis and Impact Study

3.1 Global Food Loss Trends and Data

According to the Food and Agriculture Organization of the United Nations [76], one-third of the food produced globally is lost or wasted throughout the FSC. It is essential to understand the difference is between food loss and food waste (PDA). Both concepts refer to decreased mass or nutritional value of foods during FSC. According to the United Nations Environment Program [146], the main difference is that food loss refers to food that spills, spoils, or loses its quality before its final product stage. The concept of food waste refers to those products that are discarded or not consumed in the form of a final product when it is fit for consumption.

According to the "Food Waste Index 2021," in 2019, around 931 million tons of food waste were generated, which indicates that almost 17% of world food production was wasted. This figure indicates the ineffective or non-existent residual treatment that food receives when lost or wasted. In Spain, for example, a small part of the FLW is used for aerobic composting systems or receives heat treatment. However, most FLW is sent to landfills [92, p. 3]. These strategies are essential to consider since it is estimated that between 8 and 10% of greenhouse gases are produced due to lost or wasted food. The UNEP study found that most of the food waste comes from households, followed by food services, and finally, retail Fig. 3 shows the distribution of food waste by sector in percentage and metric tons.

Data indicates that 61% of food wasted comes from households, which is explained by various situations, for example, those foods that were bought but not consumed or those that lost quality and nutritional properties because they expired. On the other hand, 26% of food is wasted in food services (i.e., places consumed outside the home) because the end-user does not consume all the food he asks for. 13% of wasted food is generated in supermarkets due to improper handling, distribution, or the disposal of products that have not been sold. Figure 4 shows the amount of food (in kilograms) discarded per person in each sector in 2019.

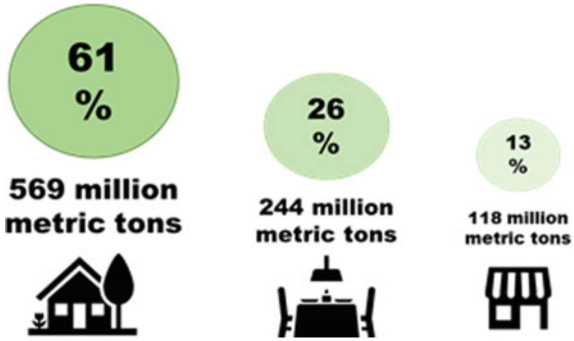


Fig. 3 Total food waste generated by the sector (*Source* UNEP [146])

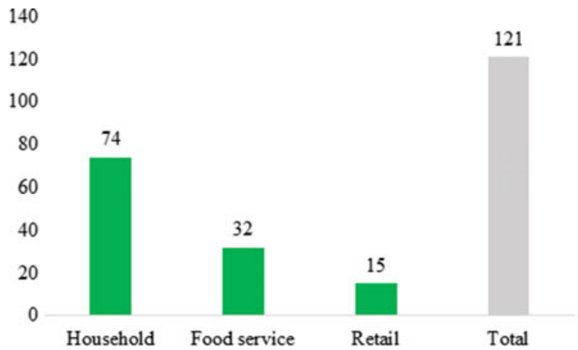


Fig. 4 Per capita food waste generated by households worldwide (*Source* Statista [139])

As indicated in the figure, approximately 121 kg of food was discarded per person in 2019. It is essential to be able to reduce this amount of food loss. We could relate this data to Sustainable Development Goal 12.3, which states the following: “By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses” [76].

It is necessary to achieve reducing the amount of wasted food can be achieved by using different strategies not only at the end consumer level but by being more efficient and controlling the food distribution processes throughout the FSC. Policies and strategies are highly dependent on FSC processes. Figure 5 summarizes the loss levels at the FSC level.

During the FSC, we could apply strategies to achieve the SDGs. Compliance with the Sustainable Development Goals is ideal for reducing food loss or waste during the different FSC processes. On the other hand, the per capita food waste and loss trend generated mainly by households show an exciting characteristic to analyze at the regional and country level. Figure 6 shows the food waste generated by households in 2020; the units are expressed in millions of metric tons.

Fig. 5 Levels of food loss throughout the FSC (*Source* United Nations [147])

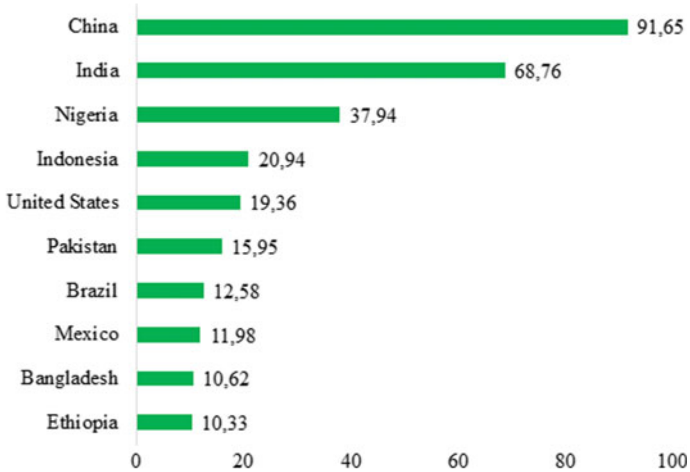


Fig. 6 Annual household waste produced by selected countries around the world in 2020 (million metric tons) (*Source* Statista [140])

As shown in Fig. 6, the levels of waste at the household level express similar amounts in high-, middle-upper-, and middle-low-income countries [146]. For example, food waste in Nigeria is 37.94 million metric tons. By way of analysis, Nigeria has a lower middle income than China or India,in addition, the prevalence level of undernourishment in that country in 2019 was 14.6% [144]. West Asia and sub-Saharan Africa countries have the highest per capita food waste at the domestic level [146]. Therefore, it suggests that the problem of food waste is not an exclusive problem in developed countries but also in developing countries that impact a social, economic, and environmental level.

3.2 Impacts of Food Loss

The social impact of food loss is related to hunger, and malnutrition is the primary social consequence. The world food production is increasing, malnutrition, far from decreasing, continues to grow. To understand this relationship, we define food loss as the decrease in volume of produced food fit for human consumption because it is discarded during the production, distribution, and marketing stages, while food waste refers to food fit for consumption discarded on purpose.

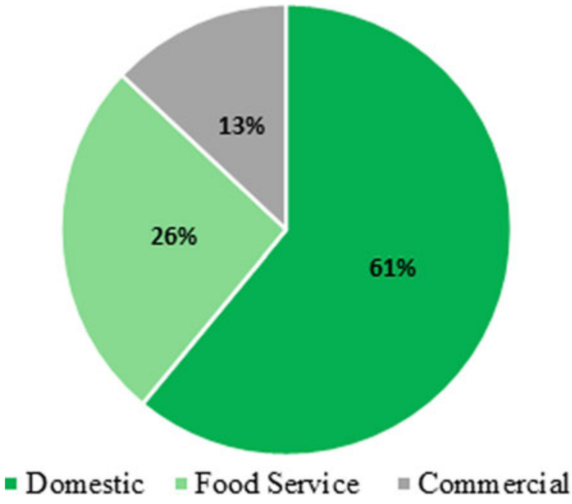
Likewise, hunger is defined as the deprivation of food, and the concept of malnutrition refers to disorders resulting from an imbalance of nutrients in the body. For the present book, three forms of malnutrition were considered: stunting in children under 5 years of age, anemia in women of reproductive age (15–49 years), and overweight (including obesity) in adult women (18 years and older), because they are the most common forms in the countries of the world. As previously mentioned, the Food Waste Index report [146] indicates that around 931 million tons of food waste were wasted in 2019. Further, Fig. 7 shows that 61% came from households, 26% from food services, and 13% from commercial establishments.

The Food Waste Index report [146] also reports that between 17 and 18% of global food production fit for consumption (plus inedible parts such as shells, seeds, and bones) ended up in a household, retail, restaurant, and other foodservice landfills. Figure 8 shows that 11% of the waste comes from households, 5% from food services, and 2% from commercial establishments.

The FAO Undernourishment Prevalence Indicator calculates a range of the population suffering from food energy sufficiency. It serves to control and monitor hunger at the global level (view Fig. 9) and even regionally since the data cannot be disaggregated sufficiently to track vulnerable populations within each region. For this report, the averages presented each year are used.

According to this indicator, it is estimated that between 766 million people suffer from food insufficiency (9.9% of the world population). Also, it is essential to highlight the significant difference between the average estimate of the range of 2019 and 2020, people suffering from food insufficiency increased from 650 million people in 2019 to 766 million in 2020; that is, in just one year, there was an increase of approximately 116 million people suffering from food insufficiency. Moreover, taking the

Fig. 7 Global Food Loss in 2019 (*Source* UNEP [146])



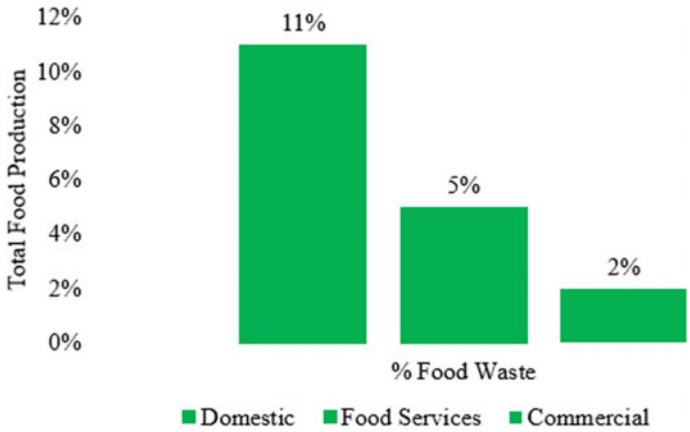


Fig. 8 Global Food Waste in 2019 (*Source* UNEP [146])

higher value of the 2020 range, 811 million people, the difference increases to 161 million people.

Considering that 933 million tons of food are lost, and 18% of total food production is wasted annually, it is inevitable to mention the relationship between food loss and waste and the hunger suffered by 766 million people (9.9% of the world population). In addition, approximately 2.3 billion people (30% of the world population) do not have access to a healthy diet, so it is essential to reduce these amounts to help people with fewer resources.

Finally, another point to consider as part of the social impact is food insecurity. Food security exists when people have physical and economic access to nutritious and safe food to have an active and healthy life [75]. Food insecurity involves a high

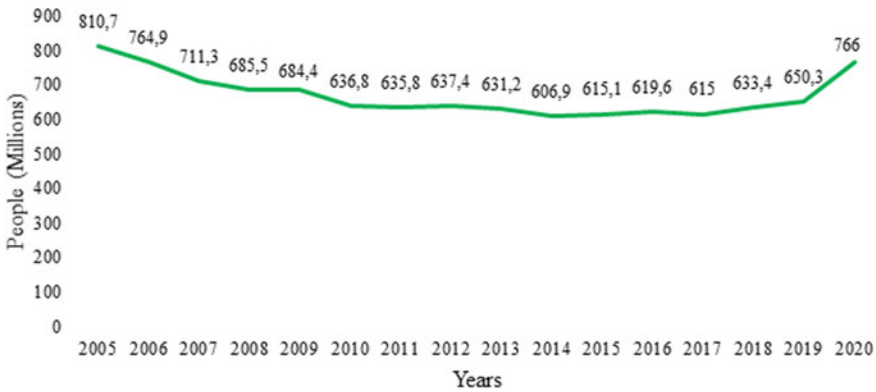


Fig. 9 Indicator of Prevalence of Undernourishment (Millions of people) (*Source* FAO [79])

degree of social impact since it arises from violence against women, climate change, and informality related to mass migration [149]. We could add that the loss of food also generates food insecurity. Around 690 million people suffer from hunger,despite that high-impact figure, food continues to be lost and wasted throughout the FSC. Food loss and waste must be reduced to improve food security levels.

The economic impact of food loss generates a series of economic costs, which impact each country's economy. According to FAO [78], the costs in the environmental sphere were the US$ 700,000 million, while in the social areas, they were US$ 900,000 million. The costs of food loss increase every year. In 2018, the amount of food lost was 2,100 tons, equivalent to US$ 1.6 billion [89]. However, companies and institutions' collaboration helped reduce costs significantly by $ 700,000 million. Table 2 shows the costs incurred for years according to social and environmental impacts.

Insignificant changes in society's thoughts and the behavior of institutions about food loss have influenced economic failures [102]. For Morone et al. [119], the

Table 2 The economic impact of food loss in US$ (billions per year)

Impacts	Costs
Emissions of greenhouse gases	US$ 394
Water scarcity in arid and dry regions	US$ 164
Soil erosion (due to the dismissal of nutrients, reduced yield, and biological deuterium)	US$ 35
Loss of resources due to soil erosion	US$ 32
Health damage from pesticide use	US$ 396
Repercussions on biodiversity due to pesticides, phosphates, and losses of pollinators	US$ 333
Risk of conflicts due to soil erosion and use of natural resources	US$ 153

Source FAO [78]

valorization of food loss requires the help of public and private institutions. Morone et al. [118] consider that a change in ecological behavior, economic awareness, and improvements in collaborative behaviors is necessary (p. 14). In this sense, Hegnsholt et al. [89] mention that five factors cause food loss, but proper management offers to save each aspect. Factors include lack of awareness that US$ 260 billion can be saved, supply chain infrastructure US$ 150 billion, chain efficiency US$ 120 billion, food chain collaboration in US$ 60 billion, and regulations US$ 110 billion.

The savings in each factor are based on the expenses made in recent years. The amount of food lost increases by around 1.9% per year until 2030, and the dollar is 1.8% per year [89]. In other words, the increase in the environmental loss of food and the increase in the dollar are related, generating a more significant impact on the economic, social, and social spheres. Figure 10 shows the costs incurred due to food loss in recent years and projections until 2030.

The environmental impact of food loss occurs in agricultural production because various natural resources are used, such as water, soil, air, among others. Chaboud and Daviron [54] mention that FLW produces an effective use of essential resources for food that are not used (p. 5). The waste of resources with food that was never consumed is evident throughout the supply chain. According to FAO [79], the environmental impacts of food loss are calculated from the life cycle analysis based on calculations of greenhouse gas (GHG) emissions and water and land use footprints. The environmental impacts of food loss cover four main aspects: biodiversity, carbon footprint, water use, and land use [79].

Biodiversity is an essential aspect that producers require to give good harvests, but the loss of food causes environmental damage that affects food crops for society [79]. For this reason, large companies consider the environmental factor as the greatest motivation to reduce food losses [102]. According to Chinie et al. [61], the mitigation of food loss can be done through reduction, reuse, recovery, and elimination (p. 2).

The land is one of the essential resources for the harvest and production of food. The degradation of this resource due to the loss of food causes damage to food production and the yield of fertile fields. According to Kummu et al. [101], the farmland used to grow these lost foods is 198 million hectares per year. The foods that most use the land for its cultivation are meats and dairy products, representing

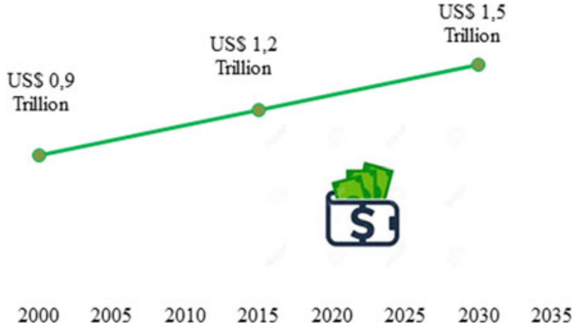


Fig. 10 Increase and behavior of waste loss costs in trillions of dollars from 2000 to 2030 (*Source* Hegnsholt et al. [89])

78%, while the loss of food represents 11% of the total surface [77]. The carbon footprint is another aspect affected since it relates to the number of greenhouse gases caused by food production during the life cycle. According to Statista [141], 10% of global greenhouse gas emissions are caused by food loss. For Mbow et a. [111], 8 to 10% is related to uneaten food (p. 200). The food loss index concerning the agricultural phase generates emissions of 16%, the post-harvest 16%, while in the processing, it produces 14% of emissions compared to the total generated by food production [77]. Finally, water is used in agricultural production worldwide, representing 92% of the available water in the world. According to FAO [79], the water used for the lost food is abundant since the representativeness of this resource exceeds the averages of water use compared to countries such as India and China who have a large population water consumption is high. In this sense, food loss substantially impacts water [79].

4 The Connection Between Food Loss and the Water Footprint

Water is the essential natural resource for food production after soil. However, this resource's indiscriminate use makes it increasingly scarce and overexploited worldwide [92]. To assess the impact of water consumption on food production, Hoekstra and Hung initially quantified virtual water (VA) flows from international trade in crops. These authors popularized the concept of the Water Footprint (WF) in 2002. As a concept, the water footprint is an indicator that measures the direct and indirect use of freshwater throughout the entire supply chain. The water footprint is divided into three components classified by color: blue (surface and groundwater), green (rainwater stored on the ground), and gray (contaminated water in the production process) [93]. It should be noted that the water footprint is not an indicator that measures the severity of the local impact on water consumption, but rather, it is a volumetric measure of water consumption.

Many economic sectors use water resources for their production processes. Agriculture has become the economic activity with the highest water consumption. By 2050, agricultural production is expected to increase by 50% compared to 2012 [113]. Increased agricultural activity could lead to higher water consumption. Agricultural products have a great demand for water resources [49].

Broadly, the food supply chain (FSC) can be divided into five main stages: (1) agricultural production, (2) post-harvest handling, (3) processing, (4) distribution/retail, and (5) consumption [4]. These stages involve harvesting the product under certain environmental conditions to consumption by the end-user of the supply chain. During FSC processes, much food is wasted, causing food loss problems worldwide. However, there are several ways to quantify food loss during FSC, the most widely used method is mass flow analysis that measures variations in the volume of certain products during FSC processes [48]. Applying methods that quantify food loss is ideal for establishing FSC processes policies. Some studies have focused on estimating the water footprint based on crop production. The differences in the estimates are mainly due to quantification techniques and modeling approaches, as well as externalities related to the environment in which the food is grown, including climate, number of crops, treatment, among others. In general, estimates of the water footprint of crop production range between 5,938 and 8,508 km^3/year [113]. Many investigations that estimate the water footprint in agricultural products, derivatives, and animal products have expanded the subject's knowledge. One of the most widely used studies for water footprint research was developed by Mekonnen and Gerbens-Leenes [113]. Hoekstra et al. [93] used a grid-based water balance model to calculate water use during a period for different crops. According to FAO [76], there are seven essential products between agriculture and animals, lost or wasted on a smaller or larger scale depending on the region under study. The groups are divided into Cereals, roots and tubers, oilseeds and legumes, fruits and vegetables, meat, fish, and dairy products. Table 3 is helpful to analyze the relationship between food loss and water footprint in more detail.

The data indicates that farm animal products require higher water consumption per kilogram production. The table shows that beef has a water footprint of 15,415 l/kg. This product is highly commercial and used by large restaurant chains worldwide; not only that but its consumption is linked to its importance as a source of protein, which has increased its demand [85]. However, as we have been pointing out, during the FSC, beef also suffers losses and waste that are not used efficiently. Table 4 shows lost or wasted beef during the five main FSC stages.

Table 3 The global average water footprint of agricultural and farm animal products

Product	Global Average Water Footprint (l/kg)			
	Green	Blue	Gray	Total
Agricultural products				
Beans, dry	3,945	125	983	**5,053**
Wheat	1,277	342	207	**1,827**
Rice	1,146	341	187	**1,673**
Barley	1,213	79	131	**1,423**
Apples	561	133	127	**822**
Bananas	660	97	33	**790**
Potato	191	33	63	**287**
Farm Animal Products				
Beef	14,414	550	451	**15,415**
Pork	4,907	459	622	**5,988**
Chicken meat	3,545	313	467	**4,325**
Egg	2,592	244	429	**3,265**
Milk	863	86	72	**1,020**

Source Hoekstra et al. [93] and Gerbens-Leenes [113]

Table 4 Activities that generate the loss or waste of beef throughout the FSC

Stages of the FSC	Activities that generate loss or waste
Production	• Animal deaths during breeding • Animals that are discarded for presenting diseases • Loss or misplacement of cattle
Handling and storage	• Deaths during transport to the slaughterhouse
Processing	• Industrial processing to produce derivatives (e.g., production of sausages) • Unused animal waste
Distribution	• Loss or waste in the market system. Unsold products that are thrown away
Consumption	• Loss or waste in household consumption • Product exposed to suboptimal conditions that cause rotting of the meat • Uneaten meat waste

Source FAO [77]

The activities described suggest that beef suffers loss and waste throughout the FSC. Strategies to reduce the amount of beef lost during the first two stages (i.e., production and handling and storage) may be challenging to implement because both stages require knowing the health status of the animals and whether they are suitable for consumption. However, numerous strategies could be applied at the final consumer level to reduce beef consumption and, therefore, the water levels required to produce this food. An alternative—among many others—could be to generate changes in eating habits. The impact would be significant in the long-term considering that the average meat consumer requires 16 Olympic pools of water to produce the meat they eat. At the country level, the annual water footprint for the crop sector (i.e., agricultural products except for farm animal products) reaches up to $1*10^{12}$ m^3/year. Figure 11 represents the annual green, blue, and gray water footprint for agricultural products in different countries.

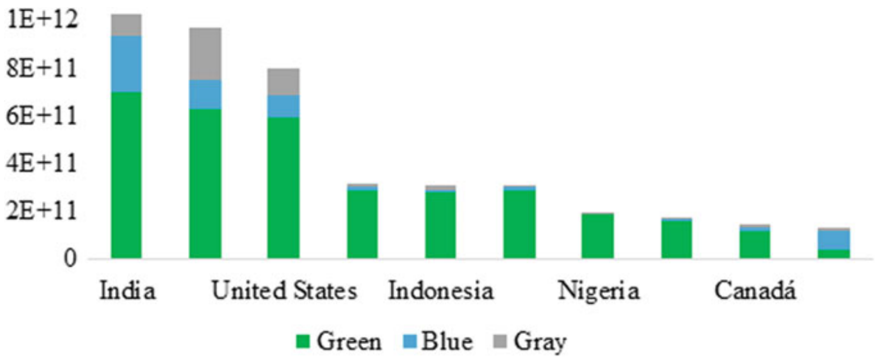


Fig. 11 Green, blue, and gray annual water footprint of agriculture (all crops) in the world by country (*Source* Water Footprint Network [153])

Based on the data recorded in the previous figure, the green water footprint is predominant in most selected countries, reaching levels of up to $7*10^{11}$ m^3/year. It is interesting to show that those countries that lose or waste food in more significant quantities have a higher annual water footprint record. In general, policies and strategies must be applied to reduce food loss and, therefore, the water footprint.

5 Food Loss Prevention and Management Options

Regarding the reduction or prevention of food loss, it is essential to create a zero hunger world and to achieve the Sustainable Development Goals (SDGs), especially SDG 2 (Zero Hunger) and SDG 12 (Ensure sustainable consumption and production patterns). Many people on the planet take food for granted, but the food is not guaranteed for the staggering 820 million-plus people who go hungry. FAO aims to increase respect for food, as well as for the farmers who produce it, the natural resources that are used to produce it, and the people who do not have access to it [79].

In Argentina, with Ministerial Resolution 392 of 2015, warned against the opportunity cost left by not making use of food and turning it into waste, establishing basic guidelines to combat problems, such as research, production of initiatives, technology immersion, communication, practical training, and partnerships [115]. Similarly, as in the case of the reduction in salt consumption, augur good results [37]. Argentina adopted the Sustainable Development Goals (SDGs) to the national context and, based on a diagnosis of the territory, was directed toward the quantification of losses and waste [134].

In Chile, it was approved Law 20.920, the Framework for the Management of Waste, Extended Producer Responsibility and Promotion of Recycling, granted powers to the Ministry of the Environment to prevent the generation of waste that, according to PASO balance sheets, are entirely avoidable [117].

Recycling Law (Universal Recycling Law) seeks the involvement of the most significant actors in the process. For the United States Department of Agriculture (USDA), there is great importance in the climatic variability and food refrigeration, as this helps stop microbial growth [148]. Among the proposals of the recent North American legislation, the one of Vermont with its Universal Law stands out. First, it expressly prohibits the incineration or landfilling of materials commercial organic, which includes food and other plant materials generated by all kinds of entities, in an amount more significant than one ton per week [143], which directly involves large producers of waste such as marketplaces, supermarkets, and the food industry.

6 Water Footprint Management Options

It is essential to indicate that water's responsible use and management represents a concern worldwide regarding the water footprint. According to the United Nations, the water footprint directly impacts the fulfillment of the Sustainable Development Goals of the 2030 Agenda of the international organization. It is worth noting that SDG 6 mentioned the following: "the sustainable management of water and sanitation and the objective is to increase the efficiency of water use in every sector and guarantee the sustainable harvest and allocation of water resources to face scarcity of water…." In this sense, water footprint policies and initiatives are closely related to the objectives agreed by governments to make fair and sustainable use of water in various sectors.

In several Latin American and Caribbean countries, governments have shown great interest in conducting water footprint assessments to monitor compliance with their mandates for the sustainable management of water resources. The Economic Commission for Latin America and the Caribbean (ECLAC or CEPAL) has identified outstanding initiatives in Peru, Colombia, Chile, Brazil, Argentina, Mexico, and Ecuador. Next, the proposals of some of the countries above are explained in detail.

In Peru, the National Water Authority (ANA) began operations in 2009 as the governing body of the National Water Resources Management System. Thanks to the joint work between the ANA and the Ministry of Water and Irrigation, several studies related to the concept of water footprint have been carried out in various sectors. It is noteworthy that, in 2018, the standard promotes the measurement and voluntary reduction of the water footprint and the shared value in the hydrographic basins with scope throughout the country. The latter aims to measure and reduce the water footprint and implement actions of shared value in the basins. The so-called Water Footprint Program comprises activities that seek to reduce consumption and impacts resulting from water resources and the development of social responsibility actions. The program led by the Directorate of the National Water Resources Information System of the National Water Authority is voluntary and, to identify the participating users, they are awarded a so-called Blue Certificate. In other words, the volunteers are recognized with a certificate as hydraulically responsible and supportive users, for which they indicate the operating unit, process, or product based on which their water footprint was measured and reduced.

In Colombia, the Ministry of Environment and Sustainable Development (MINAMBIENTE) and, more specifically, its Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) has investigated and applied the concept of water footprint since 2009. In 2014, it carried out multisectoral research on the blue and green water footprints in the agricultural, industrial, energy, and oil sectors. In addition, it is worth noting that the domestic sector was included. As a result, in the agricultural sector, it was obtained that the most important crop in the country, in terms of water footprint (HH), is coffee. It is also important to note that the study above followed the methodology and definitions presented by the Water Footprint Manual [93], published by the Water Footprint Network.

In Chile, the General Water Directorate (DGA) evaluated HH and a pilot study in the Rapel river basin in a joint effort with Fundación Chile [116]. As a result, based on socioeconomic and environmental indicators, the areas in which water consumption is not sustainable were obtained. In this way, the DGA can prioritize actions to reduce HH in those regions. The evaluation of water consumption included all production sectors, such as domestic, forestry, agriculture, mining, energy, and industrial, to have a complete vision of the situation in the territory under analysis. Therefore, it represents a significant contribution to improving sustainable water management. In Table 5, a summary of the essential tools that can be used concerning the water footprint is presented.

Table 5 Most essential tools that can be used concerning the water footprint

Tool	Description
AWS	A water management platform that provides a detailed description of sustainable water management at the local level
CDP Water Disclosure	A platform to "reveal" corporate water. It allows corporations with the most significant potential to be impacted by water management to show their actions and impacts on this resource
Ceres Aqua Gauge	The dashboard allows investors to rate the water management activities of a company under sustainability and water security criteria
CEO Water Mandate	A framework that offers standard corporate water disclosure metrics and provides guidance to determine the relevance of the report content
Water Risk Filter	Water risk assessment tool, including mapping, mitigation responses, case studies, and country profiles. The latest version includes a water risk assessment for agriculture with specific indicators, questionnaires, and responses
WBCSD—Global water tool	Excel application available for companies. It allows ordering the information for different indices, such as CDP Water, Bloomberg, GRI Report, and Dow Jones, depending on the location, use of water, and the characteristics of the user's wastewater
WRI Aqueduct	A tool that allows knowing the water risk online with a robust geo-referenced data functionality. The key indicator is the "water stress at baseline" indicator developed by WRI
SWAN system tool	The system is used to provide a sustainability indicator for farms. The first time, it forms the SWAN sustainability score according to the farm. Process updates and measurements are compared to this baseline, showing farmers their progress over time

Source Gomez and Inthamoussu [84]

7 Closing Remarks

The implementation of a circular economic model helps companies achieve that change toward sustainability that is so sought after today, at the same time improving the corporate image and promoting their growth in the market both locally and internationally. In this way, they contribute and promote the proper use of resources that exist in nature in a limited way, such as water. All foods, in general, require the use of water for their production. Beef has been determined to be one of the foods with a higher water footprint than agricultural products (approximately 15,415 l / kg). The loss of food throughout the FSC is directly related to the levels of water footprint in each product when food is lost or wasted, water is lost, and the energy that the product can provide. The application of strategies and policies should not focus only on the final stage of the FSC but rather on the initial stages such as harvest, post-harvest, handling, and distribution. The application of the circular economy is ideal for solving the problem under study. The loss and waste of food generate a moral dispute in society since the lack or waste of a resource that is difficult to access for millions of people is caused to reflect on the importance of reducing food loss and optimizing its use, especially in households, since these are the places where the most significant food loss is generated. Thus, a new approach to global food production through food optimization was feeding more people what is already produced is more relevant than maximizing food production.

The money spent on food that is not consumed ranges between the US$ 35 billion and the US$ 1.6 billion, showing a tremendous economic loss. In the same way, the environmental environment suffers damage because the agricultural sector is one of the industries that most use natural resources to harvest, produce, and process the food consumed and not consumed. However, the union between society and institutions could help reduce these impacts related to food loss for greater sustainability. To do this, it must start from a change in awareness about the damage caused by food loss through its supply chain and changes in regulations and improved chain efficiency.

Therefore, there are various initiatives in many countries to combat food loss and adequately manage the water footprint that has been carried out. It is exciting that many systems can support large corporations and companies to control their sustainable water management about managing the water footprint. All of this marks an important precedent and a source of inspiration for further similar or innovative initiatives to address concepts relevant to all the world's inhabitants.

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3D Print, Circularity, and Footprints

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Abstract 3D printing is part of the advanced technology that is beneficial in many areas such as construction, packaging, and medicine because it can create objects that can offer a better understanding of specific prototypes or models that you want to study. In addition, it also allows a smaller-scale production with lower costs for companies, so its use represents a comparative advantage and allows creating complex and more personalized designs to offer to its customers. In general, three-dimensional printing represents an efficient form of production that has a wide range of possibilities for its use. However, it is essential to know its impact at the environmental level to manage better and control its use. In the present work, we seek to know the relationship between circularity and three-dimensional impressions and the carbon footprint on the planet. Different sources and comparisons were made, and examples were proposed to explain and describe each previously proposed relationship to meet the research objective. The analysis results concluded that the impact was undoubtedly less than traditional production methods but that there is much room for improvement to reduce further the footprint left by 3D printing, such as a change in the use of materials. On the other hand, it is possible to achieve 3D prints that are circular and sustainable over time by making the necessary efforts. Additionally, the requirements for sustainable production through 3D printing must be not only feasible but also accessible to all to make a real change starting from the smallest companies and individuals that use this technology to the mass productions made by large companies.

Keywords 3D-printing · Circularity · Footprints · Sustainability · Three-dimensional · Additive manufacturing

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1 Introduction

The world has changed, and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life. Due to limited sources by COVID-19, new ways to build new materials are essential in the reactivation of the global economies. The 3D print is a significant opportunity to create new materials for sustainable factories. The world changed and people's habits about sustainability have changed too, related to characteristics before COVID-19 pandemic mainly in health regulation [100], [24], [30], [27], [124], [29], healthcare service [137], [23], [26], [25], [81], [121], healthcare management [74], education [134] and sustainability ([10], [32], [31], [75]. Sustainable efforts are needed for companies and the inhabitants to promote the efficient management of 3D printing. Table 1, present the different sectors that the COVID-19 pandemic generated.

For decades, three-dimensional printing (3-D printing), also known as additive manufacturing (AM) or rapid prototyping, has existed due to the development of the 3D printer in 1984 [119]. In the beginning, the technology was prohibitively expensive and unavailable to the ordinary public [43]; now, due to technological advances over time, it is possible to create prototypes and objects quickly and easily for visualization and interaction. It is one of the most disruptive technologies of these times that could even cause a third world war [160].

Previously, a combination of texts and images or videos was used to understand a process or model; nowadays, because of the 3D printer, people can create 3D objects as well, which are used in different areas and can bring different benefits [43, 116]. The operation of 3D printers consists of creating three-dimensional pieces through the use of raw materials that are put layer by layer until the previously detailed object is created on the machine [141].

According to Silva et al. [141], Cartesian FFF is the most widely used 3D printing process, which employs a thermoplastic filament as a raw material to create 3D structures. Three axes (X, Y, and Z) regulate the object's position in the print bed in printers that use this technology. The Cartesian coordinate system always moves

Table 1 Effects of COVID-19 in different sectors

Education	[13, 14, 17, 19, 35, 69, 110, 112, 163]
Entrepreneurship	[6, 21, 34, 36, 46, 50, 52, 57, 65, 114, 120]
Health sector	[3, 12, 15, 18, 28, 48, 54, 68, 77, 106, 132, 135, 154, 158, 159]
Hospitality	[80, 91, 95, 102, 152]
Intellectual property	[16, 33, 62, 82, 98, 109, 126, 138, 156]
Population	[9, 20, 63, 93, 115, 130, 139, 143, 148, 151, 155]
Prices	[39, 70, 84, 94, 113, 125]
Tourism	[42, 49, 56, 58–60, 83, 140]
Trade	[4, 5, 7, 22, 37, 53, 72, 105, 118, 144, 145, 153]
Violence against women	[38, 66, 79, 90, 133, 142, 146]

the X, Y, and Z axes. The table can also do these as it moves through the extruder in any direction. Every FFF printer, on the other hand, has an extruder, which is the part that builds the 3D items. It's further divided into a cold tip that draws in the tough filament and a hot portion that fuses until its fluid enough to escape the nozzle and land on the print bed. Most modern 3D printers have hotbeds, which have the advantage of allowing the use of filaments that require a hot surface to adhere to the layers on top of each other. Figure 1 explains the most basic process to perform the three-dimensional printing process.

The behavior of industries has also changed in terms of their modes of production and management. In this way, the creation of 3D printing represented a technological advance that should be beneficial in many areas [141] (Fig. 2).

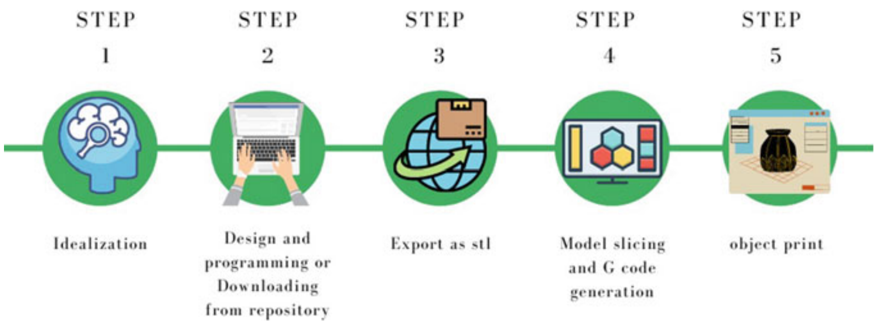

Fig. 1 Printing process (*Source* Adapted from Silva et al. [141])

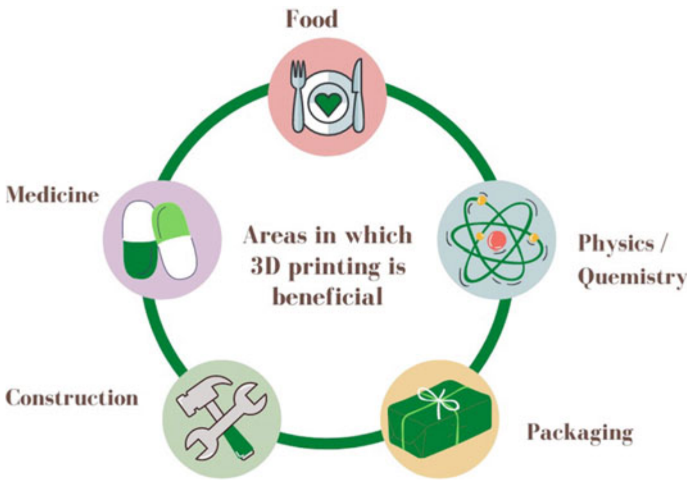

Fig. 2 Benefited areas (*Source* Adapted from Lipson et al. [1], Silva et al. [116], Otcu et al. [127], and Abdalla et al. [141])

For physics, it can be helpful to create prototypes and observe their behavior in real life, for example, kinematic mechanisms [116]. On the other hand, chemistry has also benefited from advances in 3D printing, especially in electrochemistry. In this area, research managers often look for standard yet customized ways to produce electrochemical devices that are sustainable, cost-saving, have a long-life cycle, and are produced efficiently. Three-dimensional printing has been quite beneficial to meet the requirements of preparing these chemical devices with all the characteristics mentioned above [141].

The application of the 3D printer in the industrial field allows making the manufacturing processes of certain products shorter, reducing costs and decreasing the demand for materials. In turn, this constitutes a comparative advantage for companies and allows greater customization of the products offered by them. The application in this field has many possibilities and reduces costs for manufacturing companies by offering greater control with the help of advanced technology in each production process [147].

In medicine, the existence of especially medical 3D printers is quite helpful for specific medical procedures, allowing at the same time a different and more efficient medical care for hospitals and doctors. These printers have specific characteristics to be used in this area, as they are certified as sterilized and biocompatible. In addition, its size was also designed to fit in spaces such as laboratories [55]. A specific case where 3D print has been used has been in eye care, where its earliest use was training and planning models, which later evolved to the creation of prostheses, surgical instruments, glasses, among others. In addition, it is essential to emphasize that there was an increase in demand for surgical instruments during the pandemic that led many hospitals to manufacture their instruments using 3D printers [111]. On the other hand, 3D prints also serve to recreate human body parts that can serve as training for medical personnel, providing them with a greater understanding of human anatomy [67]. 3D prints are accompanied by improvements in other technologies such as artificial intelligence that allows it to be combined with prints to create higher quality objects at lower costs and saving material, which reduces the waste of its use and creates more sustainable models [136].

In the case of the food industry, lately, the market has aided the inclusion of many AMTs in producing a wide range of meals, including chocolate, pasta, and pizza. The layer-by-layer material deposition mechanism of 3D Food Printing (3DFP) technology, based directly on a predesigned CAD file, is characterized by the treated material being food [129]. This revolutionary method of using 3D food printing can change the way food is produced, formulated, prepared, cooked, served, eaten, and even digested [127]. Because of the many disciplines of applications that 3D Food Printing brings together, this technology's foundation holds the promise of being able to "print" highly tailored foods, allowing for the creation of special meals [73, 127].

This chapter aims to identify the relationship between 3D printing and its effect on current environmental conditions according to the principle of circularity and these processes' footprint. Therefore, the positive or negative impact of additive manufacturing is presented.

2 Relationship Between Circularity and 3D Printing

The circular economy model replaces the concept of "end of life" in the manufacturing, distribution, and consumption processes in all industries by reducing the possibility of reuse, recycling, and recovery of resources [104]. The circular economy relies on the recycling of parts and resources. It reduces the usage of raw materials by including waste as a participant in the manufacturing process. Materials and components can be repaired, reused, reconditioned, and recycled in the technological cycle [86].

In the case of 3D printing, circularity is mainly achieved by reusing waste materials from different industries to convert them into the filaments necessary for final printing products, which can be seen in many examples, primarily plastics and, lately, in the food industry. Plastic is a trendy material used in different production methods to make various products, and the 3D printer is no exception. It also uses this material to create its three dimensions [123]. Plastic seems to go on and on increasing over the years, and it is estimated that around 850 million tons have been produced by 2050 [108]. Because of this exponential level of plastic production that generates negative impacts on the environment, new measures are being generated to counteract these effects [122].

Distributed Recycling for Additive Manufacturing is one of many ways to achieve a circular economy for plastic (DRAM). Consumers have an economic incentive to recycle under the DRAM technique because they can utilize their garbage as feedstock for a wide range of consumer products that can be produced at a fraction of the cost of comparable products [71, 149, 161]. PET has long been considered the holy grail of DRAM since it is one of the most easily identified polymer waste sources for consumers and is widely recycled through centralized procedures, though not at the rate required to support a circular economy [45]. PET is an excellent water and moisture barrier, and its use in the packaging sector for consumable packaging of water, soft beverages, and meals is predicted to expand at a rate of 4.5% per year [101]. PET water bottles are simple to recycle since they are already clean and available in vast quantities worldwide,this is why a few companies, such as Refil and B-PET, sell recycled PET filament [117].

Upcycling plastic waste into 3-D printer filament with a recyclebot, an open-source waste plastic extruder, is another technique of distributed plastic recycling [150]. Previous research on the life cycle analysis (LCA) or recyclebot method using post-consumer polymers rather than raw materials found that the energy performance of the filament from extracting, refining natural resources, and synthesizing was reduced by 90% when opposed to conventional manufacturing [47, 107, 108].

3D printing technology may be one such solution to address the challenge of plastic contamination as it is a low-cost and accessible technology, which uses plastics as its primary manufacturing material [122]. The EcoPrinting system is a compact nanogrid-style system with a solar-charging battery to switchgears and designed as an excellent example of how to turn plastic wastes into finished goods through this kind of 3D technology. Hand-operated granulation equipment, a low-power filament

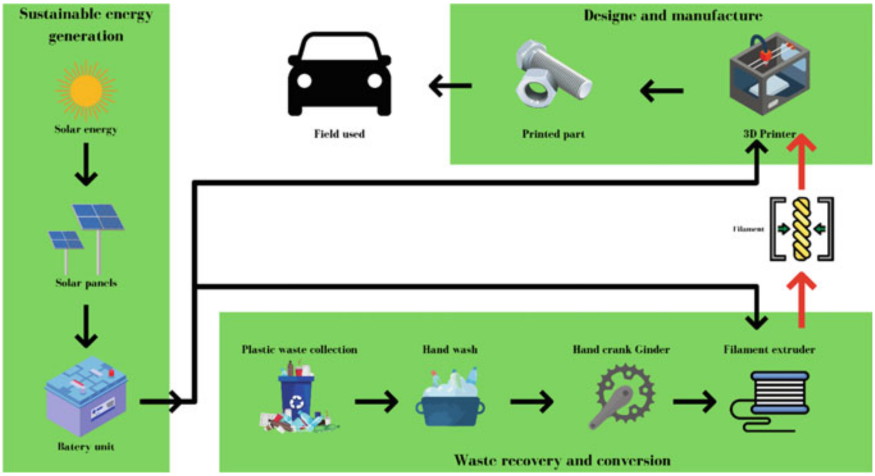

Fig. 3 The EcoPrinting system (*Source* Mohammed et al. [123])

extrusion system, a customized 3D printer capable of using recycled plastics, a laptop for design creation, and 3D printer interfacing are among the low-power gadgets created to achieve this. As a result, the recycled plastics could be formed into filaments with tolerances equal to commercial-grade filaments [123] (Fig. 3).

Similarly, another material that can be reused as a 3D printing filament is food. Several researchers and practitioners have advocated for using technology's characteristics in the food sector to address sustainability, increased regulations, complex supply chains, and so on [87], [128]. Compared to standard AM solutions, 3D food printing is still in its early stages of development and implementation. Yet, it broadens people's perspectives by giving them unrestricted design flexibility, allowing them to create more reliable products with more economic and social impact and fewer negative environmental consequences [127].

The developing method of three-dimensional printing (3D printing) should be evaluated as a feasible solution considering the mounting hazards linked with health, food shortages, and the other issues mentioned before. Food three-dimensional printing could be a viable means to assure food supply by minimizing the cultivation and stockbreeding process and a practical way to avoid being exposed to unhealthy food [162]. Powder bed AM systems are helpful in food printing for any scenarios where the input material's shape is input as a powder [129]. This 3D-printing technology was utilized to make nutrient-dense noodles from potato peel waste from processing plants. According to the research, the fine potato peel fractions were better printable than the coarse fractions. According to Pallottino et al. [128], it is possible that, per the current trends, strategies for effective food waste utilization become a key field of research and market soon.

Likewise, [61] show the potential of the salmon gelatine gels to flow as an independent filament and create 3D shapes was demonstrated at various doses. Because of its good printability, shape retention, and dimensional stability, the sample with a salmon gelatine concentration of 8% was the best suitable for the 3D printing procedure. As a result of this research, a foundation for studying food matrices based on marine gelatine has been established, which could be valuable in preparing diets for people with specific nutritional needs utilizing 3D printing.

A final example of circularity within 3D printing in the food industry can be seen through industry waste such as grape pomace and broken wheat as primary materials in a 3D printing material supply to create functional cookies [97]. The addition of grape pomace to the cookies increased their nutritional content and antioxidant capabilities leading to a final product that was high in both proteins and dietary fiber [97]. This method emphasizes the value addition potential of industrial waste streams, with a high consumer preference. As a result, additive manufacturing's unrivaled degrees of customization can be perfectly complemented by personalizing foods in terms of nutritional value while allowing for cleaner production processes and enhanced resource recovery from food processing wastes.

3 3D Print and Footprints

As mentioned above, the materials used in the three-dimensional printing process impact the environment. However, at the same time, this process can be compared with the impact of other more traditional methods and reach a conclusion about which is more efficient and leaves a lower carbon footprint. Next, the comparisons between methods and the different efforts that have been made to reduce the environmental impact of 3D printing are mentioned.

Following the plastic use in 3D printing mentioned before, according to Mohammed et al. [123], this technology has revealed that it operates at low average power (about 60Whr continuous use), perhaps allowing it to be powered by a small renewable energy system. Thus, using EcoPrinting to reprocess waste plastics into usable and functional things would generate a minimal carbon footprint and sustainable energy generation.

On the other hand, the construction sector is responsible for 46% of energy consumption annually [78]. It is also responsible for 38% of the global emission of greenhouse gasses [8]; as the sustainable objectives became relevant, the demand for a new, more eco-friendly system for this sector was growing [1]. In addition, this industry faces other problems such as the high number of accidents at work and low productivity. Three-dimensional printing is a potential solution to improve conventional construction methods that improve workers' quality of life and the work environment to face these problems. The use of 3D printing and its environmental and social impacts have been studied. A case study in China demonstrated the potential of this method through the construction of many houses of approximately 200 m2 with quality materials [103].

It was possible to conclude through the study that the results of the scenario where 3D printing was used were much more favorable than traditional methods, with a

Table 2 Environmental results

Impact category	3D printing	Conventional Construction
Global warming (Kg CO_2 eq)	608.55	1154.2
Land occupation (m^2 a crop eq)	0.4	6.8
Water consumption (m^3)	183.95	233.35
Human Health (Pt)	5.3	18.63
Ecosystems (Pt)	0.64	1.3
Resources (Pt)	0.05	0.2

Source Adapted from Abdalla et al. [1]

performance of up to 50% better since it was possible to reduce the emissions related to many processes [1]. On the other hand, other constructions under investigation have shown that implementing these 3D prints allowed the use of materials efficiently, thus reducing waste. And it could also reduce up to 5% of emissions by 2025 in larger projects.

In Table 2, you can see the results of the environmental impacts according to some specific indicators. It can be observed that comparing 3D printing and conventional construction, the impact of 3D printing is significantly less. The impacts were calculated in [1] investigation using SimaPro in four stages.

On the other hand, it is essential to mention that sustainability is crucial for the construction industry [51] and the packaging industry. The industry consumes 38% of the plastics derived from petroleum produced annually [131]. By 2050, it is estimated that plastic waste reach 12 billion tons that end up in landfills [85] which is how alternatives have emerged to use less polluting raw materials such as biomass composed of mushrooms that can significantly reduce the negative impact on both industries [44, 89].

The biomass that has been derived from agricultural residues fulfills the role of substrate and acts as a source of nutrition for the fungi that later grow as white filaments known as mycelia appointment [51]. The mycelia bind to the biomass since it has properties similar to wood and cork [41]. The benefits of using these materials are that they constitute lower costs [99], are biodegradable, and have a low environmental impact [2, 92], thus reducing the carbon footprint.

Different studies have been carried out on the characteristics of biomass-fungi, which has materials that may present different characteristics depending on their source of nutrition, species of fungi, and the method of processing [40, 92]. It is possible that even environmental factors such as light and carbon dioxide concentration also impact fungal density [41]. It has experimented on the factors and how it affects biomass-fungi since it is sought that this can be part of other productive processes of 3D printing [51].

One of the advantages of 3D printing is that it is cheaper for smaller-scale productions; it allows reducing costs that would otherwise be higher [51]. It is possible to produce complex parts in small quantities and create complex figures [11, 88]. To produce these objects, using methods based on molds are involved [96]; these molds are commonly made of plastic, that is why it is necessary to change this part of the production process to reduce the environmental impact of total production further and become more sustainable [44].

A wide range of materials meets the printer's requirements to be processed and used to find the most optimal and viable material and sustainable over time. These proposals have been given and investigated because 3D technologies, especially those with plastic as the primary material, produce a significant amount of waste that later ends up in landfills. Due to the pandemic, plastic use has increased due to the high demand for masks and protectors [157]. Although the environmental impact of prints is not as significant as energy consumption, added to the growth of plastic production, prints that continue to use this material after being discarded also need to use energy to be disposed of Zgodavová et al. [157]. The impact of prints depends on the volume produced, the materials used in the process, and the printer's technology [157]. According to the study conducted by Zgodavová et al. [157], the most suitable and sustainable material for production concerning face shields was a filament called PHA BioWOOD Rosa 3D due to its reduced environmental impact.

Just as technology is available to everyone, sustainable alternatives should also be. As mentioned before, the combination of 3D printing and other technologies such as artificial intelligence and computational intelligence [136]. It is necessary to have good management and use these advanced technologies correctly. As mentioned before, to achieve sustainable 3D printing, the material used must be considered, but other factors such as energy, emitted particles, and the waste they generate must also be considered. In addition, they are considering that these printers are increasingly accessible to the public, the waste generated by the easy manufacturing done by individuals increase [136]. To reduce this waste and the emissions generated by 3D printers that increase the carbon footprint they generate on the planet, the use of the correct technologies that can convert data into information and that later that information becomes learning is what is necessary to be able to propose changes in the current model and thus reduce the impact [76]. The correct use of the information supposes a comparative advantage for the companies since it allows them to raise much more viable hypotheses and make changes in their processes that reduce costs and increase efficiency. It also allows them to improve in environments where a problem had probably not been correctly identified [64].

Ci-based software does not replace printers but rather enhances and improves them to make them more sustainable [136]. On the other hand, being and breathing the chemicals produced by 3D printers is harmful to human health, specifically in their respiratory system, so it is essential to gather information through technologies to have better control and create safer protocols for personnel exposed to working with these printers. All this is to protect employees' health and have a better safe work environment for everyone.

4 Closing Remarks

3D printing, also known as additive manufacturing, quickly makes a model/prototype of a component or finished product. It is a very innovative and influential technology in today's world, which has gained relevance in many industries, from medicine and chemistry to the food industry, thanks to its relative ease of creating different and unique products adapted to each situation.

One relevant advantage is the possibility of contributing to the improvement of circularity in the industries to which it belongs. First, this technology can make it possible to use plastic waste by recycling it and converting it into base filaments to create final products. In the first place, this technology can make it possible to use plastic waste through its recycling and conversion into base filaments to create final products, with waste being one of the pillars of the circular economy. Moreover, recent experiments and research on the reuse of other waste such as food make the potential of 3d printing a problem-solving tool that most industries have to face, such as sustainability. In that case, chemical processes added to the 3D printing could reduce hazards related to food production due to the enhancement of food properties such as its durability and even protein and nutrients.

In addition to this possible reuse of resources, 3D printing is increasingly contributing to reducing the carbon footprints of industries. Taking the EcoPrinting System as an example, this technology can provide significant benefits to the neediest communities through sustainable energy sources and the production of necessary parts, thus avoiding the waste of resources which can be demonstrated in the same way in other sectors such as construction. The production of 3D printed parts helps one of the most polluting industries in terms of carbon emissions to reduce its footprint on the environment. Where the use of materials other than plastic is proposed for a reduction in environmental impact.

Although the production of goods in 3D can often be positive for both people and environmental issues, it should be noted that there are still difficulties in the use of 3D printers, such as the fact that many of the filaments currently used are made of materials such as metals and non-recycled plastic. Even if there are new experiments and tests to maximize the resources used in 3D printing, there are still many limitations.

Despite all the benefits that 3D printing generates for people and companies, there are still specific challenges to solve for this technology. Such as chemicals that are harmful to the health of those who work near these printers. On the other hand, since they are accessible, their use could become massive using non-biodegradable materials, negatively impacting the environment. It is also essential to consider that these 3D printers generally do not always occur directly but through the entire process of use which is how the objects created pollute even after being discarded since their recycling also consumes energy and other chemicals are needed.

It can then be concluded that efforts should continue to be made to continue improving 3D printing and reducing its impact on the planet. On the other hand, it is necessary to rely on the newly proposed models and advanced technologies that emerge over time and support them in making 3D printing even more efficient and sustainable in the long term.

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Circular Economy: Business Applications

Circular Economy for Packaging and Carbon Footprint

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Abstract The academic and scientific literature agreed that the current economic, social, and environmental contexts require it to be treated immediately, especially in the packaging industry. Even though countries, organizations, and consumers took action to solve these problems, a change in the economic situation impacts the environmental and social ones and vice versa. To address all of them simultaneously, developing an economic model considering the three factors is necessary. This chapter discusses how a circular economy can lead to economic and sustainable growth, focusing on the packaging industry and carbon footprint. Analyzing what is currently done can also show a general picture of the current circular economy practices worldwide.

Keywords Circular economy · Circularity · Carbon footprint · Climate change · Environmental impact · Sustainable development goals · Packaging

1 Introduction

Climate concern is not new as several actions have been carried out, such as the Kyoto Protocol, which focused on covering emissions of the six leading greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) [137]. The world was already facing several environmental problems that required prompt attention to find solutions. Although several efforts were made, these have been altered by the arrival of COVID-19, which has generated several changes. Life as we knew it was gone forever. There may be many human and business activities that maintain some

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pre-pandemic components, but ultimately, they now have a mix that comes from the virtual world due to the isolation of the population.

Environmental education is the basis for the population and companies to have an eco-efficient use of the different products, mainly to generate ecological preferences for ecological packaging. However, education was affected by COVID-19, creating several effects in students [9, 10, 14, 16, 51, 91, 93, 161]. These effects on people's education are seen in the coming years, and environmental education plays an active role in society.

During tourist activities, people use different types of containers and, usually, the containers used are disposable. However, several elements are used during tourism activities. With the arrival of COVID-19, tourism also underwent a change, generating various impacts [31, 36, 39, 41–43, 66, 126].

When violence against women is analyzed, a crucial issue that prevents people from having a stable life is touched. Social conflicts generate different changes in social dynamics, generating preferences and rejections. Social upheaval generates that more specific aspects such as environmental behaviors are not prioritized. Thus, it has been reported that due to COVID, several negative effects were generated [28, 47, 59, 72, 119, 133, 145].

The prices of products and services have changed significantly due to the pandemic. Thus, airline flights had different fluctuations, going from costing at least 3 times the usual price at the beginning of the pandemic to costing 50% of the price to generate the promotion of vaccination flights. Likewise, as currently observed, there are problems with containers, which has caused a tremendous logistical problem due to delays in the delivery of products, impacting prices. This impact on prices due to COVID-19 has also been reported [30, 95]. Also, it was generated the need for further research to solve the problems that COVID-19 has generated [53, 68, 77, 86, 112] and aspects such as intellectual property [22, 81, 89, 123, 155].

Due to the pandemic, the use of single-use plastics to avoid contagion increased exponentially due to the necessary protection for health professionals; at the same time, this has generated an environmental problem that already existed and has worsened. COVID-19 also generated other damage in the health sector [2, 8, 11, 20, 34, 38, 51, 58, 87, 118, 121, 154, 156–158].

Entrepreneurship has increased as a survival mechanism in the face of the crisis, generating various types of entrepreneurships, focused on solving many everyday problems of social isolation and, at the same time, based on environmental and digital issues. Ventures focused on food delivery have had to increase single-use plastics and quick-disposal packaging, with increased pollution. Entrepreneurship efforts have been diverse, including general interest in entrepreneurship from university students [23, 17, 46]. In addition, there have been other negative impacts due to COVID-19 such as in trade [4–6, 17, 19, 37, 55, 85, 100, 136, 144, 152, 159], hospitality [60, 74, 78, 84, 150], and citizens behavior [6, 24, 44, 76, 98, 117, 134, 124, 147, 148, 153, 160].

The world has changed and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life [13, 12, 15, 21, 25, 26, 18, 27, 56, 57, 62, 107, 120]. The world has changed and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life.

A circular economy intervenes as a sustainable development model that changes how we consume resources [125]. Make-use-dispose approach has been used for centuries to assume natural resources scarcity [128]. This economic model does not consider the environmental impact of the traditional production process, resulting in the continuous reduction of non-renewable natural resources [105]. Moreover, the current inexistence of effective waste management of the disposed of materials such as packaging destabilizes the planet and foments the environmental degradation of its ecosystem. The closing loop strategy behind this business model assumes the scarcity of natural resources and, consequently, looks for the production design of output such as packaging that can be reused [128], which changes the make-use-dispose model into a take-make-consume-reuse approach. Even though it sounds like a viable solution, another concern regarding performance metrics on how well countries, companies and consumers are doing arised. The Sustainable Development Goals (SDGs) became the benchmarks to ensure the environmental, economic, and societal improvement [125]. As a result, ensuring economic growth while minimizing environmental footprint requires a new business model to maximize value [69, 125]. This chapter analyzes how countries approach sustainable growth through circular economy practices based on SDGs. In this case, we focus on the packaging industry and carbon footprint, two of the essential headaches for micro- and macro-level institutions and individuals. Despite the current solid waste management strategies and policies, the closing loop production chain is still a difficult task to achieve [1].

2 A Review of the Circular Economy Framework

2.1 Circular Economy Model Approach

A circular economy (CE) is an economic system that is characterized by the sustainable growth of production, distribution, and consumption phases. This mechanism seeks to integrate definitions such as "sustainable" and "green" to reduce the waste generated in a linear system within the phases [92, 99, 103]. The method of application of the circular system performs not only among the technologies employed by companies, governments, and individuals, "but also changes in regulation, laws and infrastructures, industrial networks, consumption cultures, etc." [99]. Thus, technologies are constantly evolving to become increasingly resource-effective and environment-friendly,for this, the already existing linear economy is being developed [92]. However, with the reorganization of processes in companies, with an approach based on the 3 R's, "the key point here is that waste of output could be reused so energy and material could be arranged most efficiently" (reduce, recycle and reuse) [103].

The CE, in simple terms, "involves and integrates the production and consumption sides of our societies" [103]. In other words, it "is a simple, but convincing, strategy, which aims at reducing both inputs of virgin materials and output of wastes by closing economic and ecological loops of resource flows" [75]. The "model aimed at the efficient use of resources" and plans the "value retention, reduction of primary resources, and closed loops of products, product parts, and materials" in a long-term period [103]. Even if the CE offers diverse solutions that drive less invasive processes concerning the environment, there are several criticisms, which should not be understood as a method of highlighting the negative aspects, but instead that there are features that are supported and others that are not [54]. First, [143] refer that one of the main obstacles to achieving a higher level of resource recovery is the limitations present in material properties and modern manufacturing and reprocessing technologies, they proposed that "more effective reprocessing technologies is necessary to contribute to recovery value and closing material loops." Another critique made by [79] mentions that the CE defines strategies and solutions proposed by the CE "focus on large-scale manufacturing and industrial processes," besides, "while the actors, scales and sometimes sectors are identified, the practicalities and potential circular activities are not."

2.2 Incorporating Sustainable Development Goals in the Circular Economy Model

As part of the Sustainable Development Goals (SDGs), several indicators may be related to Circular Economy principles and strategies. Global standards are known as SDGs that promote, for instance, sustainable production and re-utilization of resources [139]. It also allows continuous monitoring and evaluation of countries' performance during a period [105] (Table 1).

The purpose of a circular economy is to encourage environmental and social prosperity and the long-term economic and sustainable growth of nations [132]. Moreover, the idea of recycling, remanufacturing, reusing, among other activities, is becoming necessary and allows the transformation of waste into a valuable asset [80]. Since the increasing environmental problems, the public and private sectors are continuously looking for new solutions [88]. Those are the main reasons why implementing the CE practices approach can lead to SDGs' accomplishment [122].

Table 1 SDGs examples related to circular economy

Sustainable Development Goal	Sub Goals Examples	Sustainable Development Goal	Sub Goals Examples
6 CLEAN WATER AND SANITATION	Improve Water Quality, Wastewater Treatment and Safe Reuse Increase Water-Use Efficiency and Ensure Freshwater Supplies Protect and Restore Water-Related Ecosystems	12 RESPONSIBLE CONSUMPTION AND PRODUCTION	Sustainable Management and use of Natural Resources Substantially Reduce Waste Generation Responsible Management of Chemicals and Waste Promote Universal Understanding of Sustainable Lifestyles Encourage Companies to Adopt Sustainable Practices
7 AFFORDABLE AND CLEAN ENERGY	Increase Global Percentage of Renewable Energy Double the Improvement in Energy Efficiency	13 CLIMATE ACTION	Build Knowledge and Capacity to meet Climate Change
8 DECENT WORK AND ECONOMIC GROWTH	Sustainable Economic Growth Improve Resource Efficiency in Consumption and Production	14 LIFE BELOW WATER	Reduce Marine Pollution Protect and Restore Ecosystems
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	Promote Inclusive and Sustainable Industrialization Upgrade All Industries and Infrastructures for Sustainability Enhance Research and Upgrade Industrial Technologies	15 LIFE ON LAND	End Deforestation and Restore Degraded Forests Protect Biodiversity and Natural Habitats Conserve and Restore Terrestrial and Freshwater Ecosystems Increase Financial Resources to Conserve and Sustainably Use Ecosystems and Biodiversity
11 SUSTAINABLE CITIES AND COMMUNITIES	Protect the World's Cultural and Natural Heritage Reduce the Environmental Impact of Cities	17 PARTNERSHIPS FOR THE GOALS	Enhance Global Partnership for Sustainable Development Promote Sustainable Technologies to Developing Countries

3 Circular Economy and Packaging

3.1 Circular Economy and Its Relationship with Packaging

The term packaging refers to a structure applied for protection, distribution, storage, presentation, use, and disuse of the enclosed goods. Packaging systems can be classified in different ways. Starting from characteristics such as the materials of its composition, manufacturing design, to its purpose, different products require different levels of handling coupled with different techniques and standards to ensure the correct shipment of the merchandise to the users [67]. Focusing on the materials, we classify them into the following categories:

- **Artificial packaging** is produced from synthetic materials obtained or processed by men whose resources may or may not be natural derivatives; examples include the production of glass, polymers (such as plastic), and/or fabrics [127].
- **Natural or ecological packaging** involves using the organic and biological matter to craft and elaborate like artisan products. This type of packaging is characterized as highly eco-friendly as they degrade quickly and do not pose a threat of becoming permanent pollutants in our environment [127].

The linear economic model, which continues to be enforced today, is based upon the principles of "take, make, waste," relying on the disposition of large, cheap, and easily accessible quantities of materials and energy [113]. However, this approach has proven not sustainable for countries that look forward to reducing their environmental footprint. Moreover, it has shown a continuous deterioration and harm toward the environment on a long-term scale. Those issues require implementing new business models such as a circular economy, which aims to optimize resource employment, reduce raw material consumption, and restate waste through a renewable flow [48]. Therefore, when applying this model to the packaging sector, we are not only focusing on the reduction of waste, but we are also switching from the traditional development processes of a product's life cycle by implementing new and more functional designs, means of distribution, and general practice, as well as the recycle and recovery of material [67].

There is an increasing need to implement a methodology on the design of industrial products where eco-design takes an impactful role, allowing to reach new opportunities with the firm's purpose of reducing production costs, the resource consumption of products, improving the quality, and increasing the shelf life of products [135]. The concept of eco-efficiency is proving to be an effective business strategy, guiding companies to assume a much more responsible role toward society and serving as a motivation for their activity to have greater competitiveness, adapting and remodeling existing production systems to the needs of the market and the environment, thus ensuring horizons of economic and social development [35]. Ecological packaging is the contribution of responsible companies to reducing waste that pollutes the environment, but they are also increasingly a requirement of consumers. A package serves to contain a product and gives it an identity. If it is made with ecological materials, it can be a compelling sales argument among new generations of environmentally conscious consumers [135].

3.2 Current Situation of Packaging in the World

After discussing the importance of the circular economy for packaging, we must understand the current situation of this industry worldwide. Let's look at two essential components of the packaging industry: plastic, paper, and cardboard.

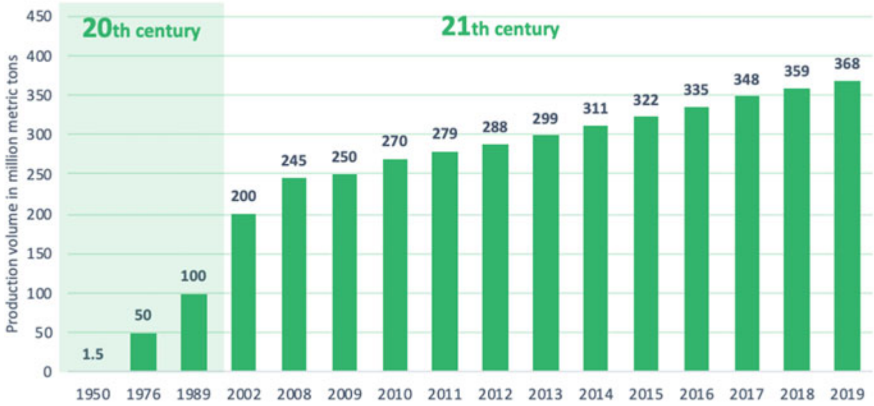

Fig. 1 Global plastic production since 1950 (*Source* [130])

3.2.1 Plastic

Plastic is one of the most common materials used for packaging nowadays. According to [130], its production has increased exponentially since 1950, rising to 368 million metric tons in 2019, and it is forecasted that by 2050 it register approximately 600 million. Geographically, the concentration of this production in 2019 was in China (30%), NAFTA (18%), the Rest of Asia (17%), and Europe (17%) [116]. If we go back to 2017, 146 million metric tons were spent on the packaging industry, making it "the biggest consumer" of the plastic industry [130] (Fig. 1).

From all these volumes, we should notice that in 2018, 54% of the 359 million metric tons of plastic produced have been discarded, 22% have been incinerated, and only 21.3% went to the recycling process [131]. As we can see, the globe has a severe problem regarding waste management. The packaging industry represented 46% of the total plastic waste generation in 2018, representing approximately 164 million metric tons of volume. For instance, the case of the European Union is fascinating. In 2018, they registered 17.2 million metric tons of plastic packaging waste, 17% more than in 2005 [131].

3.2.2 Paper and Cardboard

Focusing on the paper and cardboard industry represents a significant part of the packaging materials being used. In 2018, its production rose to 420 million metric tons [131]. 48% was produced in Asia, 26% in Europe, and 19% in North America (Fig. 2).

If we look at the paper and cardboard waste internationally, we should take the following examples:

- Singapore: Around 712 thousand tons were disposed of in 2020 [111].

Fig. 2 Production volume of paper and cardboard worldwide 2008–2018 (in a million metric tons) (*Source* [131])

- United States: 17,220 thousand tons were landfilled in 2018 [141].
- United Kingdom: 1260 thousand tons were not recycled in 2018 (Department for Environment Food & Rural Affairs, 2018).

Waste management has several challenges, such as the increased disposal and waste generation of packaging materials such as plastic, glass, and paper [33]. Since only a single part of the million metric tons of waste is being recycled, it is significant that countries promote a sustainable development approach and reduce their environmental footprint. This economic approach, known as Circular Economy, aims to reduce the dependence on natural resources through waste output management [99].

3.3 Circular Economy for Packaging in the World

Governments can play a significant role in promoting and developing a circular economy. For instance, several countries changed their perspective from waste management to circular economy principles [64, 104]. That is mainly because the traditional linear business model is no longer an option and is inefficient [104]. We look at some examples of how countries are implementing this concept.

3.3.1 China

To begin with, we should first talk about China's perspective. This country represents 31% of the world's plastic production [130]. As a result, implementing circular economy principles as mandatory objectives is complex. One answer to this dilemma is starting to move from an environmental policy to an economic development one, including these last [104]. For instance, the government decided to practice the "National Sword" policy, which banned imports of several recyclable materials such as plastic [7]. This step was aimed to reduce the current flow of waste into the country.

Other's policies implemented by the government are the following:

- Law for Environmental Pollution of Solid Waste
- Amended Law on Pollution Prevention and Control of Solid Waste
- Laws and Regulations for Reuse and Recycling Specific Solid Waste
- Amended Law of the Prevention and Control of Environmental Pollution by Solid Waste
- Environmental Protection Tax Law [113].

In this last, circular economy is focused on 3 R activities: Reducing resources consumption, Reuse, and recycling waste materials [97]. All those initiatives are based on the Circular Economy Promotion Law that came into force in 2009 [106]. The aim of the implementation of the Circular Economy policy is mainly due to the scarcity of natural resources and emissions of gases such as the greenhouse one. All the issues facing this country are caused by its rapid industrial and economic development in the last decades [113]. Focusing now on performance results over time, we can see that China's paper and cardboard recycling rate increased from 42.9% in 2009 to 49% in 2019 [129]. The plastic recycling rate has decreased from 28% in 2017 to 17.6% in 2020, mainly due to the import ban of plastic materials [131].

3.3.2 Germany

Germany consumes 2019 around 19 million tons of packaging, of which 44% and 18% are for paper and plastic, respectively [131]. This number of materials can generate significant waste if not managed adequately. That is one of the reasons for the implementation of the Circular Economy Act in 1996. This Act allows continuous packaging collection from industrial and end consumers. It was aimed to foment and implement a sustainable production system where producers develop products that minimize waste, facilitate its recovery for further recycling, and allow re-utilization of this last [113]. Other policies implemented by the German government are the following:

- Waste Disposal Act in 1992
- Producer Responsibility for Packaging waste in 1991
- Packaging Ordinance in 1998
- Ordinance on managing the municipal waste of commercial origin and specific construction and demolition waste in 2002 [113].

According to [131], since 1999, the country has experienced excellent collection practices. In 2019, it registered that almost 12 million metric tons of packaging were collected. Also, its recycling rate has risen from 81% in 2000 up to 97% in 2018

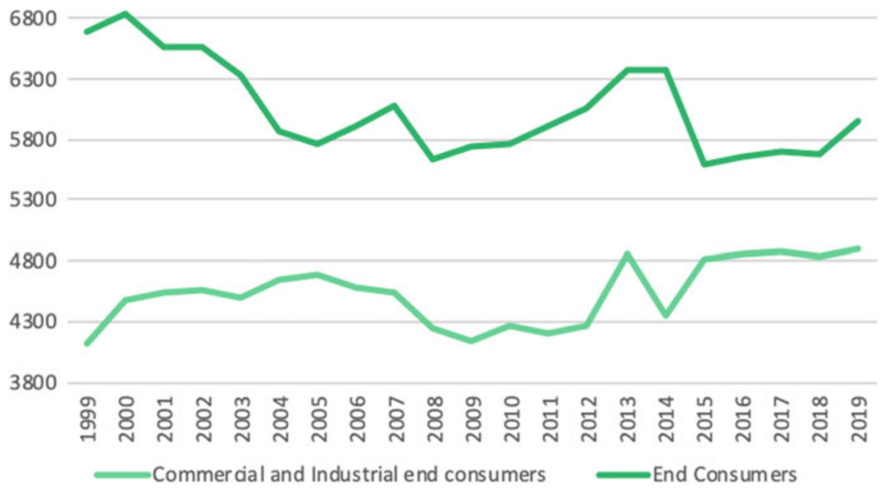

Fig. 3 Volume of packaging collected by type of consumers in Germany (in thousands of metric tons) (*Source* [131])

[131]. Specifically for each type of packaging, the recycling rate was the following: plastic packaging with 47.7%, glass packaging with 83%, and 99,7% for paper and cardboard packaging [131] (Fig. 3).

3.3.3 Other Countries

Around the world, we have evidenced similar actions implemented by other countries (see Table 2). As we can see, several strategies adopted worldwide were aimed to regulate the inefficient use of resources and waste [65]. Consequently, the traditional linear economy model is ineffective and focuses on the short term [105]. The idea of developing circular economy practices is to ensure the implementation of a *closed-loop system*, which means the continuous circulation of materials to avoid waste [132]. The minimization of the input of virgin raw materials and output of waste is the principle of this sustainable model, allowing the protection of the environment and simultaneously obtaining the desired performance metrics to achieve SDGs [75].

To sum up, a circular economy can indeed enhance sustainable development. Nonetheless, each government should implement politics to achieve economic and sustainable growth. Moreover, several authors explained the current difficulties in developing circular economy practices. Even though governments continuously issue new regulations, the current limitations are also related to organizations and consumers [54]. For instance, several business models appear with a circular approach but only focus on specific activities, which can significantly reduce the effectiveness of the total circular economy. It may be related to the unclear enactments from countries.

Table 2 Strategies adopted by other countries worldwide

Country	Propositions to achieve circular economy	Sources
Japan	Waste disposal Law in 1970 Resource Efficient Law in 1991 Environmental Law in 1993 Recycling Based Society Law in 2002	[82, 113]
Australia	National Waste Policy in 2009 Environment Protection Act in 2002 Australian Packaging Covenant National Environmental Protection Measure in 2011	[32, 73]
Peru	Law 3084—Regulation of single-use plastics and disposable containers	[19]
Brazil	Brazilian Policy of Solid Waste in 2010	[71]
South Korea	Framework Act on Resource Circulation 2016	[65]
United Kingdom	Producer Responsibility Obligations (Packaging Waste) in 2007 Packaging Regulations in 2015 Environmental Permitting Regulation in 2016	CMS [40, 94]
Colombia	Environmental Management Plans for Container and Packaging Waste (Amended in 2020)	[29]
European Union	European Green Deal	European Commission (n.d.)

4 Circular Economy for Carbon Footprint

4.1 Circular Economy and Its Relationship with Carbon Footprint

In recent years, conferences have been held on topics of global concern such as environmental pollution and ways to combat it. It should be noted that the Kyoto Protocol was approved in 1997, but it has been in force since 2005, and 192 parties have signed up to it; industrialized countries have committed themselves to limiting and reducing their GHG emissions [140]. It is also important to note that the first commitment period for all parties lasted from 2008 to 2012, a second period was signed for 2013–2020, the Doha amendment in 2012, although it has not yet entered into force, which is because there is global concern about the negative consequences that harm not only society but also business and the economy. Therefore, to calculate the amount of greenhouse gas emissions that accelerate climate change, the carbon footprint was created, which affects the economic development of nations [63]. In addition, the 6 GHGs established in the Kyoto Protocol are also considered for measurement. The main objective is to reduce emissions to slow down global warming and reduce pollution [61]. For example, China is a highly developed nation, but its cities are on the world's worst air quality lists due to their high pollution rates [101]. Since the nation entered into the World Trade Organization and its early economic recovery, $C0_2$ emissions have only increased [50]. Since 2013, the country has been conducting an anti-smog campaign, which has begun to bear fruit, such as in Beijing, which introduces blue skies [96].

According to [102], a new concept for all people was born out of the 2012 publication by the Ellen MacArthur Foundation in the United States on how to integrate environmental sustainability into the framework of economic development, which promoted the circular economy as supporting research for businesses and government entities. The old model was the linear economy model in which the extraction of natural resources, production of goods and services, consumption, and subsequent waste production is paramount, and it is in this last part that the result is pollution and an increase in GHGs [49]. On the other hand, the new CE model proposes a reconversion of waste by promoting innovation in the production process, thus converting it into a new reusable resource through renewable energy and product design [45]. Nowadays, companies that monitor their carbon emission levels have a more significant advantage over their competitors, as they can plan and take measures to reduce their measures, which results in high energy efficiency, which in the long run increases productivity and makes them more competitive not only in the national but also in the international market. In addition, companies with "green" certificates are more accepted by end customers [61].

Finally, something important to consider is that incorporating SDGs as strategic objectives by countries and companies can reduce contamination such as greenhouse gas emissions [110]. Since the circular economy approach is also based on a low-carbon strategy, this ensures economic and sustainable growth by meeting SDGs regarding carbon footprint [149].

4.2 *Current Situation of Carbon Footprint in the World*

Climate change is currently one of the main problems being faced globally, a problem originating from the product of human activities and the subsequent pressure exerted on surrounding ecosystems. Global warming is one of the significant issues, denoting a rapid development due to the continuous increase in CO_2 emissions globally. In 2019, CO_2 emissions reached 36,45 million tons [114]. Regionally, the United States (14.48%), China (27.9%), European Union (8%), and India (7.1%) are the leading territories emitting this component. Nonetheless, the current change regarding growth was around 0.6%, lower compared to 2018 (Fig. 4).

Focusing on plastic, a packaging raw material, carbon dioxide emissions related to GHG were around 0.86 billion tons in 2019 [129]. It was forecasted that by 2030 and 2050, it would reach 1.34 billion and 2.8 billion tons of carbon dioxide, respectively. Nonetheless, this increase is not seen everywhere. Taking a step back, specifically in 1990, the UK registered around 4,4 million tons of carbon dioxide in plastic product manufacturing. Nowadays, in 2019, it fell to 2,5 million tons of this last [129]. As

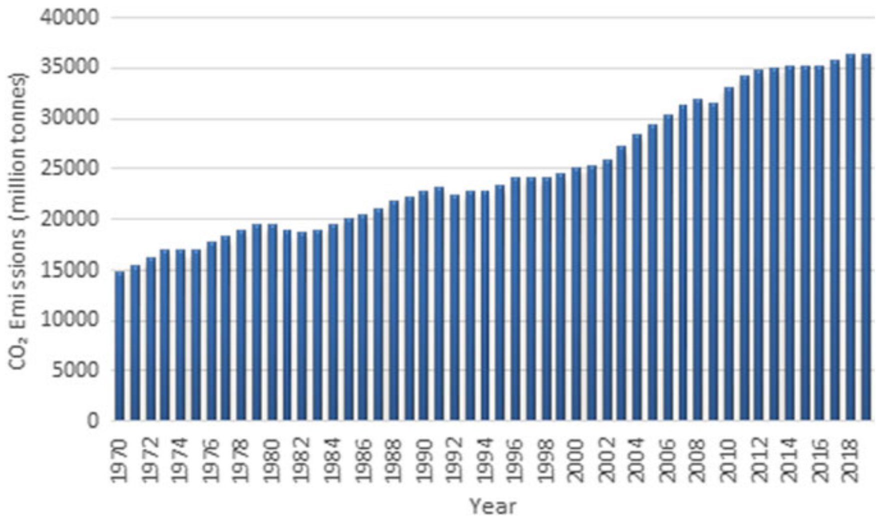

Fig. 4 CO_2 emissions in the world (million tons) (*Source* [114])

we can see, we can see an increase in GHG emissions, and in some countries, we can evidence a reduction in carbon footprint. It is then necessary to see what is happening worldwide and how countries address this problem.

4.3 Circular Economy for Carbon Footprint in the World

Governments can also play a significant role in the carbon footprint by implementing different laws and strategies. Policies made by this last ensure new sustainable practices that may reduce, for instance, greenhouse gas emissions [115]. Regulations must be clear, strong, and achievable so companies can enhance their processes, add value, take a long-term perspective, among other elements. The adoption of CE practices, as a result, requires the participation of the governments by enacting acts, strategies, regulations, laws, and policy such as the followings (Table 3).

Focusing now on consumers and companies, according to the United Nations—Department of Economic and Social Affairs (2019), the global population is estimated to continue growing to about 9.7 billion in the year 2025, which simultaneously incentivizes companies to produce more and expand their production capacity. This growth generates more significant pressure on the use of natural resources and a greater demand for consumer goods and services, causing a greater volume of waste to be cast into the environment. However, evaluating greenhouse gas emissions associated with products is rather complex. To define the footprint in its entire dimension, it is also necessary to consider consumers' responsibility in this process through their purchasing power, which could be considered one of the main causes of

Table 3 Strategies adopted by other countries worldwide regarding carbon footprint

Country	Propositions for carbon footprint	Sources
USA	Federal Water Pollution Control Act Amendments in 1972 Clean Air Act Amendments in 1990 The Federal Insecticide, Fungicide, and Rodenticide Act Amendments in 2003 Energy Independence and Security Act in 2007 Climate Adaptation Plan in 2021	[141]
China	Renewable Energy Law in 2006 Energy Conservation Law in 2007 National Plan for Combating Climate Change in 2007	[83, 151]
India	The Water (Prevention and Control of Pollution) Act in 1974 The Air (Prevention and Control of Pollution) Act in 1981 The Environment Protection Act in 1986 The National Green Tribunal Act in 2010 Hazardous Waste Management Rules in 2016	[142]
Russia	Environmental Protection Law in 2002 Environmental Doctrine in 2002 Climatic Doctrine in 2009 National Climate Change Adaptation Plan in 2019 Climate Project Concept 2020 Presidential Decree No. 666 to limit GHG emissions in 2020	[108, 109]
Japan	Energy Conservation Act in 1979 Joint Crediting Mechanism with India in 2013 Law Concerning Promotion of Measures to cope with Global Warming in 1998	[52, 70, 90]

the carbon footprint generated by certain goods or services. Therefore, developing countries find it more challenging to meet the demand for goods and services, to which export markets traditionally agreed, since these markets are raising environmental demands, circular, low carbon and could, if not anticipated, be transformed into new trade barriers [138, 146].

However, during the first half of 2020, the world suffered the severe effects of the health crisis caused by the COVID-19 virus, which has transcended a deep global economic crisis after the collapse of markets for weeks of inactivity in various sectors [138, 146]. So, in compensation for the difficulties that may be faced in the current markets, demand is expected to be significantly expanded in emerging markets which poses significant opportunities in the long term. The improvements in developing countries' productivity via the circular economy allow addressing these growing demands and increasing trade flows between developing countries, without the implications of a correlative increment in pollution, degradation of the environment, growth in greenhouse gas emissions, and potential depletion of resources in those countries.

In other words, the world is currently going through a period of profound transformation caused by the combination of a climate crisis, a latent social crisis exacerbated by the current health emergency, and an economic crisis from which we are estimated to recover for another decade. Therefore, it is urgent to lay the foundations and chart the route toward the transition to a circular economy that ensures sustainable development for the long term and economic recovery for years to come. Thus, the industrial sector should aim to accelerate its transition in implementing innovation, clean and cost-efficient technologies, and the design of ensuing professional opportunities. At the same time, markets have to reconfigure themselves in the creation of enabling mechanisms for this new economy, which, on the one hand, promote and decouple economic growth from environmental impact, and on the other hand, contribute to the closing of social inequality gaps that today play a determining role in a reality of insecurity and social precariousness for various countries in the world [138, 146].

4.3.1 Closing Remarks

There is no clear evidence about the correct development of a circular economy. Many countries adopted a specific approach according to their needs and strategic goals. Thus, implementing a Circular Economy can be done either at the micro- or macro-level. Nonetheless, it requires severe planning and continuous improvement of processes that may take years. Also, not every strategy can be implemented in each country, making it crucial to enact clear and achievable goals to ensure the scalability of the circular economy. Sustainable Development Goals regarding packaging are an efficient way to measure the environmental performance of countries and companies. These last accomplishments lead to economic and sustainable growth, resulting in a more excellent quality of life and well-being. A circular economy model shows us the importance of designing packaging to be reused, recycled, repaired, recollected, redesigned, among other strategies, which ensure the minimization of the linear model, which is harming the biosphere with its take-make-waste approach. Also, it increases the efficient use of natural resources, reduces waste generation, keeps long-term added value, and, as a result, a closed-loop system.

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Circular Economy for Waste Reduction and Carbon Footprint

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Abstract The anthropogenic activities developed in the manufacturing and distribution of products that are carried out at greater intensity to meet the growing demand and consumption worldwide produce a more significant amount of greenhouse gases (GHG), which impacts global warming. In the same way, the problem of the scarcity of natural resources, increasingly growing, creates the need to seek better alternatives with a sustainable approach to protect the state of the planet in which we live. For this, the support of governments, companies, and even consumers is required. This chapter takes the perspective of the circular economy (CE) as an opportunity to implement sustainable methods based on the management and reduction of waste, giving them a new function. Adding the use of the carbon footprint (CF) as a tool that allows knowing the impact of anthropogenic activities on the environment is added. In addition, confirmed cases aim to reduce GHG emissions by implementing a more efficient system that originates based on the CE principles.

Keywords Circular economy · Carbon footprint · Environmental · Waste · Global warming · Greenhouse gases

1 Introduction

Today's high growth of world consumerism has brought significant consequences to the environment, making its effects irreversible for the future. The application of the linear economy has not been favorable in waste management; on the contrary, the waste of final products threatens the planet both in the short and long term [74].

On the other hand, this problem has taken more significant consideration in recent years. One of the primary triggers has been climate change and biodiversity loss, so

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there is now a greater awareness of the environmental lobby and its purpose [104]. For their part, some irresponsible consumers create a gap between regular consumption and sustainable consumption, preventing such waste from being minimized and achieving sustainable consumption. In addition, this model proposes to generate greater consumer interest toward sustainable questions [46].

The CF and its implication to the environment are crucial in analyzing the environmental impact. The CF is probably the best-known indicator for measuring environmental impact. It is responsible for measuring the amount of CH_4 and CO_2 emissions on a chosen population or activity; that is, it measures the impact of certain activities that threaten the Earth's climate [93]. Among the main emitters of these gases, we find large companies, both manufacturing and non-manufacturing, and developing countries as primary threats to the environment [53, 117]. In addition, there is work on institutional organizations (OI) to ensure climate risks, increasingly complex challenges due to political factors, adaptability, interests, and others. Many regional governments tend to have a strong fragmentation between policy communities, which leads to the non-application of the actions proposed by OI. A similar case is experienced internationally [72].

The world has changed, and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life. Due to limited sources by COVID-19, new ways to build new materials are essential in the reactivation of the global economies.

In Table 1 shows the different negative impacts that the COVID-19 pandemic generated.

The CE has been widely accepted as a mechanism that seeks to balance economic, social, and environmental outcomes [65]. In response, the concept of CE brings together a set of activities that improve resource management [52]. This chapter also mentions the circular economy as a basis for creating ideal models to mitigate environmental impact, which is born apart from the obsolescence of the linear economy, characterized by the waste of reusable inputs [32].

Table 1 Changes created by COVID-19 in different sectors

Education	[8, 9, 19, 13, 12, 47, 81, 82, 149]
Entrepreneurship	[4, 21, 14, 18, 26, 30, 31, 36, 44, 86, 91]
Health sector	[1, 7, 10, 16, 12, 28, 34, 48, 55, 79, 106, 111, 144, 147, 148]
Hospitality	[58, 67, 71, 77, 142]
Intellectual property	[11, 17, 42, 59, 75, 80, 97, 116, 146]
Population	[6, 20, 43, 68, 87, 105, 130, 120, 139, 141, 145]
Prices	[24, 50, 63, 70, 84, 96]
Tourism	[25, 29, 35, 39, 62, 40, 122, 41]
Trade	[2, 3, 5, 22, 15, 33, 51, 78, 89, 133, 137, 143]
Violence against women	[23, 45, 56, 66, 110, 129, 138]

2 Problematic Situation

2.1 Poor Waste Management

Many countries are adopting policies based on waste management [136]. This growing importance is due to the promotion of environmental management tools, which involve controlling inputs and managing construction waste [131]. In addition to this, another of the great motivations is the rise in raw material costs, stricter policies on waste, and high disposal costs [136].

One industry that has made the most changes for proper waste management has been the food industry. According to the Food and Agriculture Organization of the United Nations [135], approximately one-third of the food produced globally, a value of around 1,300 million tons per year, is thrown away by the trash. In addition, there is a per capita amount of food waste, which reaches 95–115 kilos in Europe and North America, while in Africa and South and Southeast Asia, it is around 6–11 kilos. This data highlights the food gap between industrialized countries compared to developing countries.

A distinction needs to be made in food waste as avoidable and unavoidable. It is considered avoidable to those edible foods before being discarded, while the unavoidable foods never came to be considered food. Food waste implies a financial loss and a waste of the resources used to produce the food: energy, land, fertilizer, transport, etc. This loss of resources negatively impacts the environment, so waste management policies seek to ensure both the use of resources and reduce environmental damage [132].

It is a challenge to precisely calculate the amount of food wasted globally. Even so, various IOs seek to quantify the magnitude of the damage in environmental indicators [76]. Regarding the balance of damages from food waste in terms of GHG emissions, the food industry emits approximately 4,400 million tons of CO_2, representing 8% of total GHG emissions [60]. On the other hand, the construction sector also adapts processes to improve waste management. The implementation of construction waste management tools is currently part of the agenda of this industry. In recent years, there has been a greater awareness of the impacts on the environment [131].

The growing awareness of concerns about managing construction and demolition waste has led to the development of waste management as an essential function of construction project management, the overwhelming promotion of waste management tools, and sustainable development activities. As a result, there is a growing awareness of waste management issues and potential problems related to negative impacts on the environment [131]. Those responsible for regulating environmental policies in the industry have been external institutions, which provided solutions even to reuse waste. Thanks to technological advances, products made from precast steel can be seen, such as polymer recycling and safe combustion. Other responsible characters are global customers, who ultimately demand quality service, responsible for using resources without wasting them [123]. Still, many companies do not implement sustainable practices.

A survey of construction companies in Hong Kong held that minimizing the cost of the construction project is the most crucial objective, while concern for the environment is the least important. On the other hand, the lack of experience of many construction companies is the main reason why recycling construction materials is not very encouraging. In response, the Hong Kong government-imposed regulations to minimize waste and implement the WMP method for waste management. However, the companies claimed that their productivity was significantly affected [131]. For this reason, the companies themselves must invest and develop their recycling or waste reuse programs adapted to their conditions in order not to be harmed [113].

2.2 Carbon Footprint

Human activity has been responsible for the emissions of harmful gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other gases that threaten the planet [119, 140]. Also, the concept of CF has become part of the global agenda by various IOs, governments, and institutions as GHG emissions have constantly been increasing in recent years, thus generating great global concern [57]. All the tasks carried out by a company, company, or specific group to be evaluated must be considered to measure CF. From the extraction of the raw material, transportation, production, and final disposal, each of these stages must be analyzed on how much they compromise the environment [69].

There is great difficulty in measuring CF; it is necessary to calculate both direct and indirect emissions. It is called direct to those consuming domestic energy, while indirect seeks to produce or eliminate products and services at home [49]. This lack of knowledge does not allow people to apply the necessary strategies to reduce carbon levels [92]. For this reason, the scientific community seeks to inform and raise awareness among the population by showing little encouraging indicators about the accelerated rate of degradation of the planet and guiding companies toward adequate environmental policies [61, 101]. According to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, the most notorious changes caused by environmental degradation are extreme weather, scarcity of resources, air pollution, increased sea levels, and multiple epidemics [126]. That evidence that not enough is being done to compensate for the damage caused.

In response, international interest has been aroused in quantifying the magnitude of the environmental impact [69, 125, 128]. Corporate carbon calculators are valuable tools that measure business CF, an indicator that allows comparisons of other business footprints. Another tool is the Greenhouse Gas Protocol (GGP), considered the most widely used global standard tool for measuring and reporting GHG levels of a particular activity [69].

Carrying out a correct measurement of CF brings with it significant benefits. At the business level, a correct application of measurement tools generates cost savings, taking advantage of these saved resources to synergies from other areas of the company, eco-friendly innovations, corporate image, among others [121]. On the

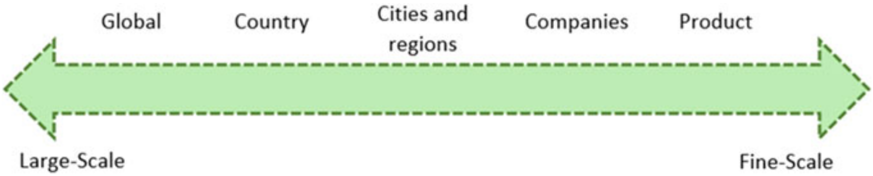

Fig. 1 Scheme of applications of the carbon footprint on a large and fine-scale (*Note* Adapted from [101])

social side, prioritizing a green agenda is vital for promoting environmental protection and global sustainable development, in addition to generating environmental awareness [69, 121].

Increased GHG emissions have been the biggest driver of climate change [73], leading to global action. Companies such as Hewlett Packard, Patagonia, and Walmart, concerned about having their current processes damage the environment, have sought to reverse this situation by managing the ecological supply chain (GrSCM). This environmental management tool ranges from designing products ecological to managing their reverse logistics [128]. In this way, the GrSCM allows reducing waste, saving energy, conserving natural resources, and, above all, reducing carbon emissions, generating both operational and financial savings for the company [37].

Like the companies mentioned, many other IOs and developed countries contribute significantly to GHG emissions [107, 109, 114]. Their respective supply chains can even be considered a threat to the environment if they do not adapt their stages to an environmental design. It is necessary to mention that, despite the current environmentalist trend, it is still a challenge for organizations, who must rigorously analyze new implementations of their processes without having some general framework that guarantees the success of their implementation [100, 114]. Operations redesign tends to focus on the efficiency of logistics networks and processes for more excellent added value [100]. That is why, regardless of being an IO, entity, or company of greater or lesser development, reducing the CF is a responsibility that all those who take advantage of the planet's resources must assume. Companies have numerous actions to take to benefit from the adaptation of their policies to more environmental ones, as well as cities and regions can implement local policies toward general national objectives [101]. In Fig. 1, we can see the different agents that, in addition to contributing to GHG emissions, are part of the large groups that must take care of environmental challenges to safeguard scarce and limited natural resources.

3 Theoretical Framework

Currently, the socioeconomic system focuses on the linear economy, which produces and consumes products that are discarded at the end of their useful life [94]. This system causes unnecessary losses of natural resources, which, year after year, lies in their existing depletion on Earth [94].

It was found in the literature that CE is considered as the trend that responds to the mismanagement of resources of the traditional linear economy system. However, changing the traditional system to a circular one entails several challenges that must be overcome [94, 112]. Therefore, it is necessary to know and investigate the subject and its representation.

The term CE is increasingly approached by scientists, whose central element is the "restorative use" of resources; in other words, it focuses on transforming the waste that remains after having consumed a product [64, 94]. For this reason, the CE concept is mainly considered a solution for insufficient resources, waste production, and increased economic advantages [85].

Given that environmental care is of great importance for the industrial business sector and its good performance, it is essential to determine the stakeholder's part of the waste management [85, 95]. Governments and companies search for a new, different, and sustainable business model (BM). However, to adopt a model attached to the CE concept, it is necessary to have a collective effort, which is made up of governments, companies, and even consumers [94, 99].

Before delving into the meaning of a CE model, it is necessary to understand the bases of a BM, which is made up of a sequence of patterns that allow it to evolve and innovate from time to time from previous methods that have already been successful [103, 108]. Similarly, the BMs that implement innovative tools to solve problems are more valuable [103].

The continuous search for commercial patterns that have circular improvement effects in the BM explains the creation of solid circular economy business models (CEBM) to rethink companies' general sense of value creation. Moreover, the different factors, whether internal or external, that affect the competitive environment or the set of laws that govern the market must also be taken into consideration since they could influence changes in the BM [32, 85, 103].

In recent years, sustainability has been an increasingly popular factor in the business world, meaning a competitive advantage for companies due to the excellent response from consumers by providing them with greater value. Therefore, the principles of sustainability were added to the BM, forming part of the model's design. Incorporating these sustainable models achieves a triple result due to its social, environmental, and economical approach [102].

Going from a linear economy BM based on the "manufacturing-consumption-waste" system, which is shown in greater detail in Fig. 2, to a CEBM implies that it

Fig. 2 Linear economy model (*Note* Adapted from [38])

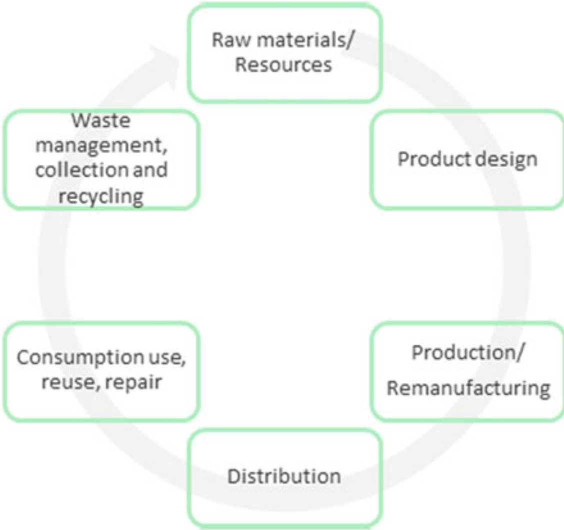

Fig. 3 Closed production circular economy model (*Note* Adapted from [38])

includes sustainable principles and maintains the purpose of increasing the productivity of natural resources. The CEBM is specified through strategies for reducing or closing resource flows [103, 115, 127]. In this way, it proves to be a model that can replace the traditional model and reduce the negative impact on the environment [118].

The CEBM is an option that proposes a path toward a more sustainable economic development, which proposes different solutions to face environmental challenges both locally and globally, taking care of the availability of resources and the preservation of the planet. The CEBM shown in Fig. 3 represents the closed production model, in which the raw material constantly travels in a loop [38, 115].

3.1 The Closed-Loop Model Focused on the 6Rs

The first of the 6 is "Reduce" which is the act that focuses on our commitment to reducing the number of products we consume, to avoid excesses to reduce the number of items to be discarded. "Reuse" refers to seeking to get the most out of the goods, even if they are not in their best condition or if they have already passed their useful life. "Recycle," probably the most prominent term in the 6Rs, is responsible for segmenting waste according to its nature to give it a new function. Another task is to "Redistribute" assets that are not being fully used and, failing that, maybe more valuable in other hands. Finally, "Repair" the goods that have supposedly been out of the use or with some damage. To not encourage unnecessary consumerism, it seeks to give them a "second life" [74].

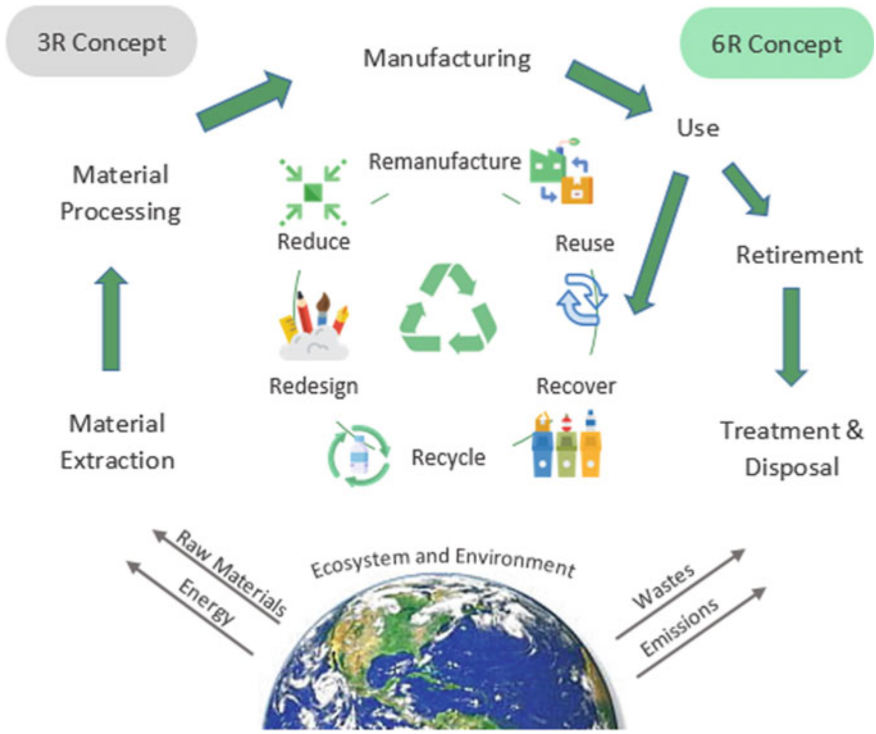

Fig. 4 The closed-loop model focused on the 6Rs (*Note* Adapted from [74])

The following model shown in Fig. 4 graphically represents a closed-loop system that follows the 6R concept, which proposes a sustainable system that confers a flow of very close to imperishable materials. Therefore, a model is established that optimizes processes and promotes GHG emission reduction [74].

3.2 Reverse Cycle Circular Economy Model

The closed-loop supply chain (CLSC) models are schemes adapted to the demands of today's market: a cost-effective model that in turn meets the environmental requirements proposed by the IOs. Ellen MacArthur Foundation proposes a CE model where each of the stages of the CLSC seeks to make the most of resources [94]. It consists of 5 stages, where each product can be repaired, reused, redistributed, reconditioned, or remanufactured [90].

It also proposes to reinvent supply chains, ensuring more optimization of systems than components, eradicating waste in an organized manner to maximize profitability while, at the same time, minimizing environmental impact and maximizing social

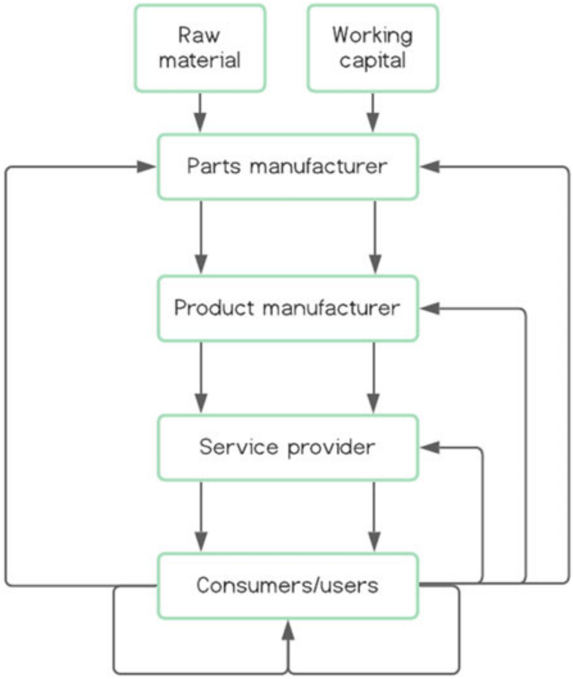

Fig. 5 Reverse cycles for the circular economy (*Note* Adapted from [90])

well-being [90]. In Fig. 5, you can see the model explained above, which includes the stages of a usual supply chain, adding reverse logistics actions in each of these.

3.3 Cases

If we talk about the industries in which there is the most significant amount of GHG emissions, the food production sector can be taken as an example due to its significant participation in anthropogenic GHG emissions, generating between 10 and 14% of these types of emissions in the world [124, 134].

During 2000–2014, the United States presented a decrease in CO_2 emissions regarding agribusiness. While, the case of the countries of China and India was the opposite, showing a pronounced increase in these emissions [27] (Fig. 6 below). It should be noted that China was the country with the highest record of carbon emissions, going from 280 to 475 Mt at the end of the period studied.

On the other hand, the closest way to measure CF levels is by segmenting them into three types: Direct, Indirect, and Global Indirect. The first classification is defined as those actions that lead to the use of products or services that directly generate consumption of natural resources, while indirect emissions refer to consumption without expending natural resources. Regarding the significant countries that emit

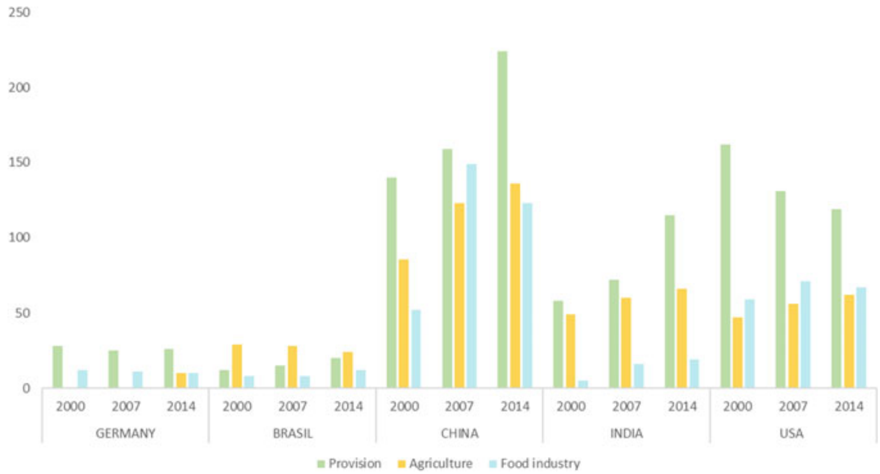

Fig. 6 Carbon emissions from agribusiness in 5 central countries (*Note* Adapted from [27])

GHG, we find China and India the countries with the highest proportion of indirect gas emissions, with 90% and 82%, respectively. Also, global indirect emissions are led by Canada and Japan, with 44% and 36%, respectively. Direct emissions are not usually that high, with Japan as the largest emitter, with 11% [98] (Fig. 6).

Larger companies are those that cause a more significant impact on the environment from their activities, compared to small companies. For this reason, large companies are the most potential candidates to look for reports, articles, and chapters and to implement new practices that have a more sustainable approach [52]. Therefore, below are some cases of countries adopting a CEBM and using CF as a support tool to manage GHG emissions.

3.4 China

This case analyzes China and different cities to determine whether the Chinese government's decision to implement a circular economy model was favorable or not. Its application was essential to overcome the problem of environmental degradation and shortage of sources. Another great success was the development of a comprehensive legal framework for the benefit of recycling. It is necessary to mention the complications and the risk assumed by implementing something different, especially in a country as influential as China. Aspects such as rapid industrialization and urbanization were significant obstacles, but it was not until the Asian country acted, such as relocations and regulations. In addition to this, the cities chosen had the necessary conditioning and resources to make this implementation more user-friendly [127].

The main reason behind the potential success of the upgrade would be the government's decision to focus its efforts on those sectors, which produce the most significant short-term impact, such as the relocation of heavy industry and the enforcement of instrument regulations that are likely to be the most influential sectors. Second, those four pilot cities are more modernized, more prosperous, and have more advanced energy efficiency technologies and equipment than other regions in China, making it relatively easier for these four cities to increase their energy efficiency [127].

3.5 United States

This new trend for using recyclable material applying CE strategies has been an excellent opportunity for the United States to enter the reused plastic or recycled PET (rPET) industry to represent a significant saving in raw materials while giving a message of care for the environment. This CE campaign seeks to unify the government, companies, and society to reduce the use of natural resources and, in contrast, prioritize recycled products [88].

A significant issue in implementing rPET bottles is its contribution to the GrSCM, giving more excellent circulation to final products instead of spending natural resources to manufacture more bottles. This action includes significantly saving time, money, resources and mitigating the environmental impact. However, these same bottles could be used for many other products such as fibers, sheets, and footwear [88].

3.6 Germany

The author argues that the current dominant linear economy causes a total waste of natural resources. He proposes a change from the traditional model toward a circular carbon one was, in addition to reducing GHG emissions, business efficiency increases. The competitiveness of the chemical sector in Germany is highly competitive, having total revenues of up to € 185 billion as of 2016, plus 447,000 jobs and investments of more than € 7 billion. For more than 30 years in the chemical industry, reduced GHG emissions by up to 50% [83].

Developing renewable energy from domestic lignite is essential; the European country is favorable, with the necessary raw material and fine chemicals originating from national carbon resources. For its part, Germany has more than 72.7 kg billion tons of brown coal, of which 50% is considered exploitable. Given this, the author adds that the energy sectors have a circular carbon economy [83].

3.7 Closing Remarks

Given the increase of the world's inhabitants, the global demand for resources is also considered increasing amounts of GHGs to the environment and waste [85]. The problems caused by the current linear economy model become an increasingly vital cause to seek more friendly options with the environment and society. Consequently, closed-loop models are adopted for manufacturing and consumption, that is, models focusing on the CE [54]. In this way, the waste that remains after consuming a product is given a new use instead of simply discarding it and polluting the environment.

The CE model must stop being seen as an alternative and necessary in everyday life. The misuse of natural resources caused by poor supply chain management is a short-term and long-term threat [100]. Economic prosperity and the ecological balance must coexist harmoniously to guarantee sustainable development [65, 74].

Faced with this, the implementation of tools for measuring environmental indicators, such as CF, is decisive when measuring the CE model's results. CF as a tool to manage and control GHG emissions due to anthropogenic actions can impact a global level in the same framework. However, it should be considered that it is more difficult to achieve its full implementation in practice [101].

Finally, it is expected that models continue to be applied that support the predisposition of caring for the planet, taking advantage of goods in a sustainable way. CE business models are an essential tool in a context where resources are increasingly scarce to safeguard the environment. The next generations also deserve to enjoy these goods, so implementing these models is no longer an alternative but a necessity in the business world [74].

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Food Loss Reduction and Carbon Footprint Practices Worldwide: A Benchmarking Approach of Circular Economy

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Abstract Unsustainable food supply chains are negatively affecting the environment. As a result, this topic has been debated worldwide, and several actors came to the same conclusions: intervention and actions are a must. Nonetheless, this approach was not standardized, and countries and companies are implementing circular economies differently. This chapter aims to outline the current circular economy approach taken internationally and discuss the barriers of this last. A qualitative analysis was conducted by collecting several case studies and understanding the identified practices and challenges. In the findings, the authors discovered that countries' policies remain weak globally, though the demand is increasing. Drawbacks and limitations such as economic resources, technological innovation, and incentives are evidenced.

Keywords Circular economy · Food waste · Carbon footprint · Policies · Sustainable development

1 Introduction

In recent times, the term Circular Economy (CE) has been spreading, not only from generation to generation but also throughout different nations; this proposal works as a solution to different challenges such as waste generation, shortage of resources, and sustaining economic benefits [106]. The specifications of the CE concept consist of are implemented in different aspects to be regulated to configure new models in production and consumption systems [70]. Governmental and non-governmental entities have identified the need to improve the food industry, CE is modified to be

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used in agricultural processes, food chain, and alimentary systems, to reduce food loss and waste (FLW) and other adverse effects of traditional production [1, 59, 70]. For the development of the CE, [80] establish the existence of three circles: the corporate level (this means that the responsibility lies with the manufacturers and their production processes); the interfirm level (created to increase the commercialization of by-products). Finally, social level (which refers to eco-friendly activities that encourage a change in society's attitude toward intelligent consumption).

Today's high growth of world consumerism has brought significant consequences to the environment, making its effects irreversible for the future. The application of the linear economy has not been favorable in waste management; on the contrary, the waste of final products threatens the planet both in the short and long term [93].

On the other hand, this problem has taken more significant consideration in recent years. One of the primary triggers has been climate change and biodiversity loss, so there is now a greater awareness of the environmental lobby and its purpose [128]. For their part, some irresponsible consumers create a gap between regular consumption and sustainable consumption, preventing such waste from being minimized and achieving sustainable consumption. In addition, this model proposes to generate greater consumer interest toward sustainable questions [54].

The CF and its implication to the environment are crucial in analyzing the environmental impact. The CF is probably the best-known indicator for measuring environmental impact. It is responsible for measuring the amount of CH_4 and CO_2 emissions on a chosen population or activity; that is, it measures the impact of certain activities that threaten the Earth's climate [113]. Among the main emitters of these gases, we find large companies, both manufacturing and non-manufacturing, and developing countries as primary threats to the environment [61, 138]. In addition, there is work on institutional organizations (OI) to ensure climate risks, increasingly complex challenges due to political factors, adaptability, interests, and others. Many regional governments tend to have a strong fragmentation between policy communities, which leads to the non-application of the actions proposed by OI. A similar case is experienced internationally [92].

Human life has changed, and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life. Due to limited sources by COVID-19, new ways to build new materials are essential in the reactivation of the global economies. In Table 1, detail the sectors impacted by COVID-19 pandemic.

The purpose of this chapter is to develop an approach related to the importance of the CE in the face of alimentary systems within four sections; of which the influence of the CE in the reduction of food waste is exposed, in addition to the policies implemented by different countries, the strategies generated by companies and the actions carried out by individual actors, finally the barriers that interpose the application and appreciation of the Circular Economy.

Table 1 Changes created by COVID-19 in different sectors

Education	[10, 11, 14, 16, 22, 56, 102, 103, 166]
Entrepreneurship	[6, 17, 24] [21, 30, 34, 36, 42, 52, 107, 112]
Health sector	[2, 9, 12, 19, 15, 32, 40, 55, 63, 100, 130, 134, 161, 164, 165]
Hospitality	[66, 86, 90, 97, 159]
Intellectual property	[13, 20, 49, 67, 94, 101, 123, 137, 163]
Population	[8, 23, 51, 87, 108, 129, 148, 141, 156, 157, 162]
Prices	[27, 57, 75, 89, 105, 122]
Tourism	[29, 33, 41, 44–48, 74, 142]
Trade	[3, 4, 7, 25] [18, 39, 60, 98, 109, 150, 153, 160]
Violence against women	[26, 53, 65, 85, 133, 147, 154]

2 Circular Economy Approach for Food Loss Reduction and Carbon Footprint

As global food waste increases, changes along the food supply chain are necessary [5]. Circular economy (CE) has been defined as a strategy that provides a business perspective to achieve sustainability and increase brand positioning and profits [79, 124]. CE initiatives help companies reduce food waste and pollution by ensuring the maximum value utilization of resources and outputs [31, 81]. Industries and policymakers design regulations and standards so that businesses adopt CE principles to reduce food waste and carbon footprint [124]. According to [155], policy measures can be classified as the following (Fig. 1):

Despite the development of policies aimed at reducing food waste and carbon footprint, the difficulty is evidenced in the actual transformation of these lasts into laws, regulations, standards, awareness campaigns, fiscal incentives, among others [131]. Businesses must adapt and deal with several obstacles such as financial aspects, regulations, corporate culture, and others [5]. One of the reasons for such change is that the Circular Economy requires consumers and companies to change behaviors,

Fig. 1 Classification of policy measures (*Source* Adapted from [155])

consumption patterns, manufacturing practices, etc. [64, 127]. This situation can result in a more challenging transition toward a circular economy approach, which may discourage organizations from acting [78]. Nonetheless, the correct implementation of circular economy practices in the food supply chain can give products a "second life" and be used for new purposes [127]. A circular economy may imply the development of strategies for waste reduction through innovation and technological development [38].

A circular economy allows the incorporation of the "waste = food" concept, meaning industries and organizations can use food dispositions as reusable materials [38, 82]. As it can be seen, though CE offers several opportunities to reduce waste by adopting several plans of action, it is not easy to achieve [152]. Governments and organizations can help companies achieve CE goals in various ways. Based on the Fig. 2, three types of variables influence food waste and carbon footprint reduction.

For actors, non-lucrative organizations can collect food surplus from companies such as supermarkets and donate this last as part of the interventions on food waste policy [104]. Supermarkets, as a result, are crucial for the decrease in food waste. These lasts were already influenced by different kinds of legislation, awareness campaigns, and incentives to foment food surplus donations [72]. Other exciting participants are schools. These can adopt several initiatives to reduce waste, such as catering staff training, recompositing of menus, and reduction of portion sizes [37, 151]. Finally, on the policy-initiatives side, governments can foment the private sector contribution with fiscal incentives, awareness campaigns, waste quotas regulations, among others, which result in the reduction of food waste and carbon footprint.

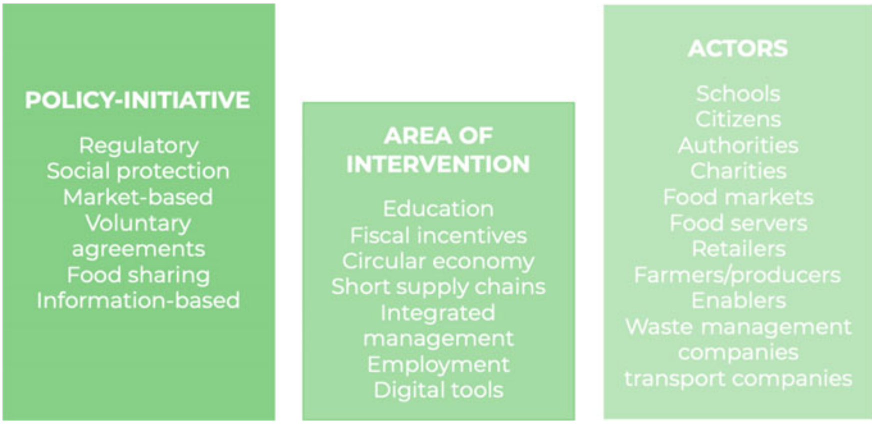

Fig. 2 Urban food waste policy (*Source* Adapted from [71])

3 Food Loss Reduction Practices Worldwide

3.1 Countries' Policy

During countries' development, governments adopted several strategies to reduce food waste. For instance, France adopted the Law 2016/138 to promote a donation from supermarkets' unsold food to organizations [116]. Others, such as Romania, are promoting voluntary commitment from companies in the agri-food sector to participate in awareness campaigns conducted by national authorities [126] (Table 2).

A government approach that promotes private sector contribution reduces food waste and carbon footprint. Indeed, supportive infrastructure and collaboration between actors are crucial for creating awareness campaigns and promoting food loss reduction initiatives [143]. For instance, in the United Kingdom, the "Love Food Hate Waste" campaign was raised in 2007 to increase consciousness from consumers and provide tips and measures to reduce their food waste [135]. Therefore, laws that encourage closed-loop business models result in a higher probability of sustainable operations implementation behaviors from companies [143]. Campaigns, as mentioned above, are not the only way to reduce food waste. Countries adopt different approaches.

An example is France, which implemented penalties if companies are not complying with the Law 2016/138 [62]. This last mandated supermarket to sign

Table 2 Food loss reduction policies practices

Country	Food loss reduction policies	Sources
Italia	National Waste Prevention Program, 2006 Law against food waste, Law No 166/2016	Giordano et al. [83], Arcuri [28]
France	Law for fighting food waste, Law No 2016-138	Condamine [58], Bunting Eubanks [43]
United States	Bill Emerson Food Donation Law, 1996 Federal Food Donation Act, 2008 Food Recovery Act, 2016	Bunting Eubanks [43]
Romania	Romanian Law 217-2016 against food waste	[126]
Spain	"More Food, Less Waste" Strategy, 2013	Magrini et al. [111]
Sri Lanka	National Agriculture Research Policy and Strategy	[131]
Czech Republic	Amendment 180/2016 on Food Act 110/1997	[135]

a non-profit organization to collect unsold food. In the case of Italy, the 166/2016 legislation offers to donators tax exemption, new funds, among other benefits [77]. For the United States, the American law before the Bill Emerson Donation Law followed the following approach. If a person gets sick from the food consumed, the direct distributor is automatically liable and responsible [77]. As fear of getting sued, companies, people, and organizations were not donating, though their desires were the opposite. It is worth emphasizing that national and supranational policies focus on achieving Sustainable Development Goals (SDGs), such as the number 12, focused on reducing and minimizing food waste by 2030 [88]. As a result, the growing international and national policies' development regarding circular economy practices is becoming more critical over the years [78, 144].

3.2 Companies and Actors Strategies

We can observe that several organizations of different sectors are adopting CE initiatives to improve economic-social-environmental development [35, 140]. Taking the example of charitable food aid in Finland, those organizations aimed at providing a solution for food poverty became one of the strategies to embrace sustainability as they reduce food waste disposal from retail sectors [149]. One of the problems evidenced in this industry is the shelf life, which increases food waste [50]. In Indonesia, an organic fertilizer company sends their output waste to other sectors such as the poultry and fish supply chain and reduces, consequently, final disposal [121]. Previous studies such as the one made by [70] identified 40 case studies of companies worldwide which implemented circular economy principles. Though they belong to different industries, they achieved several sustainable development goals by adopting circular economy principles and initiatives. For instance, the agri-food sector is considered one of the significant sectors of greenhouse emissions, and specific companies are redesigning their supply chain to reduce this indicator [136]. An example is 9 agri-food companies based in Italy, which developed corporate social responsibility initiatives as circular economy practices such as transforming waste into resources [73].

4 Carbon Footprint Reduction Practices Worldwide

4.1 Countries' Policy

As for food waste, countries are also implementing carbon footprint reduction practices to meet several sustainable development goals (Table 3).

Table 3 Carbon footprint reduction practices policies

Country	Carbon footprint reduction policies	Sources
Norway	Extended Producers Responsibilities policy (EPR) (2004)	Karstensen et al. [96]
Japan	Promotion of Effective Utilization of Resources (2010?)	[145]
China	12th five-year plan (2011–2015)	Murray et al. [117]
Singapore	Zero Waste Masterplan (2019–2030)	[132]
Portugal	Strategy and Action Plan for Combating Food Waste (2018)	[76]
Malaysia	Movement Control Order (MCO) (2020)	Naderipour et al. [119]

The environment is a topic of global concern that has been transmitted from generation to generation, and that gave rise to the concern of individuals and companies for the environment, generating concrete actions such as management of carbon emissions, waste and, carbon footprint others [76, 110, 158]. Table 3 shows only a few examples of policies implemented by certain countries, but it should be noted that these same countries have established a more significant number of policies and plans for the development of the Circular Economy and other countries that have not been mentioned. Thus, following a production and consumption model that is conscious of the importance of the 3Rs to minimize environmental impact [118].

Several actors are making efforts to meet carbon neutrality [44]. In the case of the European Union states members, they are required to implement waste management programs based on the Waste Framework Directive (2008/98/EC) [45]. As in Europe, practices such as recycling have been promoted [110], governments should enact restrictive laws and policies to increase carbon footprint reduction [44]. Such measures are often developed to manage waste and carbon emissions [145], increase recycling and improve composting [110], reducing packaging [132], in addition to other policies.

The solutions proposed by governments and various entities are based on CE [76]. Lack of fiscal incentives for food donation, lower VAT for recycled materials, among other initiatives, are broadly implemented by the European Union [45]. Working in FLW leads to trying to improve each of the steps in the food supply chain, from farmers, manufacturers, convenience stores, and large markets, such as restaurants, workplaces, colleges, universities; as well as working in the mind of the end consumer [158]. For these efforts to have the desired results, the actions to be taken must be worked on jointly, since the production of food integrates the use of resources such as non-renewable mineral resources, water from groundwater reserves, and fossil fuel [118, 158].

In this regard, policymakers are promoting low-carbon economic incentives to encourage companies to develop eco-friendly technological innovations [120]. It is proposed the creation of eco-friendly packaging design, the promotion of clean and conscious consumption of materials, and the adaptation of rules that allow buyers to adapt their consumption to an eco-friendlier one [114].

4.2 Companies and Actors Strategies

In this case, we can also observe different actors implementing CE to reduce the carbon footprint in different industries, as Greenhouse emissions keep growing and consumers are looking forward to modifying their choices [125]. For example, Spain has the largest agro-ecosystem that can be observed in Europe, which is facing climate change and the decrease of resources at the same time, this problem is being faced with the modification and improvement of farming activities, thus developing more sustainable systems from the beginning of operations [91]. The building sector makes efforts to reduce carbon emissions and energy consumption.

In Metropolitan Melbourne, Australia, the law created the "Building Code of Australia," which ensures that the construction of new houses is carried out in compliance with energy regulations [139]. Similarly, in La Abundancia-Florencia highway, Costa Rica, the need for a conscious construction in the mentality of public and private groups [68].

5 Barriers to Achieve Effective Circular Economy

The circular economy policy seems attractive for countries and companies. Nonetheless, several factors can make this objective difficult. Authors such as Stangherlin and de Barcellos (2018) mentioned that external influences might impact directly or indirectly individuals. In this sense, we can find the following aspects: historical, supply chain factors, and regulatory issues. For example, food waste can be generated when it is not adequately preserved [95], which requires suppliers' and consumers' contribution to initiatives to reduce food disposal [78]. Focusing on an organizational perspective, the lack of circular economy indicators reflecting food loss and carbon footprint reduction, lack of scalability of initiatives, and network support is also present [78].

It is possible to classify barriers to circularity in the food supply chain into 7 types: cultural, business and business finance, regulatory and governmental, technological, managerial, supply chain management, and knowledge/skills [5]. The academic field validates that these lasts affect businesses. For instance, awareness, capabilities, resources, and infrastructure for implementing green supply chain practices are not homogenous in all organizations [84, 140]. Furthermore, aspects such as government contribution in establishing regulations remain weak in a significant part of the globe [69]. It has been argued that their governments are not pushing the transition toward circular economy practices in the food sector because of the scarcity of economic resources and adequate infrastructure [99].

6 Closing Remarks

Over the last decades, food waste and carbon footprint awareness increased exponentially [121]. As a result, a circular economy, as a solution to these issues, can be implemented for diverse purposes in the supply chain to increase waste management. To promote this trend, governments have recommended implementing food waste policies [71]. Nonetheless, several challenges were identified. For instance, a lack of indicators, information, supply chain deficit analysis, among others, are present [50]. Moreover, food waste varies along the entire supply chain and can be affected by climate conditions, shelf life, manufacturing practices, fiscal incentives, etc. The private and public sectors must adopt initiatives to reduce the environmental impact [50, 146]. A possible solution can be the circular economy based on the interconnection between industries, focusing on delivering disposed output to other companies [70]. This proposal is challenging since it breaks the traditional linear model, requiring technological investment, redesigning the supply chain, among other strategic decisions [70]. Despite these drawbacks, food waste mitigation can be achievable and monitored efficiently [131] Nowadays, the current food production system is unsustainable [95]. Consequently, countries are developing programs and policies to increase and fasten the transition toward a circular economy but remain weak worldwide [71]. Also, actors such as NGOs, charitable organizations, among others, are strategic partners for the effective implementation of circular economy activities to reduce food loss [71, 115].

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Fashion and Textile Circularity and Waste Footprint

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Abstract Year by year, the waste footprint has been increasing significantly; thousands of tons of waste generated by various industry sectors is already bringing irreparable changes in the world. One of the principal industries that produce these effects is the fashion industry, which used to follow a traditional linear fashion promoted by marketing where consumption by demand becomes a "necessity." However, this perspective has been changing, where the final consumer nowadays is more conscious about the process and the negative aspects that fast fashion means for the environment and the social aspect. This current chapter analyzes the aspects that the fashion industry generates, such as economic, environmental, and social impact, and the solution that provides the fashion and textile circularity for the sector with practical cases being implemented.

Keywords Fashion industry · Circularity · Waste footprint · Recycling · Circular economy · Sustainability · Clothing

1 Introduction

It is crucial to know in detail the most relevant evidence of the impact of the COVID-19 pandemic and can develop more specific and successful plans for the recovery of the economy and commercial activities around the world (Table 1).

Worldwide, 80 billion new garments are sold, equivalent to $1.2 trillion annually for the fashion item. Garments are usually manufactured in higher proportions in China and Bangladesh, but Americans are the largest consumers of textile products [52]. The volume of garments purchased in the EU has increased by 40% compared to previous years and could triple by 2050 [80].

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Table 1 Impact of COVID-19 in different sectors

Education	[10, 11, 17, 20, 31, 77, 126, 127, 205]
Entrepreneurship	[6, 30, 22, 33, 44, 51, 53, 60, 72, 133, 141]
Health sector	[2, 9, 13, 27, 19, 49, 58, 76, 85, 122, 162, 167, 199, 202, 203]
Hospitality	[87, 99, 106, 119, 195]
Intellectual property	[14, 29, 68, 91, 112, 125, 155, 171, 201]
Population	[8, 32, 70, 101, 135, 160, 181, 174, 193, 194, 200]
Prices	[38, 78, 95, 104, 129, 154]
Tourism	[41, 50, 59, 65–67, 94, 177]
Trade	[3, 5, 7, 34] [24, 56, 79, 121, 136, 186, 190, 197]
Violence against women	[37, 73, 86, 98, 165, 180, 191]

The growing demand for textile products increases pollution, as it is positioned as one of the most polluting industries [57, 175] with a generation of 5% of waste in the world [93]. It employs toxic chemicals [176], produces polluting carbon from waste pyrolysis [198], uses energy [149], and makes packaging waste [96]. It added that fashion businesses quickly bring out new collections to market [143], which is related to the term fast fashion, which caused the textile sector to be distinguished as an industry that discards goods quickly, reducing the useful life of textile products [61, 124]. About 90 million clothes go to landfills annually [157]. 20% are reused and recycled [156].

For this reason, there is an increased awareness of the environmental damages of this sector, causing the creation of new business models with a sustainable vision [156]. Companies in this industry have started to consider their social and environmental footprint [118]. For example, waste such as yarn can be employed for new fabric manufacturing [103]. Management performed within a textile and fashion circularity is related to the concept of economic circularity emerging in the mid-1960s [54], but for [178], it is a controversial form of business. However, since 2015, the European Commission reported that the circular economy is an important model to consider in business [120].

The application of the circular economy has a focus on reducing waste [40, 88]. For textile products that are not being reused but wasted [92]. Much research on this concept [89, 147]. Due to its sustainable contributions to business and the planet [107, 170]. However, [172] and [161] pointed out a slight increase in studies on applying this concept due to the different barriers that industries encounter when they intend to implement it within their business. Among the barriers are cultural, market, technological, and regulatory barriers [120].

In the same sense, the poor traceability related to the number of textiles available in commerce causes it to be complicated to quantify the number of textile materials that are wasted [150], and textile companies do not incorporate circularity strategies due to limited resources [164]. However, the importance of reusing and recycling textile inputs or the products themselves would allow introducing new products to the market, which could occur through incorporating the circular economy with strategies such as the return and reuse of products [117].

2 The Economic Impacts of the Textile Sector

Living in a globalized world has generated the development and economic growth of various industries present in the market [184], and the fashion industry is no exception. A study found that the footwear and apparel industry is equivalent to about 2% of the global economy, which is 3000 billion dollars [159, 176], which means that the industry being studied in this paper has a significant influence and what happens to it have a positive or negative impact. In commerce, the textile sector needs employees to remain in operation, so this industry employs many workers and generates income at a global level [69].

With time, the increase in sales volume of textile clothing has been observed because the amount of clothing a person consumes has increased; according to [159], in 1995, there was 7.6 kg of fiber per person; while for the year 2018 it was 13.8 kg of fiber per person, this being an increase of 47%. The significant increase is due to fast fashion companies executing a strategy of price reduction through offers, in addition to incentivizing seasonal or campaign fashion products, which has been driven mainly by the era of globalization [43]. An increase in volume brings the need to hire more staff, so the textile industry generates many jobs. For example, in Table 2, only H&M in 2010 had 59,440 employees globally. The growth for the company increased the number of workers from 104,634 in 2015 to 110,325 in 2020.

In the fashion industry, haute couture, fast fashion brands, and the ones that sell sports clothing are considered the biggest in the world. Also, [159] say that countries such as Australia, the United States, Canada, and several located in Western Europe tend to consume a more significant amount of fashion textiles and that there is also a relationship between purchasing power the amount purchased. Furthermore, [39] emphasize that women usually consume apparel just for fashion needs and no longer basic needs. Within the price of products sold in various market industries, taxes are included, which are taxes collected by the state to finance public works, health, infrastructure, education, and others [12].

[63] mentions that Nike is the biggest has a value of around 35 billion dollars, followed by Gucci, the Italian luxury fashion brand with 17.6 billion dollars,and then have placed two brands in the third position with 16.5 billion dollars, one is a sports

Table 2 Number of employees around the world of H&M and Macy's

Year	Number of employees
2020	110,325
2015	104,634
2010	59,440

Source [100]

Table 3 The most valuable clothing brands in the world

Brand	Country	Brand value	Market capitalization
Nike	United States	34.8	180.2
Gucci	Italy	17.6	79.0
Adidas	Germany	16.5	71.1
Louis Vuitton	France	16.5	327.5
Cartier	France	15.0	51.3
Zara	Spain	14.6	97.1
H&M	Sweden	13.9	32.6
Chanel	France	13.7	N/A
Uniqlo	Japan	12.9	103.8
Hermes	France	11.9	118.0

Source [63]

brand again which is Adidas and the other one is the French luxury brand, Louis Vuitton. In Table 3 appears the ten most valuable clothing brands around the world. Also, the brand which has the highest market capitalization is the French company Louis Vuitton, with $327 billion, followed by the American sports brand Nike with $180 billion; the French Hermes with $118 billion, and a Uniqlo, a not to known brand with $103 billion.

3 The Environmental Impacts of the Textile Sector and the Circular Economy

The textile industry has a high rate of pollution on the planet [114], which is because companies use materials such as nylon, elastane, and cotton where they develop a method of production and disposal without the vision of reuse during the manufacturing chain [74, 144, 189].

For example, cotton is linked to high consumption of water, soil, and chemicals [80, 179, 187], use of polluting chemical dyes [138]. In the face of this, [75] investigated a tool that allows assessing the level of water preservation as well as monitoring the amount of contamination in the manufacturing chain using a preservation technology that helps to manufacture with a higher level of cleanliness in the textile industry [130].

It generates 3% of GHGs, positioning it within the top 5 pollution-producing items in the world [153]. Each year, the textile sector produces about 110 million tons of clothing and fibers that generate textile waste globally [131]. These are incinerated, causing environmental damage such as emissions [48, 109, 111, 196]. It should be specified that the damage of fibers or fabrics depends on the type of garment [80]. At the same time, the thickness of textile yarn and fabric causes pollution [189]. Among the types of waste from the textile and fashion sector are cardboard/paper, plastics, chemical, fiber waste, spinning waste, weaving waste, knitting waste, and clothing waste, which are pollutants worldwide.

Therefore, today there is a growing awareness of the environmental footprint generated by the textile industry, such as waste and carbon emissions [152, 163]. In this regard, [71] mentioned that the incorporation of cleaner production practices promotes environmental benefits for the textile industry through the minimal use of toxic materials and reducing accidents related to the environment. Waste management involves all parts of the chain, from the manufacturer to the customers of textile products [131].

Within the circular economy, the circular supply chain (CSC) can be found, which provides a flow that has no end since companies perform reuse, remodeling, and recycling of materials [140]. It is used to study pollution problems by decreasing waste during the manufacturing process of textile items [132]. It aims to improve resource management [132]. Therefore, these negative impacts can be reduced by applying the circular economy.

4 The Social Impacts of the Textile Sector and the Circular Economy

In the textile and fashion sector, there is no unanimity about the social impacts to be considered [116]. However, it is considered an item with significant negative impacts due to many worker rotations [128]. This problem is related to a large number of informality that triggers the possibility that employees in this sector do not receive additional benefits from the company or the government [62]. In addition, companies recruit migrants to pay them less. And they hire cheap labor demonstrating the exploitation of workers [96].

SMEs account for at least 45% and 40% of industrial manufacturing and exports. They provide jobs to more than 42 million people where employees are engaged in dyeing, cutting, and sewing [158]. In addition, they provide 8,000 goods of excellent quality produced for international markets, but with a production where informality and minimal labor payment abound [138]. For example, India is a textile manufacturing country after China and Bangladesh.

Another problem is the benefits of employees in the entire garment chain and the population's welfare [52]. Workers can acquire respiratory diseases in the industry due to the constant use of chemicals [47]; they can also suffer different occupational incidences. For example, in 2017, Brazilian companies in the textile sector presented a high percentage of occupational accidents, being 16.4/1000 employees [146]. Table 4 shows an example of labor incidents occurring in textile companies located in Brazil between 2015 and 1017, where males suffered the most damage.

However, today, social pressures seek to improve Corporate Social Responsibility within fashion companies [96], which allows companies to be more competitive in

Table 4 Labor incidence in Brazilian companies in the textile and fashion sector

Variable	Amount	2015	2016	2017	Annual variation rate (%)
Textile production	490,540	1.1%	1.1%	1.1%	−9.1
Clothing production and accessories	1,064,874	0.5%	0.6%	0.5%	−8.6

Source [146]

international trade, as well as to improve the quality of work of their employees, which affects their efficient performance [192]. To do this, companies can train workers to learn how to collect waste and send it to recovery sites [131]. In this way, employees learn about sustainable practices and take care of their health. Against this, circularity can also be incorporated, focusing on reducing environmental and social problems [55].

5 Circular Fashion and Waste Footprint in the Textile and Fashion Industry

The increase in the world population, the increase in the socioeconomic level of the middle class, and the low prices for purchasing clothing items have brought with it a high demand for these products [123, 139], which has resulted in the fashion industry being one of the most polluting, so its carbon footprint is large [42, 148]. On the part of the offer, many clothing brands, with low prices, contributed with the manufacture of garments of poor quality but fashionable each season, in this sense, consumers would see the need to acquire new fashion apparel in a linear way which is called fast fashion to [123]. This sector generates a negative impact on the environment because different types of waste are produced, such as water, solid waste, and the disposal of textile garments once their life ends [105, 176], and the production of CO_2 caused by the supply chain [123].

Nowadays, especially the companies related to textile and fashion products are related to unfair conditions involving health problems and child exploitation [157]. Social impacts are also related to environmental damage because fashion companies are looking for solutions to generate less impact on the carbon footprint [42], which is because of the high volume of fashion waste that the brands in the industrial production of fashion [151].

It is necessary to consider that consumers are becoming more conscious about the process involving the production of one fashion item and its consequences on the environment [45, 185, 188]. Previous research made in the UK found that income, culture, and prices work as determinants when consumers make decisions [204]. Because of that, fashion companies are trying to improve their supply chain by rethinking and designing models which focus circularly and avoid the traditional linear fashion [97]. In that sense, the brands are going through challenges to reduce their environmental impact. [204] also, add that the support of governments is needed by improving policy interventions such as subsidies and taxes to promote sustainability in the fashion sector of each country.

For example, the European Union decades ago has started regulations and policies to reduce the carbon emissions that used to be produced from industrial processes, transportation of goods, the energy of the factories, and others [12]. Also, some of the policies involucrated incorporating the concept of recycling in commercialized products, including fashion textiles, to generate less impact on the waste footprint [142].

The linear economy model generates a high carbon footprint because it generates the depletion of non-renewable resources [64]; that is why it is proposed to use the circular economy in various industries [55, 82], especially in the fashion industry [110]. In addition, [64] add that for success in the circular economy, it is essential to select partners with whom trust can be developed with a common goal, a circular economy, and customers. However, the culture of fast fashion consumption by clients in the sector is considered one of the main factors preventing the fashion industry's fluid, circular economy model [81]. To add, fashion companies execute marketing strategies to increase demand, hiding the environmental damage caused by consuming fast fashion items [46].

In their research, the authors [81] mentioned that in fashion circularity. There are many barriers, initiatives depending on the material, and drivers in every statement. In Fig. 1, the process is shown in a simplified way. The design stage is related to market circular economy initiatives about reduction, reuse, recycling, institutional regulation from governments, and the stakeholders are the conscientious consumers. Then in the manufacturing stage, technological initiatives are present, market organizations and many technical challenges are manifested. Then, the consumer usage focuses on the consumer culture and depends on them not to throw and not to buy constantly. And finally, the collection or recycling where technical challenges are involved as barriers and organizations. In the distribution, the authors found that circular initiatives are needed to reduce the carbon footprint because of the logistic process.

Some limitations of the fashion circularity in the literature according to [168], on their research, the main findings were that there are necessary more studies about

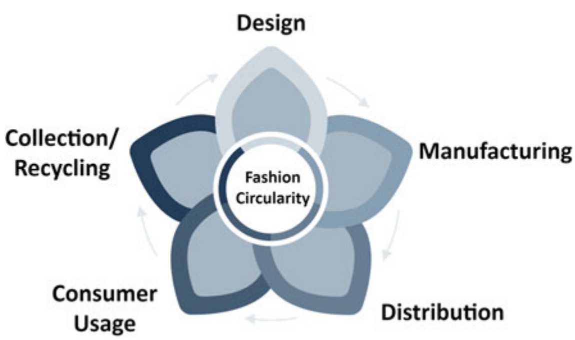

Fig. 1 Fashion circularity process (*Source* [81])

processes related to the collection, recycling, and classification. They add that fewer studies about wool and viscose, while the most studied are cotton and polyester. So is necessary more knowledge about these materials to process those to create new alternatives for the circularity process.

6 Case Studies of the Application of Circular Economy in the Textile Sector

The following paragraphs show various cases of companies and countries dedicated to the fashion industry implementing circular economy strategies and practices. The cases focus on countries such as the Netherlands, Brazil, and Australia, the incorporation of upcycling, and the company H&M, one of the companies that markets a large volume of textile products.

6.1 Garments Took Back by H&M

Companies in the fashion industry have implemented actions that involve returning clothing items in the store, by the end customer, through the collection in the same store, or working together with a social aid organization, among others [117]. With this innovative business model, brands make known their commitment to the associations with which they work together, in addition to their environmental responsibility [117].

Consumers' perception of this action has a positive influence because they capture the environmental and social awareness generated by the company in the garment collection campaign [113]. An example of a brand that is in the process of changing from traditional fast fashion to now opting for sustainability is H&M, with around 5020 stores worldwide, according to H&M 100, which seeks to exploit the garment waste [55]. It should be mentioned that it is essential to highlight the role played by the consumer since it depends a lot on them whether the fashion and textile circularity model works [148]. According to [115], the fourth industrial revolution in the fashion industry is a reshape of living and working. Both, in their research, highlight the importance of new technologies in the fashion companies and recycle the fashion textiles and give them another life with circularity and reduce the waste footprint that they would come with if the cloth ended in a dump. To carry out this process, the company mean high investment, but the implementation of this is considered as a tool of marketing that benefits the company [46] because of the consumer's conscience [45, 185, 188] as it was mentioned.

Table 5 Percentage approximately of fabric leftover while manufacturing

Fabric leftover	Large manufacturer (%)	Small manufacturer (%)
Cutting leftovers	12	21
End-pits and roll ends	2.5	4.2
Rejected fabric and garments	4.2	5.2
Excess made by the fabric	2.5	3.7
Over production	3.5	5.1
Total leftovers	24.7	39.2

Source [42]

6.2 Integrating Upcycling

The concept of upcycling refers to using textile leftovers that are considered waste for the creation of new textile garments [42], which works as a new method that many apparel brands can implement. Table 5 shows the high quantities of fabric leftover generated by large and small manufacturers where the main difference is cutting waste. In that sense, it demonstrates that when comparing both, the large manufacturing companies produce less leftover fabric because small companies can get an excess fabric. After all, their sales are in a smaller quantity.

6.3 Australia: Recycling Cotton from Denim

In the continent of Oceania, being specific in Australia, research made by [139] demonstrated a process of recycling where the denim waste goes through a process of dissolution to a binary solvent, and then while it is wet, it is spun. In that study, they show that using this process, the spun fiber, the color that belongs from the original textile, can keep on the new threads or, in the other case, can be regenerated if color is absent. Figure 2 shows the process that the authors propose.

6.4 Netherlands: Textile Materials in Circulation

In the Netherlands, research was developed to address the circular economy in the textile industry as an efficient method for the utilization of textile materials [147]. The approach was based on the analysis of institutional transformation in the circular economy transition [93] since no theory provides knowledge for organizations to develop new institutions to favor circular textile materials.

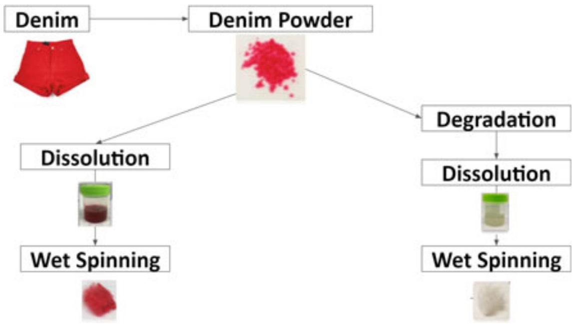

Fig. 2 Process for Denim recycle (*Source* [139])

Table 6 Strategic situations for a circular economy according to Dutch companies

Companies	Circular economy strategies	Strategic positions or situations
Mud Jeans	Rent a jeans	Develop a chain of coordination between all parties involved
Dutch aWEARness	Corporate rental of Dresses	
Lena Fashion Library	Fashion library	

Source [93]

The Netherlands and Nordics have a 61% rate of discarded clothes, go to landfills, or become incinerated [93, 111]. In some cases, they go to recycling, but recycling implies a downward life cycle of the materials after being reused. Therefore, Dutch apparel companies are founders of different companies that make transition processes toward circular development of materials, and this is executed with the generation of new organizational ways. For example, reconditioning and remanufacturing, sustainable strategies found in the circular economy [140] allow lengthening the utilization of materials by decreasing the application of harmful chemicals [176].

About institutions, new standards were created in this country regarding the use of textile materials to supervise the fair use of recycled fabrics and to develop cascade actions in the apparel chain. To this end, they created two agreements called PAS and SQ that are helping companies and institutions to produce positive impacts on the planet and society. The PAS agreement includes Mud Jeans, Lena Fashion Library, and Dutch aWEARness, which apply the circularity regulations proposed in this agreement. Table 6 shows the strategies implemented by these Dutch companies.

6.5 *Brazil: Textile Recycling*

Brazil ranks fifth among the countries involved in textile and fashion manufacturing and fourth in clothing manufacturing globally [146]. Within the state that produces the most polo in this country is São Paulo, followed by Santa Catarina. This second, in 2017, generated an income of more than 19.7% in the textile and fashion industry,

Table 7 Brazilian companies that recycle textile waste

Name	Raw material	Final product
Benefibras	Post-industrial waste of natural fibers	Fiber
Ecosimple		
Lonatex		
Superfios		
Ecofios	Post-industrial waste of natural fibers	Wires and strings
Benefios		
Eurofios		
Maxitex	Post-industrial waste of natural and chemical fiber	Yarns, fabrics, and clothing

Source [36]

Table 8 Cost of textile waste about recycling Brazilian companies

Components	Value per kilogram
Combined waste	R$ 0.05 < R$ 0.10
Cotton fabric with colors	R$ 0.70 < R$ 1.00
White cotton fabric	R$ 1.20 < R$ 1.70
Acrylic fiber or polyamide	R$ 0.70 < R$ 1.00

Source [36]

where companies provided jobs to 162,845 inhabitants since, in this state, there are 1,832 companies dedicated to this item [146].

In Brazil, companies use Jean's waste as inputs for the automotive industry, materials that are manufactured from 100% cotton and polyester are used to produce wires and ropes [36]. For this reason, it is essential to provide a practical example from this country related to sustainable textile waste practices based on waste recovery through recycling [131, 169]. Table 7 shows the name of Brazilian companies dedicated to recycling textile waste to improve their sustainability as a company to take care of the planet and society in general. While Table 8 shows the price of textile waste in companies located in Brazil.

7 Closing Remarks

The fashion industry influences the world economy due to the era of globalization. It is mainly due to the high demand of consumers to buy fashion garments driven by marketing [46], which has brought with it economic income for large companies that sell textile fashion, as well as for the GDP of these countries, it has also generated jobs for 45 million people at the international level [69, 173]. For example, in Bangladesh, 4.2 million job opportunities have been generated Hossain et al. [108], and 42 million for India [158], while the H&M company employed around 110,325 people in 2020 [100].

However, although this industry has been bringing a positive impact on the economy of the different countries, it has also brought with it a negative impact that harms the environment [137], despite having environmental regulations to control pollution in the sector [102]. Among the damages it causes are the high amount of "gray water" that causes the water footprint to be harmed and the climate due to accelerated variations in aquatic ecosystems [75, 182]. The waste is incinerated or thrown away [111]. The high levels of chemicals [187], among other problems detailed in items of environmental impacts of this industry.

Regarding social impacts, there is evidence of a high rate of labor incidents due to the activities carried out by employees to manufacture garments or textile accessories [146]. Added to this are stressful workloads [1] and the minimum payment for migrant labor [134]. Even though the institutions have implemented good employment conditions, they have not managed to ensure the well-being of the workers in this industry. For this reason, [4] states that the owners of international companies and local and international public authorities have to pay more attention to these problems related to confections. In the same sense, [183] pointed out that the industry needs an empowered workforce obtained through sustainable regulatory policies by international institutions and collaborations.

Because of that, to keep using the traditional linear fashion, [97] propose the implementation of the fashion circularity. The primary purpose of this is to avoid waste produced by the cloth garment, where basically the idea is that the process continues from the design, the manufacturing, the distribution, the consumer usage, then the collection of the apparel to recycle this, and then goes the design again and so forth [81].

The companies such as H&M have been implementing the clothing garments take back to reduce the waste solid created [55]. Also, innovative proposals such as integrating upcycling in Australian research [42], recycling cotton from denim [139], the recycling of textile materials in Dutch companies through the collaboration of institutions can later create new sustainability regulations [93], (Fischer et al. 2017). Finally, there is the recycling of textiles in Brazilian companies, where they develop transformations to waste by converting them into new products such as cables and ropes [36].

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Material Selection for Circularity and Footprints

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Abstract Companies that offer a good have a significant carbon footprint due to the production of their products. In this way, a selection of more environmentally friendly materials is sought to reduce pollution, so that unused or no longer helpful raw materials can be reused in the production of other derived products. This research details a circular economy framework for carbon footprint reduction, focusing on material selection. Most of the articles reviewed date from 2017 to 2021, demonstrating that the topic is new to the research area. Based on the literature review, research on the circular economy in feedstock sorting has focused on the recovery and recycling of waste to facilitate circularity in future. The framework presented also allows analysis from an eco-efficiency point of view because it considers economic and environmental aspects that improve products and processes using technologies. This way provides professionals with a new approach to efficiently cost-effectively managing their waste. In addition, circularity can be especially useful for the long-term strategy work of various companies regardless of the sector they are in, but which are in the goods production sector.

Keywords Material selection · Circular economy · Environmental footprint · Green design · Sustainable development · Product durability

1 Introduction

Because of the exponential growth of technological advancement and human population, energy supply and environmental threats have become significant concerns worldwide [132]. Companies must examine their operations to see if there are any

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opportunities to reduce wastage, energy demand, gas emissions, and resource exhaustion [45, 46, 113, 132]. It is no longer an issue of whether to include environmental management in business activities; instead, it is a question of how [46, 88]. From the standpoint of industrial sustainability, in which goods and wastes are created concurrently, it is attempted to identify how the industrial system may be constructed in such a manner that environmental consequences can be measured quickly and accurately, making it environmentally friendly [34, 46, 126]. Product designers must consider environmental consequences from the early phases of the product design lifecycle and the selection of essential materials [36, 55, 88, 109]. The selection of materials can guarantee that items adhere to environmental guidelines, make product maintenance and disassembly easier, and increase product reuse, recycling, and regeneration [93, 109].

Green product design not only plays a vital role in the manufacturing business, but it has also become a primary focal point in future, thanks to increased environmental consciousness and the implementation of environmental protection regulations [88, 123]. Consumers' needs are no longer satisfied just by practical and industrial design [88]; they now look for items that adhere to environmental principles and standards [45, 109].

In recent years, the circular economy as a concept has been part of the popular and scientific debate [90, 93, 138]. Because resources are mostly finite, the intensive extraction produced over time to obtain materials needed in a linear economic model for subsequent use and disposal has resulted in environmental pollution [75, 104, 138]. New laws and regulations have progressed with global development toward a sustainable one, in which environmental preservation is fundamental [100], although it is trendy in the public debate and still requires further refinement of its theory [93]. The costs arising from the disposal of waste have been increasing, thus with new technological advances, there has been an understanding of the potential value of waste, and an alternative for entrepreneurs has been to rethink waste materials into a renewable resource [93, 100, 135]. Because of this, it is imperative to know the necessary development for decision-making by companies that provide residual waste treatment [128].

A circular economy is viable for reducing environmental impact [93]. Its goal is to reduce waste through design while preserving financial and ecological value [69, 88, 132]. Product integrity is an important idea in the circular economy model [88], and keeping products functional takes precedence beyond material recovery [34, 109, 142]. Product value can be kept through durability, lifespan extension, and product recovery strategies, while the material value may be sustained through recycling [46, 93, 120, 134]. In addition, the quality of materials is critical in determining the economy's circularity [88, 109]. The functionality of compounds contained in materials is significant to downcycling [110], and this consideration is consistent with the concept that "as long as feasible" functionality and practicality conservation is vital for a circular economy [59, 69].

Worldwide, the population and companies work hard to reestablish the life that they enjoy daily before the COVID-19 pandemic. Initially, some activities have changed in differents areas [13, 16, 17, 21, 22, 25, 31, 29, 32, 62, 64, 70, 102, 118].

It is crucial to know in detail the most relevant evidence of the impact of the COVID-19 pandemic and can develop more specific and successful plans for the recovery of the economy and commercial activities around the world (Table 1).

2 Background and Environmental Context

Environmental issues have become more global in scope in recent decades, both in terms of their existence and repercussions, as well as the socioeconomic factors that cause them [79]. Upon sporadically acknowledging the rise in global awareness of climate change, this entry looks at the nature of environmental issues and their long-term implications, as well as evidence that humans are increasingly pushing against worldwide environmental boundaries [129] (Fig. 1).

Through the efforts of environmentalists, activist groups, and politicians, concern over air and water pollution quickly expanded to various other problems: climate change, deforestation, natural resource depletion, and waste production, among others [129]. The environment supplies us with the natural resources needed in industrial economies and production [68, 100]. The environment serves as a supply point for human cultures by offering what is referred to as the sustenance basis. It provides renewable and non-renewable resources [68]. Excessive use of natural resources, such as water, air, and biomass, may lead to shortages, while excessive use of non-renewable resources, such as coal, fossil fuels, and natural gas, might lead to scarcities [68, 79]. However, humans produce waste due to the utilization of natural resources [100]. Nowadays, it is quite conceivable to state that we live in a wastage-oriented culture, as a result of population expansion and increased production of waste, which causes landfills to become more frequent and deteriorate the biosphere [79, 100, 140] (Fig. 2).

Day after day, massive volumes of waste are created in cities and agricultural regions [100]. Millions of tons of waste material are delivered to the world's significant landfills [130]. The Sudokwon landfill facility in South Korea receives around 6.9 million tons of waste produced yearly, which is the most of any landfill site in the world [130]. The Apex Regional landfill in Las Vegas is the world's most considerable surface extension, receiving approximately 3.8 million tons of debris per year [130]. While escalating urbanization and industrialization have accelerated the rate of resource scarcity and environmental damage throughout the world, popular support for sustainability has risen [79, 84]. Now, green material selection, also known as sustainable material selection, is presented as an alternative model aiming to ensure product functionality while reducing the overall environmental and human health burden [109].

Table 1 Impact of COVID-19 in different sectors

Education	Ali [8], Allen et al. [9], Alvarez-Risco, Estrada-Merino et al. [23], Alvarez-Risco, Del-Aguila-Arcentales, Rosen et al. [18], Alvarez-Risco, Del-Aguila-Arcentales, Yáñez et al. [20], T. Chen et al. [56], Lackie et al. [94], Lashley et al. [95], Zollinger and DiCindio [151]
Entrepreneurship	Afshan et al. [4], Alvarez-Risco and Del-Aguila-Arcentales [15], Alvarez-Risco, Mlodzianowska, García-Ibarra et al. [26], Alvarez-Risco, Mlodzianowska, Zamora-Ramos et al. [27], Belitski et al. [38], Block et al. [41], Brown et al. [42], Bacq and Lumpkin [48], Chafloque-Cespedes et al. [53], Maritz et al. [97], Liguori and Winkler [101]
Health sector	Abiakam et al. [1], Alan et al. [7], Alsairafi et al. [10], Alvarez-Risco, Dawson et al. [12], Alvarez-Risco, Del-Aguila-Arcentales and Yáñez [19], Alvarez-Risco, Del-Aguila-Arcentales, Yáñez et al. [20], Barello et al. [39], Bozdağ and Ergün [44], X. Chen et al. [57], Deressa et al. [65], Koetter et al. [89], Raudenská et al. [116], Rojas Román et al. [119], Yáñez, Afshar Jahanshahi et al. [144], Zhang et al. [149], Zhang et al. [150]
Hospitality	Duarte Alonso et al. [67], Gursoy and Chi [78], Ho et al. [83], Kaushal and Srivastava [86], Yan et al. [143]
Intellectual property	Altindis [11], Alvarez-Risco and Del-Aguila-Arcentales [14], del Castillo [63], Erfani et al. [71], Jecker and Atuire [85], Krishtel and Malpani [92], Okereke [108], Sekalala et al. [124], Zarocostas [147]
Population	Ahsan [6], Alvarez-Risco, Mejia, et al. [24], Cegarra-Navarro et al. [52], Hanzl [80], Lim and Prakash [98], Quispe-Cañari et al. [111], Sánchez-Clavijo et al. [121], Shaw et al. [125], Wen et al. [139], Wu et al. [141], Yáñez, Alvarez-Risco et al. [145]
Prices	Apcho-Ccencho et al. [35], Chung et al. [58], Galanakis et al. [74], Hepburn et al. [81], Leiva-Martinez et al. [96], Obergassel et al. [107]
Tourism	Assaf and Scuderi [37], Baum and Hai [40], Brouder [47], Carvache-Franco, Alvarez-Risco, Carvache-Franco, Carvache-Franco, Estrada-Merino and Villalobos-Alvarez [49], [73], Carvache-Franco, Alvarez-Risco, Carvache-Franco, Carvache-Franco, Estrada-Merino and Rosen [50], [127], Carvache-Franco, Carvache-Franco et al. [51]
Trade	Abudureheman and Nilupaer [2], Acuña-Zegarra et al. [3], Aguirre et al. [5], Alvarez-Risco, Quipuzco-Chicata et al. [28], Alvarez-Risco, Rosen et al. [30], Borzée et al. [43], Cruz-Torres et al. [61], Kirk and Rifkin [87], Lopez-Odar et al. [99], Tran [133], Vidya and Prabheesh [136], Yasin Ar [146]
Violence against women	Amarillo [33], Chafloque-Cespedes et al. [54], Dominelli [66], Gulati and Kelly [77], Roesch et al. [117], Sánchez et al. [122], Viero et al. [137]

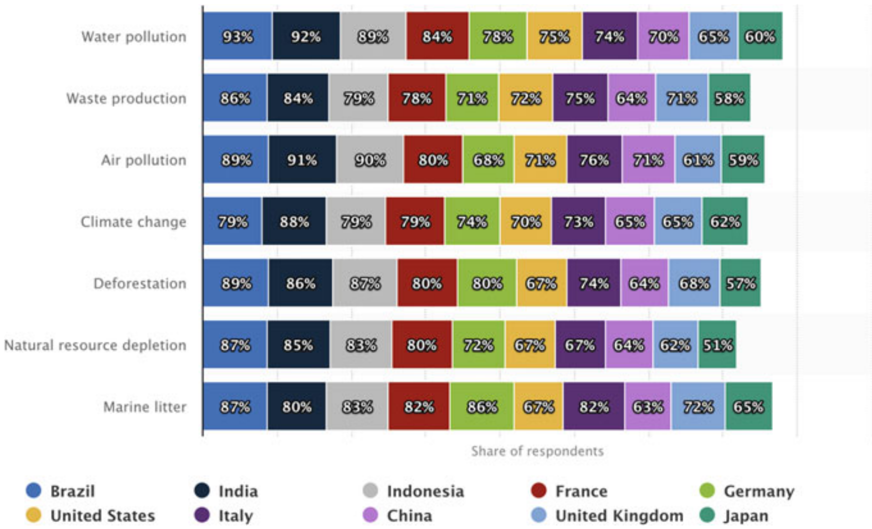

Fig. 1 Concerns about the environmental impacts of packaging worldwide 2020, by country (*Source* Statista [129])

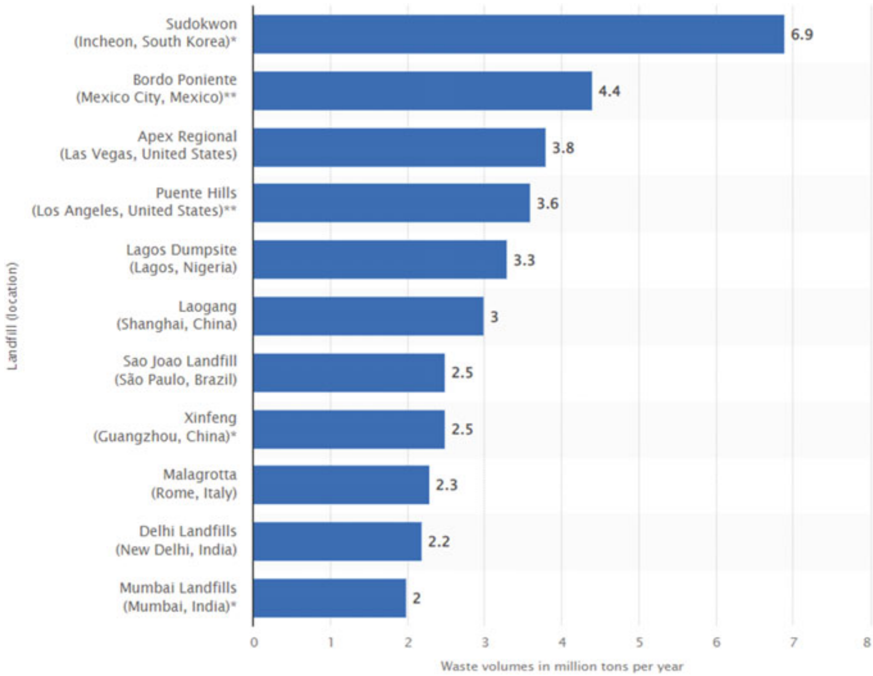

Fig. 2 Annual volumes of waste disposed at the largest landfills worldwide as of 2021 (in a million tons) (*Source* Statista [129])

3 Material Selection

The selection of a material for a new product or to improve an existing one is an essential part of the industrial design process [36]. The techniques for selecting materials are based on factors developed by physicists, mechanical engineers, thermal engineers, electrical engineers, and production engineers that define a material's technical utility [36, 132]. Previously, material selection approaches were mostly cost-driven [148]. Material selection is, however, becoming more critical in the context of the change from linear to the circular economy during the last decade, which has resulted in new aims to decrease ecological consequences, enhance process efficiency, and generate both social and economic advantages while retaining a product's usefulness, practicality, and value [109, 148].

The residues of unused materials can be reintroduced into the production chain and recycled as much as possible [72, 106, 115], which would be very beneficial for the environment [60]. Being paramount to reduce the extraction of raw material coming from natural resources so that the carbon emission is lower, which these measures are in favor of the environment, this is due to the circular production model [91], which tries to decrease land and marine pollution [140]. All plastic-related products are significant because they have a very short lifespan, the volumes in which they are produced are high, and their composition in many cases is harmful to the environment [84], which is why the management of these is of optional interest to governments that are investing in the EC [79].

3.1 Circular Model

The current linear economic model, based on the disposition of cheap and easily accessible large quantities of materials and energy, as well as cheap means to dispose of what no longer interests, has been at the heart of industrial development and has produced unprecedented levels of growth, is reaching its physical limits [72, 90]. The circular economy is a production and consumption framework that encourages people to share, reuse, repair, and recycle existing resources and products for as long as feasible, prolonging a product's life cycle [76, 91], which means reducing waste to the absolute minimum [90, 114]. When a product reaches the end of its useful life, its materials are reused as much as possible [76, 90]. These may be put to good use over again, resulting in increased value [72, 76, 91]. By design, a circular economy is restorative and regenerative, aiming to retain goods, components, and materials at their current use levels [72, 128]. The paucity of natural resources and high levels of pollution in the world have pushed productive systems toward the CE model, which emphasizes better material applications, longer product lifespans, and more innovative product creation and usage [84, 114]. Environmental implications are determined once the materials for each component are established, considering materials selection occurs during the product design process [109, 148]. Profits drive most manufacturers' production activities since any specific firm's existence, and financial state usually defines its operations [84, 148]. Enterprise decision-making must be directed by both market demand and the value toward a community based on environmental protection principles, resulting in more sustainable manufacturing processes, preparation procedures, and material selection schemes, based on the assumption of addressing economic issues [84, 109, 128]. As a result, the definition and selection of manufacturing materials have become a significant problem in CE approaches [72, 128].

Sustainable production should prioritize the use of renewable resources and the efficient use of non-renewable resources, and the avoidance of waste that the environment cannot absorb [88, 148]. Previous studies point out that materials must be chosen to ensure durability when it comes to material selection for increased circularity [103, 109, 148]. However, in terms of economic and marketing considerations, designers may consider durability a non-desirable feature [103, 115]. Durability and maintainability in product design have significant potential to improve and maximize product longevity [103, 132]. According to previous research, durability has been extensively investigated in the field of construction and buildings, where it has been supplemented with modular strategies to optimize structure assembly and disassembly as per product lifecycle prerequisites or the use of environmentally friendly materials [103, 112]. According to Rahla et al. [112], the purpose is to define the best product dependability and durability, allowing for extended periods of operation without failure. Increased longevity enhances resource efficiency by reducing material consumption and delaying demand for new products, allowing for shorter material cycles, according to Steinmann et al. [131]. Durability helps resource preservation and wastage mitigation, according to an examination of standardized tests and processes for goods and materials [103, 112, 131].

3.2 Environmental Footprint

The planet's ecological footprint is a measurement of human demand on the earth's natural ecosystems [123]. The amount of biologically productive land and marine area required to maintain current levels of resource consumption and generation of waste by the global population [105]. Choosing the suitable materials affects the product's functional performance and its pollutant emissions and energy consumption throughout its product life cycle [105, 109, 148]. The entire amount of carbon dioxide emissions, directly and indirectly, generated by activity or accumulated during the lifespan of a product is defined as the total amount of carbon dioxide emissions [105]. The total direct and indirect CO_2 emissions and the equivalent CO_2 emissions of other greenhouse gases are computed during the lifespan of a product, process, or activity [105, 123]. Moreover, the quantity of carbon accessible in various fuels and the efficiency of energy conversion determine the amount of carbon released [68, 79, 105].

With public awareness for sustainable development growing, material selection must adhere to green design principles, increase product quality, and expedite manufacturing processes, reducing negative environmental and human health consequences [109, 148]. Eco-design tools may enhance a product's environmental performance early in the design process, not only because they can cut manufacturing costs and materials, but also because they can minimize embodied energy and CO_2 emissions, as well as remove waste [34, 59, 109]. The manufacturing sector is dealing with building a product that has a lower environmental effect to create a more sustainable society, and green design plays a crucial part in this [105, 120, 123]. Green product design, also known as eco-design, can be defined as the use of elements that might lessen a product's environmental effect throughout the design phase [109, 123]. Eco-design provides businesses with a variety of benefits and prospects, not only in terms of the environment but also economic growth and social responsibility [46, 59, 123].

By optimizing the inputs and outputs of the manufacturing process, minimizing resource consumption, lowering environmental impact, and enhancing system efficiency, a product's environmental performance increases, lowering its overall ecological footprint [109, 123, 134]. Furthermore, the adoption of Environmental Management Systems (EMS) may be aided by green design approaches [109, 120]. Environmental data, as external factors, may be utilized for user communication and marketing while also enhancing the presence of the environment as a decision-making criterion affecting purchase intention [59, 120, 126]. Furthermore, better environmental profiles comply with existing standards and anticipate increasingly stringent norms in future [59, 82, 120, 126].

4 Closing Remarks

To validate the selection of materials in a CE context and reduce the carbon footprint, this is an issue of relevance for both the public and private sector, which can make decisions focused on a more circular measure using technologies. In a framework where production and consumption are designed to encourage people to share, reuse, repair, and recycle, extending the life cycle of products. In this way, waste is reduced to a minimum, with a positive impact on the environment, promoting a shift from linear to circular, increasing competitiveness in new markets with its end products being eco-efficient.

Knowing how to select a material that can be reused in the short and long term is paramount, as it becomes attractive in both the commercial and waste markets because it can be a potential raw material for a downstream product being demanded in different markets; therefore, good quality plays an important role. It is worth mentioning that an eco-design in a product in its early stages can reduce production costs, CO_2 emissions and eliminate waste, being more sustainable in its production. In addition, it offers companies very positive economic growth and projects a favorable image from a social responsibility point of view. In summary, we conclude that companies must adapt to the change to more environmentally friendly options, with the CE model being an alternative, and that regulatory frameworks are necessary for accordance with the evolving needs of the markets so that the private or public sector should also adopt environmental management systems (EMS). We hope that this document is part of future research and scientific studies related to the EC and the environmental footprint.

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Application of Virtual Strategies

Water Footprint in the Textile and Food Supply Chain Management: Trends to Become Circular and Sustainable

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Abstract The textile and food industries are two sectors whose water consumption generates a significant environmental footprint. The production of industries must be focused on sustainability if the organizations for these sectors are improved. Therefore, it is necessary to focus the analysis on the sustainable alternatives applied in the supply chain by applying circular strategies. This chapter presents water use and its water footprint in the industries above. In addition, some strategies applied to improve water footprint levels—which involve water consumption and pollution—through circular strategies are presented. Finally, some trends and external and internal factors that can determine the successful implementation of a sustainable supply chain are presented.

Keywords Textile industry · Food industry · Water footprint · Sustainability · Supply chain · Circularity · Sustainable strategies · Resource management

1 Introduction

Countries such as India, China, and Bangladesh generate between 2.8% and 3.3% of the world's wastewater from the textile sector. The wastewater generated by these countries is 640, 1840, and 1030 million m3/year, respectively [82]. Overall, water use in the textile industry accounts for a significant environmental footprint [113]. Along the supply chain, many stages require large amounts of resources to be carried out. Mainly, garment production requires higher water consumption, especially the dyeing stage. From this stage, large amounts of water resources are used and polluted [148]. There are various ways to apply circularity in the supply chain. Some authors suggest the application of technologies, while others propose changing

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and improving the stages of the supply chain. Whatever the alternative, it is necessary to be efficient in managing and controlling resources, especially water.

Overall, assuring a sustainable food supply for the world's fast-growing population is a significant challenge in the agricultural and food industry. The supply chain in this industry is one of the critical areas that require action, alongside food consumption, nutrition, and food security issues. The methods of global food production must change to minimize the impact on the environment and support the world's capacity to produce food in future. As well as other economic sectors, food production contributes to climate change, water scarcity, soil degradation, and the destruction of biodiversity. In this paper, the environmental effect we focus on is on the water footprint and scarcity. This research analyzes what type of immediate changes can be made to food production to make it more sustainable, with organizations such as the European Commission.

It is crucial to know in detail the most relevant evidence of the impact of the COVID-19 pandemic and can develop more specific and successful plans for the recovery of the economy and commercial activities around the world (Table 1).

For this chapter, information on the water footprint in the textile and food industry is discussed. Strategies for implementing a sustainable supply chain that focuses on the management of production resources, especially water, are proposed. Finally, some external and internal factors that improve the supply chain are presented. Conclusions are presented based on what has been developed.

2 Literature Background

2.1 Water Footprint in the Textile Industry

Reducing the water footprint in the textile industry is a concern for achieving sustainable development globally [137]. China, for example, has become the largest exporter of textiles in the world [121], which is reasonable considering that the Asian country has become the most significant global producer [54]. In this country, manufacturing industries are not eco-efficient and even transgress planetary boundaries, including freshwater use [146]. The study of the water footprint in the textile sector has focused on finding sustainable alternatives for the industry worldwide, considering that water consumption in this industry is high [137]. The water footprint provides valuable information regarding the consumption (in quantity and quality) of water in the production processes of different sectors, whether at industrial, domestic, or agricultural levels [83].

The water footprint has been high in the textile sector and can be supported by research from significant garment-producing countries. Wang et al. [133] calculated the direct blue and gray water footprint Chinese companies use for garment production. Three subsectors of the textile industry were studied: textile, footwear, cap manufacturing sector, and chemical fibers. It was concluded that the sector's water

Table 1 Impact of COVID-19 in different sectors

Education	Ali [10], Allen et al. [11], Alvarez-Risco, Estrada-Merino et al. [17], Alvarez-Risco, Del-Aguila-Arcentales, Rosen et al. [14], Alvarez-Risco, Del-Aguila-Arcentales, Yáñez et al. [16], T. Chen et al. [55], Lackie et al. [90], Lashley et al. [91], Zollinger and DiCindio [149]
Entrepreneurship	Afshan et al. [4], Alvarez-Risco, Mlodzianowska, Zamora-Ramos et al. [24], Alvarez-Risco, Mlodzianowska, García-Ibarra et al. [19], Alvarez-Risco and Del-Aguila-Arcentales [23], Belitski et al. [31], Block et al. [34], Brown et al. [36], Bacq and Lumpkin [43], Chafloque-Cespedes et al. [52], Maritz et al. [94], Liguori and Winkler [100]
Health sector	Abiakam et al. [1], Alan et al. [7], Alsairafi et al. [12], Alvarez-Risco, Dawson et al. [21], Alvarez-Risco, Del-Aguila-Arcentales and Yáñez [15], Barello et al. [32], Bozdağ and Ergün [40], X. Chen et al. [56], Deressa et al. [61], Koetter et al. [87], Raudenská et al. [112], Rojas Román et al. [115], Yáñez, Afshar Jahanshahi et al. [141], Zhang et al. [145], Zhang et al. [147]
Hospitality	Duarte Alonso et al. [64], Gursoy and Chi [73], Ho et al. [77], Kaushal and Srivastava [84], Yan et al. [139]
Intellectual property	Altindis [13], Alvarez-Risco and Del-Aguila-Arcentales [22], del Castillo [50], Erfani et al. [67], Jecker and Atuire [81], Krishtel and Malpani [88], Okereke [107], Sekalala et al. [118], Zarocostas [143]
Population	Ahsan [6], Alvarez-Risco, Mejia et al. [18], Cegarra-Navarro et al. [51], Hanzl [74], Lim and Prakash [95], Quispe-Cañari et al. [111], Sánchez-Clavijo et al. [123], Shaw et al. [119], Wen et al. [135], Wu et al. [136], Yáñez, Alvarez-Risco et al. [142]
Prices	Apcho-Ccencho et al. [28], Chung et al. [57], Galanakis et al. [69], Hepburn et al. [75], Leiva-Martinez et al. [92], Obergassel et al. [106]
Tourism	Assaf and Scuderi [30], Baum and Hai [33], Brouder [42], Carvache-Franco, Alvarez-Risco, Carvache-Franco, Carvache-Franco, Estrada-Merino and Villalobos-Alvarez [49], Fotiadis et al. [68], Carvache-Franco, Alvarez-Risco, Carvache-Franco, Carvache-Franco, Estrada-Merino and Rosen [47], Sigala [120], Carvache-Franco, Carvache-Franco et al. [48]
Trade	Abudureheman and Nilupaer [2], Acuña-Zegarra et al. [3], Aguirre et al. [5], Alvarez-Risco, Quipuzco-Chicata et al. [25], Alvarez-Risco, Rosen et al. [20], Borzée et al. [38], Cruz-Torres et al. [60], Kirk and Rifkin [86], Lopez-Odar et al. [97], Tran [127], Vidya and Prabheesh [129], Yasin Ar [140]
Violence against women	Amarillo [26], Chafloque-Cespedes et al. [53], Dominelli [62], Gulati and Kelly [72], Roesch et al. [114], Sánchez et al. [122], Viero et al. [130]

footprint was 1.8 billion m^3, which is a worrying figure as textile activities generate water pollution that could cause depletion of water sources and health problems for citizens. Despite this, the water footprint has decreased by applying water-saving technologies and encouraging it with government policies. Similarly, Hossain and Khan [78] found that the textile supply and production chain consumes and pollutes water in Bangladesh. In general, most research suggests a negative impact of the textile industry on the water footprint and water pollution [89].

Research has focused on determining the overall water footprint of a country's textile sector. The complexity of calculating the water footprint in the textile sector is the number of garments, materials, and processes involved in textile manufacturing [99]. Quian-Ulloa and Stange [110] investigated and calculated the water footprint of viscose staple fiber blouses and men's suits. It was determined that the stage whose water consumption is higher in the same viscose staple fiber production. This stage, in turn, has a more significant environmental burden on the water resources used. Thompson et al. [125] determined the water footprint throughout silk production in Thailand. It was evidenced that in 2019 the water footprint was the highest, with a record of 1,710 m^3/ton, which directly affects the textile industry since the water footprint of the production of a silk shirt is 376L. The authors propose alternatives based on the sustainability of the supply and production chain through the joint work of authorities and entrepreneurs. On a general level, not only this country but also the Asian region is going through a problem of water scarcity and wastewater pollution [93].

Water pollution contributes to 80% of the water footprint of the productive activities of the textile industry [134]. The water footprint measures not only water consumption but also water pollution. Different stages can be identified within the textile industry that increases the water footprint (Fig. 1).

Water consumption in the textile industry covers not only production processes but also previous stages such as obtaining raw materials and indirect consumption in the final stage. The amount of water used in the sector depends on the type of fiber, machinery used, the type of product sought to be made, and the stages applied [116]. Reducing water consumption by constantly evaluating the water footprint is an alternative to be more efficient with the water resource [93]. Achieving this goal

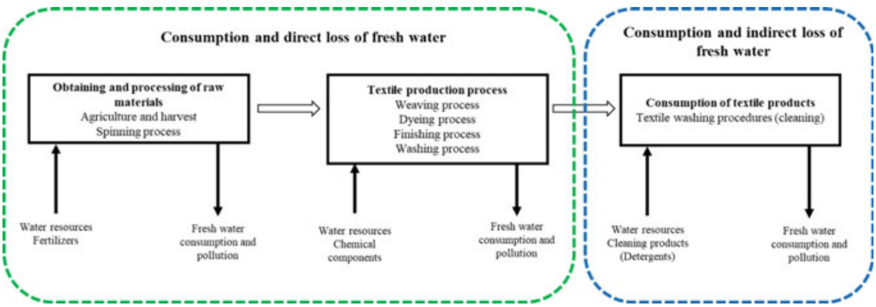

Fig. 1 Direct and indirect loss of freshwater (*Source* Adapted from Wang et al. [134])

is possible by becoming more sustainable along the supply and production chain of the textile industry.

3 Sustainability in the Textile Industry Supply Chain

To understand what sustainability alternatives have been applied to the textile supply chain, we must understand what activities comprise it. Table 2 summarizes the main stages of the sector's supply chain.

Many manufacturing industries seek to acquire technology to reduce production costs (i.e., labor hiring) and leverage the resources used to manufacture their products [63]. The supply chain has been characterized as long and complex [66]. For that reason, new tools have been integrated to achieve a more efficient and optimized supply chain.

Achieving a sustainable supply chain through the application of the circular economy requires textile industries to reduce their pollution levels, the number of resources used in the production of garments, and the reduction of greenhouse gas emissions [41]. Applying responsible measures such as using renewable energy to reduce the amount of CO_2 emitted or using eco-friendly fibers and dyes promotes the transition from a conventional supply chain to a sustainable one [110]. Saxena and Khare [117] applied the concept of green manufacturing within the textile industry, the main objective is to reduce the number of hazardous substances within the design and production of garments, which affects resources such as water, air, and land. It is wrong to think that all products generate positive impacts despite the above [76] demonstrated that within the bio-textile industry, bio-based leathers are used to produce shoes, clothing, and upholstery, which require a large amount of water for their production. It must be sustainable in terms of the materials used and the production processes.

Table 2 Textile industry supply chain

Primary Activities	Secondary Activities
Inbound Logistics: Activities to receive and store raw materials. It involves relationships with supply providers **Operations:** Activities of transformation and production of the final product **Outbound Logistics:** Activities to store and distribute the final products **Marketing and sales:** Activities to facilitate and promote the final product **Service:** Involves working effectively with the customer once the purchase has been made	**Procurement:** Acquisition of resources for the company **Human Resource Management:** Involves the recruitment and hiring of personnel for the company **Technological Development:** Involves the acquisition of technological equipment Other activities in the areas of accounting, finance, legal

Source Adapted from ElMessiry and ElMessiry [66]

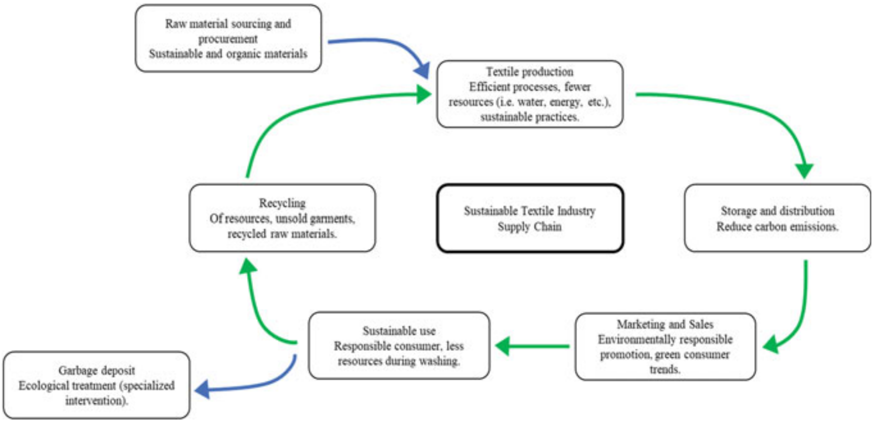

Fig. 2 The sustainable supply chain for the textile industry (*Source* Adapted from Wang et al. [134])

The leading sustainable practices in the textile industry focus on product design with longer lifetimes, energy efficiency and control strategies, implementation of circular strategies, and resource savings [80]. Water management, as a production resource, focuses on seeking alternatives to use various sources such as rainwater, seawater, wastewater, among others [82]. A priori, this would be a complex strategy considering that using this type of source requires having technology capable of processing such water and making it sound. It has been determined that water pollution occurs in different stages of garment production, mainly in washing and dyeing activities [109]. Some countries, mainly Europe, can recycle and reuse water from textile activities. For this, technological, economic, and environmental options are abundant and applicable at the industrial level [59]. However, this could be applied only by companies that can implement this strategy. Therefore, it is necessary to focus our strategies on small and medium-sized companies that do not have the resources to be sustainable. Figure 2 shows a circular strategy that can be sustainable and applicable at any scale.

4 Water Footprint in the Food Industry

With the food industry being one of the most demanded ones within the global economy, there are several environmental problems it relies on, which is an obstacle in the progress of the sustainable development goals. Even though there are guidelines on food, such as the food-based dietary guideline (FBDGs), the question is if it is being integrated into the practices [46]. Water footprint (WF) investigations are primarily directed to lower freshwater consumption. However, if biogas plants, photovoltaic panels, and other types of renewable energy are used in the agricultural sector, studies showed that not only carbon footprint can be reduced, but water footprint as well [37].

The water footprint is divided into three categories: green, blue, and gray waters, according to the Water Footprint Network [98]. For the type of water footprint, this industry is significant in, a study on the global water footprint in the food production of different crops shows that the more significant part is associated with green water and a small part on blue water, meaning that indeed green water is a significant factor in the crop production worldwide [101].

For instance, Blas et al. [35] studied two countries, Spain and the United States (US), and compared their water consumption due to the US having more water footprint than the Mediterranean diet. Overall, this paper concludes that the origin of products and the consumption pattern is prevalent and essential factors in reducing water footprint [35]. In the case of South America, a study based in Argentina showed that in the agricultural process, water footprint is lower, given that irrigation is not used commonly in the sector [131].

Over the years, there have been methodologies to save water and its consumption in the food supply chain, standing out both the water footprint assessment (WFA) approach and the life cycle analysis (LCA) one. These two methodologies have been compared and applied to numerous food products to develop the benefits and disadvantages each one may have [39]. It is essential to mention that the water used in the crop growing season is based on production. Using the accounting of water footprint would be an efficient measure to manage the relationship in terms of the use of water and crop yield [102].

The main reason for the increase in water footprint and environmental issues among the food industry is the evolution it had; nowadays, habits related to the diet have gone in the direction of processed food, meat, refined sugar, and less consumption of fruits and vegetables [71]. Studies have proved how diet-based choices significantly influence the food system's impact on the environment [132, 105, 126].

On the other hand, there are different levels of impact among each type of food, depending on the production system. For example, ruminant meats have tripled to tenth times the impact compared to plant-based food [58]. However, implementing projects to decrease the consumption of meat would be difficult in meat-loving countries like Argentina [29]. It is essential to evaluate the country's conditions, capabilities, and technologies because these are the significant factors regarding water volumes and water use [128].

5 Sustainability in the Food Industry Supply Chain

For sustainability, there have been actions taken to prioritize the environment's well-being and promote sustainable farming and processing among the food industry. First, water footprint is not the only indicator that can measure how sustainable food production is. Other considerations to be taken include the local, pedo-climatic, and technological factors [98].

For example, in the countries that belong to the EU, the European Commission posted an evaluation on the situation the EU is facing based on REFIT data. This program (REFIT) is an initiative in charge of improving the performance of EU businesses without creating burdens, especially in the framework of environmental issues [27]. It is aligned with the European Green deal, which is an institution focused on reducing the damage the food production impacts on the environment; it aims to transform the UE into a carbon–neutral sector by 2050 [9]. On the other hand, there is another method being used called Waste to Energy (WTE) for waste management (including water) that acts with the mindset of energy sustainability based on sustainable energy sources and sustainable energy systems [70].

Among the strategies promoted by the European Green deal, there is also the Farm-to-Fork one, which aims to create sustainable food systems in line with the United Nations Sustainable Development Goals (SDG). This strategy focuses on the food supply chains and looks at ways of reducing food waste and using it as a resource aligned with the food waste hierarchy [9]. In China, a recent foam system intends to shift from using inorganic materials to materials with a biological origin in stabilization, which is because inorganic materials in the food industry have shallow sustainable tendencies [144].

6 Trends to Become Circular in Sustainable

By 2030, 118 billion cubic meters are expected to be used for apparel production globally [113]. Therefore, companies must implement a sustainability approach through the SDGs that seek, among other things, to reduce the number of resources along the supply and production chain [44]. The massive water consumption of the textile industry is a problem with social, economic, and environmental impact in different countries. For this reason, it is necessary to apply the strategies above, such as water reuse [108], wastewater treatment, staged production system [124], use of ecological and sustainable fibers that consume fewer resources [8, 65, 96]. The solutions contribute to the improvement of the supply chain and improve the company's image considering that consumer behavior and their tendency toward environmentally friendly products is increasing [113].

For the food industry, there have been techniques to mitigate water footprint, such as the Micro-filtration (MF) one, which causes a significant reduction in chemical and biological oxygens (COD and BOD); additionally, it reduces the count of total bacteria in wastewater. In the case of the food processing industry, techniques such as the Microbial Fuel Cell (MFC) is an effective response to treat wastewater coming from various sectors because it reclaims water for applications in agriculture [79].

To achieve sustainability in terms of water consumption in the supply chain of the industries under study, companies should consider external and internal factors that can be applied. Table 3 indicates the factors that could contribute to achieving the circular economy and, therefore, becoming more sustainable.

Table 3 External and internal factors that enable sustainability

Factor	Level	Description
Globalization of competition (Differentiation)	External	Textile industry: Countries with lower production costs exert pressure on pricing and costs. Being responsible with the number of resources used to manufacture textiles. Therefore, it is ideal to differentiate our products Food Industry: Consumers' tendencies put pressure on businesses; nowadays, they look for traceability and organic food with an environmental focus and choose environmentally responsible companies
Change or improve the supply chain	Internal	Textile Industry: Companies must change their traditional supply chain to a sustainable one. Firms must apply strategies such as recycling and reusing resources Food Industry: The supply chain in this industry depends on each country's level of technology; there are also technological trends within this process, including blockchain, QR codes, and tracking systems to please the consumers' needs
Modify production processes (Automation)	Internal	Automating production processes is difficult depending on the size of the company. Small companies (Startups or SMEs) should make significant investments to acquire technology. However, companies should improve their processes to be more productive and efficient In the food industry, there needs to be an investment in innovation and technology. The change in the processes depends on each market's needs; for example, many companies have implemented omnichannel consumption, which gives the consumer more access to the information the product has driven by food safety and transparency
The role of government in policymaking	External	Governments should prioritize promoting support and incentive policies for sustainable textile and food companies. Companies, for their part, should embrace such policies, improve their processes, and make them more efficient

Source Adapted from Bressanelli et al. [41]

7 Closing Remarks

The application of the circular economy is presented as a sustainable alternative to the linear model that is mainly applied in the business environment [45]. Changes in product design and supply chain are required to achieve this [41].

On the other hand, in the case of the food industry, it is essential to acknowledge the methodologies used by already established organizations, given that they already have good results in reducing water footprint. Apart from that, there are also excellent and effective new technologies emerging in European and Asian countries. Overall, food industries must extend these technologies without losing the nutritional content that food has, which should be focused on the availability of their compounds; apart from that, promote and provide sustainability not only environmental but also economical. To achieve this, they need to embrace and take into consideration all the processing steps. Additionally, it would be efficient to have a global agricultural sustainability framework done by a multi-stakeholder congress that would secure the standardization of the certifications that farmers and users all over the food supply chain need to accomplish for their product to enter each market [103]. This result should still accomplish the final goal to fulfill consumers' needs in the case of sensory characteristics [103].

Sustainability focuses on efficiency [104]. Therefore, it is necessary to focus the organization of the supply chain in terms of the resources used in the sector, mainly water and energy. It is ideal to look for alternative sources and, above all, to promote innovation in the companies of the industry. For the most part, innovation focused on the acquisition of technology that allows us to facilitate and improve supply chain processes [138]. In general, improvements in the supply chain led to environmental differentiation that improves the performance of companies [85].

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Virtual Tourism, Carbon Footprint, and Circularity

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Abstract This chapter aims to analyze the tourism sector globally and the creation of virtual tourism. It is presented along with the previous context of the sector and the damage made by the COVID-19 pandemic. This lens shows how virtual tourism emerged as an alternative to traditional tourism while people worldwide were forced to stay home during the uncertainty of the pandemic. Virtual tourism would be related to the arising environmental tendencies expected to be embraced by the industry companies to make tourism a more sustainable economic activity and, therefore, reduce its carbon footprint through circularity. Finally, it also analyses the possibility of its per durability once the consequences and lags of the pandemic are solved.

Keywords Virtual tourism · Circular economy · Circularity · Sustainability · Carbon footprint

1 Introduction

Due to COVID-19, tourism was one of the sectors most affected because of social distancing. Fortunately, it also became an opportunity for companies to innovate and rebuild themselves.

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This chapter presents previous scientific articles about the impact of tourism on climate change, greenhouse gas emissions, and the circularity of said industry. Next, the most relevant antecedents to carry out this investigation are presented. The world has changed and people's habits regarding sustainability have changed, depending on the characteristics of pre-pandemic life [14, 17, 18, 20, 23, 26, 30, 32, 33, 58, 60, 64, 92, 103]. In Table 1, it is presented different sectors that have been damaged by COVID-19.

Rastati [100] analyses the impact of virtual tourism in times of COVID-19 in Indonesia and its impact in different areas. For this, a qualitative study was carried out to know the experiences of the people and workers of the sector participating in virtual tourism during the COVID-19 pandemic. The methodology used consisted of conducting interviews with these groups of people and asking them about their opinions about this new activity and what they considered to be the advantages and disadvantages of virtual tourism. Research results demonstrated that virtual tourism could be a starting point as an alternative to traditional tourism during and after the COVID-19 pandemic ends. In addition, the people interviewed stated that although some experiences of traditional tourism (such as trying local food) were lost, the virtual one turned out to be more accessible, motivated the interviewees to know the attractions after the end of the world situation, and generated less environmental impact than ordinary tourism. However, it was highlighted that for these activities to be carried out correctly, the government must provide advanced technology, such as virtual reality and panoramic images.

Kitamura et al. [80] investigated the carbon footprint in the tourism sector in Japan with a view to more sustainable tourism because this is a critical issue to act in all sectors, which also has relation with the goals of Japan to contribute with the Sustainable Development Goals. A life cycle assessment (LCA) based on processes and an input and output analysis was agreed upon; it was calculated based on tourism consumption using a Japanese input and output table, and the industry, in general, showed that total emissions were around 136 million tCO_2 per year. Regarding the

Table 1 Impact of COVID-19 in different sectors

Education	[9, 10, 19, 22, 24, 54, 83, 84, 130]
Entrepreneurship	[4, 16, 27, 28, 39, 42, 43, 47, 52, 86, 90]
Health sector	[1, 8, 11, 13, 21, 40, 45, 55, 61, 81, 101, 104, 125, 128, 129]
Hospitality	[63, 70, 73, 77, 124]
Intellectual property	[12, 15, 59, 65, 76, 82, 98, 107, 127]
Population	[6, 25, 51, 71, 87, 99, 105, 108, 120, 123, 125]
Prices	[36, 56, 68, 72, 85, 97]
Tourism	[38, 41, 46, 48–50, 67, 109]
Trade	[2, 3, 5, 29, 31, 44, 57, 79, 88, 113, 118, 126]
Violence against women	[34, 53, 62, 69, 102, 106, 119]

relationship by percentages according to sectors, it was determined that mainly transportation represents 56.3%, souvenirs 23.2%, gasoline 16.9% and accommodation 9.8%, food and beverages 7.5% and activities 3%.

Lu et al. [89] investigated the potential of virtual tourism in the tourism industry's recovery during the COVID-19 pandemic in China. For the development of the study, they used the Theory of Planned Behavior and qualitative and quantitative studies. The methodology used was questionnaires and interviews with samples of residents of China. Different statistical measures were used for the quantitative research, such as the Wilcoxon test, non-parametric methods, and binary logistic regression, and in the qualitative research, thirty interviews were conducted with Chinese residents. The findings of this study revealed that it is necessary to promote virtual tourism to museums and other indoor attractions to include this activity as part of their services and products offered to the public. In addition, to achieve a more significant amount of income from the tourism industry (especially during the pandemic), tourist places should develop new ways of using the internet to promote their new virtual tourism services. It should be noted that several interviewees mentioned that virtual tourism could help promote sustainability, accessibility, and diversity in the sector.

To determine the global impact of tourism activities, an environmental assessment that covers the entire life cycle of what is consumed by tourists has been identified as an appropriate methodology. WTTC [121] conducted a study to examine the potential for saving greenhouse gas emissions through 3 different strategies: prevention of food waste, reduction of single-use plastics, and recollection and recycling of waste. The general methodology used for the article was the analysis of databases regarding the waste of tourists and their accommodations, differentiated by their top-down or bottom-up approaches. The results were expressed in two measures: per kilogram of waste that could be avoided and per thousand tourists. The strategies presented demonstrated the potential savings in greenhouse gas emissions between 4 and 189 kg of CO_2 equivalents per 1000 tourists. The measures to reduce food waste and the collection and recycling of waste showed low emissions; however, the emissions associated with the single-use plastic reduction measure were relatively high.

O'Grady et al. [96] analyze how the construction industry generates the most significant percentage of waste. The methodology is based on an applied index to our purpose-built prefabricated building. The 3DR method illustrates the steps and decision-making that the research results show that building refurbishment is possible through the 83% of walls and ceilings that can be disassembled during the operation phase. The UNEP circularity platform provides an understanding of the circularity concept, its scope, and its contribution to promoting sustainable consumption and production patterns. As outlined by Inger Andersen, UNEP Executive Director, circularity and sustainable consumption and production are essential to delivering on every multilateral agreement, from the Sustainable Development Goals to the Paris Agreement to the post-2020 global biodiversity framework. They are essential to a sustainable recovery from the COVID-19 pandemic. Circularity builds upon value retention loops, as shown on the UNEP circularity.

2 Tourism Background

The tourism industry has been one of the most important contributors to the global economy for a long time. UNWTO [115] pointed out that as of 2018, this sector had nine consecutive years of sustained growth, improving people's lives all over the world. The importance of tourism is notable in certain countries, especially for those from America and the Asia–Pacific region. According to the WTTC [122], the total GDP contribution in 2019 was 10.4% generating about USD9,170 BN and 334 MN jobs. Moreover, during 2014–2019 about 1 in 4 new jobs were created by this industry alone.

The outburst of the coronavirus pandemic has dramatically changed the world. What once was a growing industry with high expectations was shocked by the sudden stop of people flowing worldwide. The measures taken by every government to reduce the spread of the virus were severe and progressively longer, such as the lockdown, close of borders, and curfew. Therefore, all nations experienced a period of uncertainty about when it would be safe to get back outside their houses and go back to how things were before the outbreak. Lots of lives were lost, and multitudes were fired from their jobs. The economy was severely wounded, some industries more than others, especially tourism, where interaction was crucial. This sector stopped all its activities in April 2020, leading just in said year to the loss of about 62 million jobs, representing a reduction of 18.5% [122].

The governments took several measures to reduce the impact, such as financial aid provided to tourist companies but still, the travel and tourism sector suffered a loss of 4.5 trillion dollars, a significant drop of about 49.1% compared to 2019. The countries whose economy depends more on tourism were the most affected. According to Statista [111], Fig. 1 represents the contribution of travel and tourism to the GDP of the world's major economies in 2019.

In addition, there has been a significant variation in the GDP contributed per country at a global level comparing 2020 and 2019. According to the WTTC [122], the average contribution per area during 2019 was 9.64%, however, during 2020, the average was 5.14%, nearly half of 2019's contribution. As we can convey from Fig. 1, it represents a decrease of 48.3% on average in the contribution of each geographical area. In 2019, the area with the smallest share in the whole GDP reached 6.6% (South Asia); during 2020, the smallest area (Africa) contributed only 3.7% of the GDP. It can also be noticed that the Caribbean region was the most affected, with a decrease of 58% from one year to another (Fig. 2).

A vivid example of the adverse effects of COVID-19 on tourism can be seen in the Dominican Republic, a country situated in the Caribbean, the most affected geographical area according to the WTTC. The country's strength in the services sector before the pandemic was an essential factor in the recovery of its economy. Nevertheless, it still affected the country by shrinking its GDP by 6.7% in 2020 [74]; with the vital measures applied by the government, many jobs were lost, especially those related to tourism. The authorities decided to implement social assistance programs for those who lost their jobs and others directly affected to face the situation.

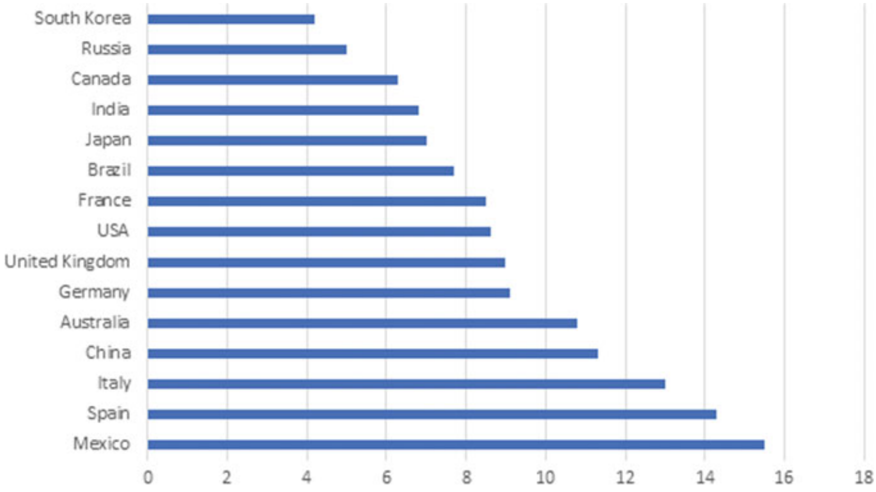

Fig. 1 Countries that are more dependent on the tourism industry (*Source* Adapted from Statista [111])

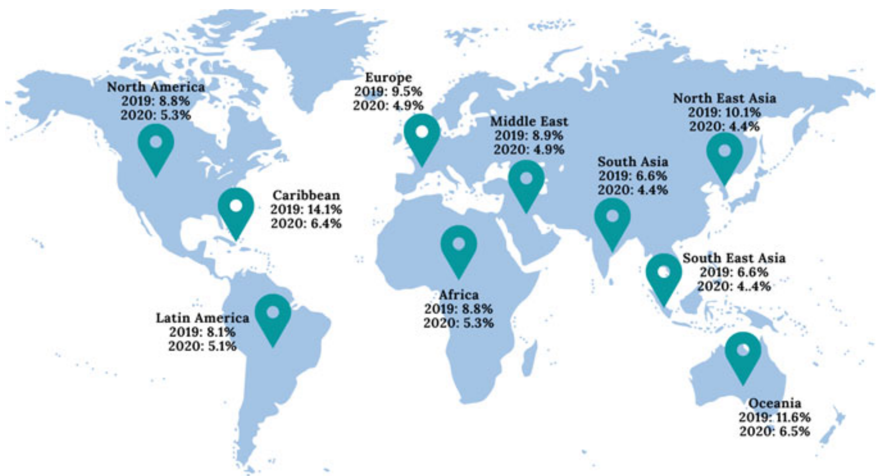

Fig. 2 Contribution in global GDP by geographical region (*Source* Adapted from WTTC [122])

Another exciting example is India. Before the pandemic, this country was an emblematic crowded touristic nation frequented because of religious and non-religious reasons that happened to be critically injured by the restrictions apply mainly for foreign tourists. Even though this country is in the south of Asia, the geographical area least affected by the pandemic, it was still severely shocked by the closure of borders and lockdown. Just in 2020, the government reduced its expenditure on travel and tourism by 30.7%, a significant sector in India's economy [122].

Luckily, in mid-October of 2021, the government decided it was time to reopen borders, and it is expected to recover quickly.

Despite the great efforts to go back to "normal" or the pre-pandemic habits, the pandemic is still far from over. The governments of all nations, especially those more dependent on tourism, face a significant challenge for recovering the industry and retaking the previously established objectives while creating new ways for travelers to experience the beautiful locations without endangering their health. With the help of foreign direct investment, government leaders are already implementing measures to recover the sector, such as inoculation programs and the progressive reopening of borders. These measures are showing their effectiveness and giving the expected results so far.

3 Virtual Tourism: A New Opportunity

Due to social distancing and people being restricted to stay at home, the already rising environmentalist tendencies increase, even more, influencing how people act and think while using a specific product or service. The tourism sector was no exception and started to notice the multiple ways it contributed to the world's contamination, starting to worry about their carbon footprint while preparing themselves to adapt to the new normality. A fair number of companies started to realize that it was time for them to make relevant changes that may be over the budget but would allow them to be sustainable and green in the long term. And although it is essential that companies are concerned and accept the necessity to take a sustainable path, people from the local communities must accept this too and push both tourists and companies to do their part, mainly because the changes would affect everyone. According to the UNWTO [116], sustainable tourism must include an optimum use of natural resources, respect host communities' social and cultural authenticity, and ensure that the activities are viable in the long term. Virtual tourism gives new options to consumers out of their new necessities and protects the world everyone lives in. According to Stainton [110], virtual tourism is the activity of "touring" various locations without traveling to them and using innovative technologies to feel as if you are there in real life. Many new technologies have been created to develop this venture, taking advantage of this tourist's new interest. It is related to the new tourism trends that have emerged from the COVID-19 pandemic, which created some restrictions in the industry, leading companies to innovate and try new ways to keep tourism going. Some of the technologies used by these businesses are virtual reality, augmented reality, 360°, and holograms (Fig. 3).

By using these new resources, tourism companies can provide new experiences and make virtual tourists feel they are in a foreign location, appreciating its beauty and features while being far away. To some people, virtual tourism may not be the best option since it may not give them the experience they are looking for when trying to meet different cultures. According to Mura et al. [94], people perceive virtual tourism lacks the authenticity factor because when participating in a virtual tour, you cannot

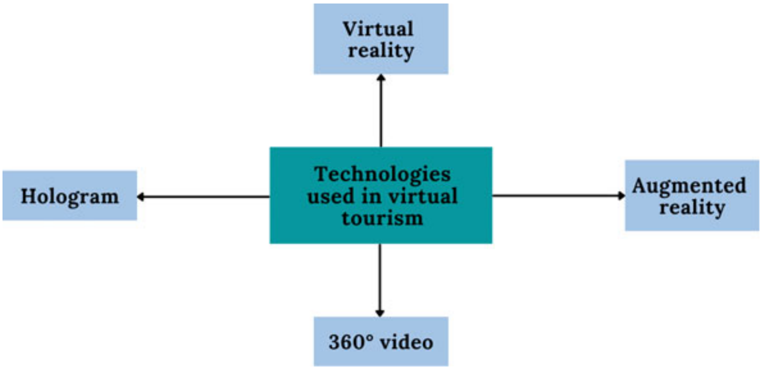

Fig. 3 Technologies used in virtual tourism (*Source* Adapted from Stainton [110])

become familiar with the atmosphere, the weather, the local language, and overall, all of the sensorial experience is lost.

Virtual tourism is mainly directed towards people that want to know more about the country but not necessarily travel there, probably because of the lack of means or time. This type of activity could be unconventional compared to natural tourism to some people and may bring skepticism; even so, this kind of service must be directed at people who want to appreciate, learn, and understand the cultural part. It can also be a terrific start to have an insight into the destination before a trip is booked, and based on the findings, plan the itinerary according to the locations and activities that appear to be the most compelling.

Virtual tourism can come in handy if you have a low budget and want to see various places. After having experienced some trips virtually, one could save money, smartly plan an itinerary, and finally book the actual trip of your dreams, knowing what to expect when you get there. In contrast, the segment of people that would not consume this type of tourism would be those interested in more adventurous activities and in an interpersonal connection with the locals of that country or space; for those people, a virtual tour would be boring and far from enough. Although these people only use virtual tours to complement their authentic tours, they may only cause more contamination, an action that would end up defeating the primary purpose.

Regardless of how much or less captivating the tourist might find virtual tourism, the reality is that it has changed the way tourists and tourism workers see this industry. For example, many touristic places are guided by the people who live there, so while implementing virtual tours would increase the number of people in each group, it would also decrease the tour guides needed in every expedition as a recording can be used in its place. It also would affect countless jobs generated by this sector. All the benefits obtained through virtual tourism can generate another way to contaminate and increase the carbon footprint. It's important to mention that being viable in the long term means that if virtual tourism is promoted, companies must ensure that this can be used after the pandemic, and it can sustain in the future because people do not accept this new way of traveling.

France is a strong example of the new opportunities provided by virtual tourism. The information reviewed by France Diplomacy [93], this country remains the first world destination with a record influx of between 88 and 89 million foreign visitors, and tourism is a crucial sector for the French economy with a presence of about 8% of GDP. It is at this point and in the wake of the COVID-19 pandemic that the European Union member country has sought new opportunities to be able to create tourism; clear examples of this are the virtual sessions of the museum of Le Havre, the Museum of Fine Arts in Rouen, the Castle Museum of Dieppe and many more. Italy is another example of countries whose industry has successfully adapted to virtual tourism. ItalyGuides [75] express that there are at least 20 different destinations that anyone can visit through the internet from the comfort of their sofas. These destinations include the eternal city, Roma, Florence, Verona, and Venice, all of them are possible to reach by audio guides and unique apps for every technological device. Blogs such as Headout include views from attractions such as the Colosseum and the Vatican with 360° tours.

Peru, despite being a developing country, according to Martínez [91], the Ministry of Foreign Trade and Tourism during the pandemic has promoted various activities so that companies and tour guides can use different technologies (virtual visitors through applications such as Zoom, Google Meet or 360º views, Google Maps, special effects, and even music) to develop tourism further but virtually. To give a more panoramic view, we can see that these new technologies are being developed in the Uros Islands, Manu National Park, Huascaran National Park, etc.

4 Virtual Tourism and Carbon Footprint

Therefore, with virtual tourism, another factor can be calculated. The Carbon Footprint is "the measure of the impact of all greenhouse gases produced by our activities (individual, collective, eventual, and from products) on the environment," according to the United Nations [114]. It is measured in tons of kilos of carbon dioxide equivalent to greenhouse gases. In the Earth's atmosphere, the main greenhouse gases are carbon dioxide (CO_2), water vapor (H_2O), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3). Currently, companies carry out this calculation to identify and reduce contamination levels of the different production processes, engage employees in environmental issues and promote a product. It is a differentiating element that can satisfy the demands of a global society with greater environmental awareness. An analysis of the necessary activities to obtain the product must be carried out to know the carbon footprint, from the moment the materials are acquired for its preparation until its management to be reduced [114].

Tourism generates approximately 8% of the total carbon emissions in the world. They are mainly created due to boat rides and plane travels to the world's leading tourism hubs. The main activities that contribute to the total carbon footprint of tourism are Transport (49%), Goods (12%), Food and beverage (10%), Agriculture

(8%), Services (8%), Lodging (6%), Construction and mining (6%) and others (1%) [112].

Since the COVID-19 pandemic started, as mentioned before, all the tourism industries had to stop their activities for an unestablished period and wait until the cases started to reduce and find new ways to keep generating revenue. During this time that the routine activities stopped, the carbon footprint reduced its growth since travels by airplane or sea were stopped for a long time until the governments of the countries created new measures to do these activities in a safe way to prevent more contagions of COVID-19.

One sector that generates the most carbon emissions in tourism is transportation. Aviation is responsible for approximately 12% of the carbon emissions in all the transport sectors in the world. According to the Air Transport Action Group [7], in 2019, flights worldwide produced 915 million tons of carbon dioxide into the atmosphere. The tourism sector is tightly linked with the aviation sector because most people travel by plane to their destinations since it is the fastest way to do so. The COVID-19 pandemic has generated a considerable reduction in plane travels due to the restrictions imposed by governments of different countries around the world, which has had an enormous impact on the generation of carbon emissions. The airplanes generate many outflows of this chemical into the atmosphere, causing damage to the environment. However, with the reduction of traveling with this method, these emissions have been reduced considerably.

With the implementation of virtual tourism, many airline companies could see a decline in passengers because some people are still a bit scared of catching COVID-19 and do not want to be in a twelve-hour long plane and risk catching the virus rather than experience their destination from the safety of their homes. Also, for those who only want to know the place and see it, not necessarily in person, it would be much cheaper to pay for a virtual tour rather than a plane ticket. Another thing to keep in mind is that virtual tourism may affect local communities that work in tourism sites such as hotels, restaurants, and transport since people are now going straight to their virtual destination and do not need any of these services.

According to Aminy [35], countries such as Indonesia that have experienced substantial tourism lots (88.9% drop rate in tourism in 2020) have innovated and started offering virtual tours. Websites such as Traveloka have released more than 10,000 virtual tours that people can choose and take from their homes. However, being a country that is very dependent on tourism, these virtual tours could negatively impact the local communities since they are not receiving tourists that they can offer their services to, generating losses in these sectors. It is essential for governments, not only in Indonesia but also around the world, to find ways to try to incorporate local businesses that benefit from tourism into this new reality so that countries that depend heavily on tourist activities can still generate some income in this new global context.

However, not all these effects of virtual tourism are still in the future. With the COVID-19 pandemic coming to an end, it is hard to know if people still log into virtual tours when they can buy a plane ticket and head there in person. Another essential thing [95] is that virtual tours take away some aspects of regular travel, such as the foreign environment and culture that you experience for the first time when going to a new place. Some people may feel that if they take a virtual tour, it takes away all the illusion of seeing a new country or city in person since they have already experienced it virtually, and thus, the “wow” factor gets lost.

After the pandemic ends, many people usually start traveling again. The environmental benefits generated by the lack of international travel and the new implementation of virtual tours could be reversed and end up like the pre-pandemic times. People need to start to take conscience about the environmental impact of traveling and start taking actions to reduce their carbon footprint impact.

In recent years, many environmental-related topics such as climate change have been very prominent among people, and now there is more awareness of environmental care and what to do to prevent long-term effects. Because of this, virtual tourism may be one of the choices that people take when deciding to meet a new culture or country since they are aware of the benefits that this type of activity has on the environment and help reduce their carbon footprint in the long term, so is undeniable that some tourism companies may still have virtual tours as part of their services after the pandemic comes to an end.

Virtual tourism can be used as a new form for people to experience tourism through the internet. It is well known that while being abroad, there is hardly enough time to visit all the available cultural places. So instead of trying to visit all the places in one day, tourists can choose to visit it from their homes before or after their trips, this would save a lot of money, energy and most importantly it reduces the carbon footprint generated with transportation, food, and others. It could also be an excellent opportunity for travelers with a meager budget that want to know all the culture from the place but can’t afford to visit; virtual tourism can be a new way to enjoy touristic experiences.

5 Virtual Tourism and Circularity

The tourism industry has been most affected by the COVID-19 pandemic. Mainly because mobility restrictions made it difficult to carry out the different activities that make up the tourism value chain and severely damaged tourism results, but it is in this context. With the growing awareness of creating a new economic system that helps the environment and does not exceed the global ecological limit, new ways of doing tourism have opened. In this change, virtual tourism emerges among the ways of adapting to the new reality. It should be noted that according to Aprende de Turismo [37], the economic activity model of virtual tourism is still linear, it is a model that depletes resources and generates too much waste, which does not make it environmentally sustainable. For this very reason, and to reduce the adverse effects of this model on tourism, it seems necessary to seek a new, more integrated production model, through the conversion of "systems," in which the cost of the production-environmental damage-product price equation is optimized, thus generating greater profits. This model would be based on circularity.

According to Vargas [117], circularity or circular economy applied to virtual tourism is a model created to replace the linear economy, based on the following sequence: obtain resources from nature, manufacture them, use or consume them and dispose of them. The circular model tries to keep resources in the economy if possible, preventing them from becoming waste, in this way, it contributes to the regeneration of the environment. Its method can be proactive (to avoid waste) or, if it fails, passive (to manage it by recycling). Due to the negative impact of waste—accumulated in landfills—on the environment, increasingly scarce resources, and rising costs.

The dilemma is how to apply circularity in virtual tourism; in other words, create circular tourism. As stated by Estévez [66], circular tourism is the tourism model that allows not only the protection of cultural and natural heritage through the reduction of resource extraction and the reduction of negative externalities but also the regeneration of the natural capital of the territory, which allows having leading tourist destinations in quality and innovation.

Virtual tourism is essential to help with this work since this type of tourism can be used as a lever to introduce the circular economy to the tourism market more efficiently, which is because virtuality is a way to avoid the wear and tear of the cultural heritage of different countries; it also avoids the transit and pollution of the mobilization of so many people that occurs in tourism. In addition, virtual tours can become a realistic experience where visitors can get to experience more about their destination and help people who cannot travel (time or financial constraints).

Closing Remarks

But despite all the benefits that can be achieved with circularity in virtual tourism, a few aspects may not be favorable for the circularity chain. Virtual tourism involves the constant use of new technology trends, whether computers, cell phones, tablets, virtual reality goggles, or others, which produce a large amount of electronic waste. According to a United Nations (UN) report, Kenny [78] quoted, the world recorded 53.6 million tons of e-waste in 2019. E-waste (discarded products that use a battery or a plug) increased by 21% in the last five years and is predicted to reach 74 million tons by 2030, almost double the e-waste of 16 years. For these reasons, applying circularity is imperative also in virtual tourism because it allows the industry to reduce the level of consumption of resources and waste products in the process of production, circulation, and consumption. Additionally, it is reusing products directly, using them as a new product after waste once modified, restored, or renewed, or using waste as a component of other products. And finally, recycling is where waste is used as a direct raw material or recycled waste.

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Virtual Education: Carbon Footprint and Circularity

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Abstract Virtual education has appeared to upgrade traditional education in different dimensions, such as easing the learning process, developing new teaching methodologies, and eliminating distance barriers. Since the pandemic outbreak by COVID-19, this situation has intensified, forcing students and educators to adapt to this new scenario, which involves staying at home and using electronic devices for long hours, which seems to contribute positively to the environment, as there is no need to attend education centers where physical installations and different services are used. However, little has been said about the environmental impact of virtual learning. Nevertheless, to have a transparent approach and determine virtual education sustainability, it is essential to analyze its implications.

Keywords Education · Virtual education · Carbon footprint · Climate change · Circularity · Environmental impact · Circular economy

1 Introduction

The world changed dramatically by COVID-19. Some specific areas involved include education [5, 12, 17], tourism [35–37], violence against woman [39, 90], prices [27, 68], research [41], intellectual property [24], health care [22, 11, 40, 92, 116, 118, 119, 120], entrepreneurship [25, 13, 18, 38], commerce [10, 20, 15, 43, 70], hospitality [115], and citizens behavior [11, 84, 117].

The sustainability of many issues has changed since the usual behavior and characteristics [3, 4, 7, 9, 12, 14, 16, 21, 23, 45, 46, 49, 73, 91]. The changes are mainly

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in communication, with increasing virtual behavior such as e-commerce, virtual tourism, and distance education, in different academic levels.

Due to the enormous concern over environmental care and reducing greenhouse gas emissions, it becomes relevant to analyze if virtual education is sustainable. Distance education can be considered a turning point in the education system. Therefore, it has always been compared with face-to-face instruction [1, 33, 60, 62, 83].

A comparison between face-to-face education and virtual education, from an environmental perspective, is presented by analyzing how carbon footprint and circularity work in both scenarios, which provide a clear overview of the direct and indirect effects of these two situations on sustainability. The innovations that the virtual world has brought to education and the environmental practices implemented in this sector are mentioned. Additionally, it is shown the initiatives and plans made by international organizations focused on reducing our carbon footprint and increasing circular sustainability. Finally, some conclusions and recommendations for educational institutions to implement excellent sustainable education programs, mainly in virtual education, presented after the current pandemic situation by COVID-19 are given.

All the information in the current chapter aims to create consciousness about the impact of virtual education by providing an environmental approach.

2 Face-to-Face Education

Every sector in the world generates greenhouse gases, whether it be agriculture [64, 72, 76, 79, 87, 89, 97, 100, 111], livestock [2, 48, 57, 112, 121], fishing [54, 58, 81], construction [28, 69, 94, 95], mining [29, 55, 61, 88], telecommunications [74, 85], and others. However, one sector cannot generate these gases. In the following lines, the concepts of carbon footprint and circularity and their applications are presented in the context of face-to-face education.

2.1 Carbon Footprint in Face-to-Face Education

Decades ago, sustainability issues did not consider in educational centers. However, after the Earth Summit in Rio de Janeiro in 1992, it generated awareness in European universities. Consequently, the Copernicus University Charter for Sustainable Development was drawn up in 1993 [56]. The carbon footprint is used and works as an environmental metric for calculating greenhouse gas emissions. According to Torres et al. [101], three scopes are considered:

Scope 1. Direct emissions produced by the educational center.
Scope 2. Indirect energy emissions.

Table 1 Description of the scope of the carbon footprint in face-to-face education

Scope 1	Scope 2	Scope 3
• Combustion of vehicles owned by the educational center • Combustion of canteen kitchens of the educational center	• Electricity consumption	• Private or public transportation of students and staff • Food consumed indoors • Waste generation • Services purchased from various companies

Source Adapted from Torres Ramos et al. [101]

Scope 3. Indirect emissions that may be generated.

In addition, the latter is usually the one that generates a higher percentage of participation, unlike scope 1 and 2. Table 1 details those above.

We can evidence that both variables decreased their participation in the carbon footprint impact. To better understand, as shown in Fig. 1, from 2018 to 2019, in scope 1, the variation was lower by 1%; scope 2 also had a reduction of 4%. However, in scope 3, where the student generates this carbon footprint, there is an increase of 5%, mainly due to the transportation factor (use of private vehicles instead of public transportation). The latter represents an entirely understandable preference in a pandemic context in which people seek to reduce the chances of contagion and spread of the virus.

In face-to-face education, according to the report by Filimonau et al. [52], scope 3 is the one that generates the most significant carbon footprint emissions, unlike scope 1 and scope 2. However, in 2020, the suspension of physical classes due to isolation to avoid contagion impacted the scope 3 because the student did not use public or private transportation, did not generate external solid waste, did not generate food waste at the university, among others, however, this gave rise to the following another point to consider: studying from home. Although the students do not very much consider it, it also negatively impacts the environment due to the frequent use

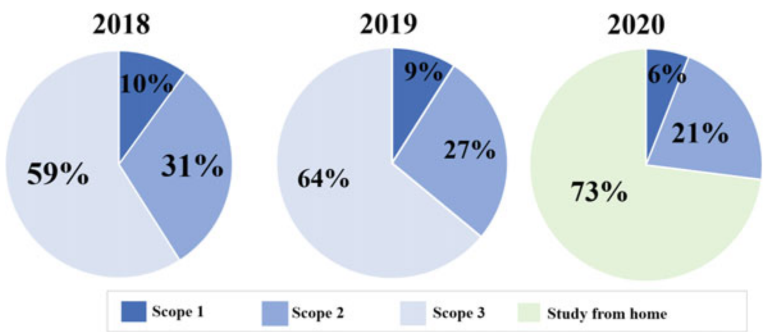

Fig. 1 Emissions per scope of assessment in the United Kingdom from 2018 to 2020 (*Source* Adapted from Filimonau et al. [52])

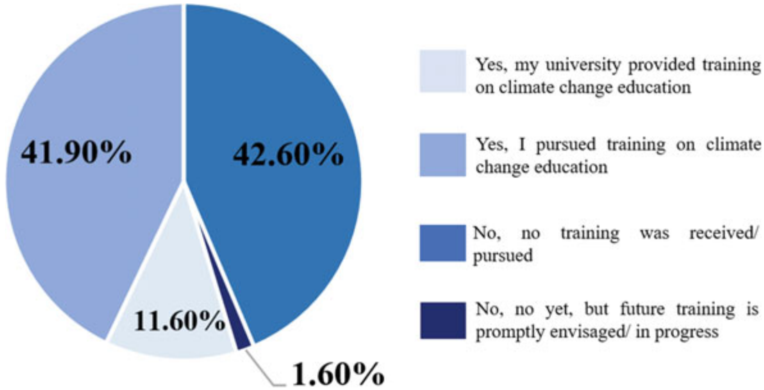

Fig. 2 Survey question: have you received or pursued training on matters related to climate change? (*Source* Leal Filho et al. [67])

of laptops from Monday to Friday, which increases energy consumption. These kinds of initiatives are discussed in more detail below.

2.2 Circularity in Face-to-Face Education

Many universities worldwide recognize their role concerning circularity to reduce climate change [65, 66, 75]. According to Leal Filho et al. [67], to have a minimal impact on the carbon footprint, they point out that universities are in search of becoming carbon neutral and are developing curricula and pedagogical approaches to educating about some topics like climate change mitigation and adaptation. Work is indeed being done, talks and activities have been started in many universities about climate change awareness, however, there is still a lack of knowledge about the student's carbon footprint. Figure 2 shows the survey results to know if students have received or pursued training on matters related to climate change. Around 44% of them have not yet received any information on the subject.

3 Virtual Education

3.1 Carbon Footprint and Virtual Education

Virtual education has brought numerous advantages for the environment, including a far lower carbon footprint emission [53, 82, 93, 110]. Students sometimes have to travel between one city to take classes because of distance learning. Less transportation is used, but the energy consumption is also increasing due to this now-standard

Table 2 Description of the scope of the carbon footprint in virtual education

Scope 1	Scope 2	Scope 3
• Direct emission from sources that are from the educational institution such as heating, cooling system, and electricity consumption	• Indirect emission from the institution provoked by the electricity consumption	• Indirect effects from the institution that are not controlled by it and are from other sources such as commute of staff, or the consequences of teleworking done by the professionals and students

Source Adapted from Versteijlen et al. [110]

method of education. Versteijlen et al. [110] indicate that "one of the great advantages of online education is a substantial decrease of carbon emissions" (p. 7). For their study, they interviewed professionals to ask them what they think about this fact, in which, surprisingly, most of them did not have an idea of the reducing carbon footprint that online education can bring, however, Filimonau et al. [52] explain that there is a possibility that virtual education might be less climate friendly than it seems. Considering that studying or working from home can generate significant emissions of the carbon footprint that the university generates, a significant share of the carbon footprint reduced from lengthy trips for the students' transportation can be effectively negated (p. 9) (Table 2).

3.2 Virtual Education and Circularity

As well as in face-to-face education, in online learning, there are also courses to give students environmental awareness and knowledge of the circular economy [63, 77, 113]. The inclusion of sustainability principles is needed in the plans of university studies as well as undergraduate teaching courses [26, 32, 86, 98]. Sites widely known, such as Coursera [42], edX [47] and Udemy [107], are teaching courses solely about this topic, and because they are fully online courses, more people can have access to its advantages and may apply its core in their professional life. Many universities globally have courses related to sustainability and are trying to boost awareness.

For example, student training projects seem to be an exciting and potential way to organize academic outreach. Those projects are challenges related to academic research protocols and provide new opportunities for universities, students, teachers, and community members. The latter dramatically benefits university students since volunteering as group consultants develop their hard and soft skills. In addition, the most important thing is that they contribute to the development of sustainable goals in their communities within the framework of the UN 2030 Agenda [80]. In this sense, the objective from now and on is for student training projects to be a promising method to integrate capacity building and empowerment in community sustainable development in higher education [44].

3.3 *Virtual Education Innovations*

Educational innovations in the context, based on international principles for sustainable education (see Table 3), implement novelties that allow students to develop their theoretical and practical knowledge about what they can do to contribute to sustainability.

Various ways of taking advantage of technological resources were found during the research, from sustainable computing to renewable energy sources applied to education. There is a tangible diversity of innovations in this field, which led us to

Table 3 International principles of education for sustainable development

Principles	Description
Future-oriented thinking	Thinking ahead involves people imagining preferential situations for the future. This future visualization process leads people to become aware of and take responsibility for a sustainable future. It allows people to understand the significant aspects of sustainable development and makes it possible to explore those assumptions
Creative and critical thinking	It allows people to explore new ways of thinking and acting, make decisions based on information, and create alternatives to present and choose wisely. It involves reflecting on how people interact, understanding cultural differences, and creating alternative ways of living together
Participation and participatory learning	Achieving the commitment of people is essential for building a shared future. Engaging diverse people and communities is essential as it broadens the knowledge system and perspectives. The participatory process is also important in creating a sense of ownership and empowerment
Partnerships	Those are motivating forces toward change. These organizations empower groups and individuals and allow them to act in taking action and making decisions and the processes that are part of sustainable development
Thinking about systems and networks	Thinking systematically is essential for sustainable development. Sustainable development requires approaches that go beyond problem-solving or cause of an effect

Source Adapted from Tilbury [99]

develop a greater awareness of the inordinate efforts of society and governments to provide excellent quality. The development of new technologies such as immersive augmented reality or the educational application of artificial intelligence shows a considerable improvement and a correct application at an educational level. The main innovation in the educational field is mainly found in digital immersion that connects and complements reality as we know it, the possibility of having a virtual campus, connecting with people from different parts of the world, and openness to a diversity of applied topics to the UNDP's Knowledge Management Strategy [102]. Visual communication in the digital age is seen as a convex source in the face of the diversified needs of people. Considering the energy consumption that virtual education implies, diversity in the electric field can be analyzed and on the other hand, the implementation of more and more sustainable sources.

4 Webinars and Talks to Reduce Your Carbon Footprint

As an example, it is possible to mention that the University of Lima, through its sustainability center, offers various conferences, awareness campaigns, recycling, and among many other activities that encourage university students to become interested in topics such as carbon footprint and circularity, which are the central focus of the current chapter, in a virtual education context. The last event developed, called "Development Opportunities with the UN Volunteers program," is especially noteworthy, in which the university offered the possibility of connecting with the world-renowned institution [108]. In the same way, the University of Cambridge brings solutions about educational procedures around new politics of business sustainability management and distance learning to manage better practices in the development of new technologies implemented in virtual educational systems [109].

Currently, in the Climate Neutral Now Events 2021 organized by United Nations Framework Convention on Climate Change [105], there are a series of virtual events with different actors sharing their experiences and inspiring others on their way for more sustainable and climate-neutral or net-zero emissions targets. The Path to Climate Neutrality: The basics for schools explained more about the importance of virtual education in the new generations and how it impacts the ecosystem of many organizations in how they interact with the environment. The discussion showed the increasing commitment and support for governments to the private sector, with policies to achieve more sustainable practices to reduce the footprint [105].

In the interaction with other stakeholders, the OECD Green Talks Live webinar series [78] starts the discussion with the implementation of new environmental efforts in the last decade. The relationship of environmental policies with productivity and sustainability systems management empowers the circular economy. Additionally, the UNEP experimented with new technology for reducing carbon footprint in VR in a talk about new tendencies in educational systems growing [103]. In the context of COP26, there is increasing knowledge about decarbonization and the role of

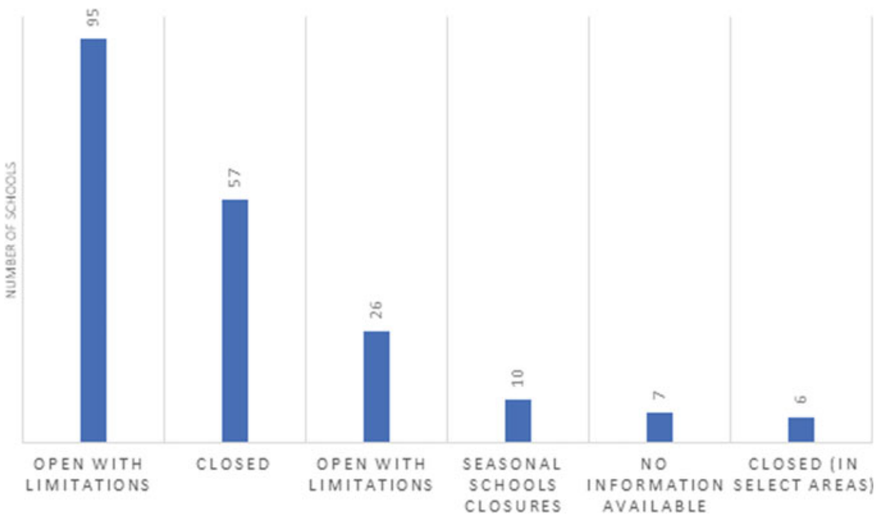

Fig. 3 Number of countries with close schools worldwide 2021, by status (*Source* Adapted from World Bank [114])

governments and capital markets to encourage the transition to a net-zero industry [106].

As shown in Fig. 3, there currently exists a massive variation for schools with high potential to return to face-to-face learning. Most of them, until this moment, wait to be restructured in a different industry or keep with less equipment for blended learning. In contrast to the established idea of events, virtual learning transforms into a different one with digital tools. In that context, webinars and online talks become the better improvement for virtual education.

5 International Organization Initiatives

In terms of sustainability, due to the UN's drive toward organizations promoting sustainable development, institutions such as the World Bank and the International Monetary Fund that are part of the United Nations system evaluate the initiatives or progress made to achieve the SDGs. In his case, these issues are more closely related to his financial and economic development functions.

In terms of education post-pandemic, Huang and Holotescu [59] explain that UNESCO, as a response to the pandemic, launched various initiatives such as releasing publications like "Guidance on Open Educational Practices during School Closures: Utilizing OER under COVID-19 Pandemic in line with UNESCO OER Recommendation" which has the objective to show the consequences if Open Educational Practices (OEP) and Open Educational Resources (OER) were to be applied on learning outcomes. Likewise, the Organization for Cooperation and Development promotes improved economic and social well-being policies. This guide explains innovative approaches when using both, and these experiences are lined up with UNESCO OER recommendations for five areas:

- "Building capacity of stakeholders to create access, use, adapt and redistribute OER
- Developing supportive policy
- Encouraging inclusive and equitable quality OER
- Nurturing the creation of sustainability models for OER
- Facilitating international cooperation." (p. 4)

Moreover, UNICEF, UNESCO, and the World Bank have been working together to monitor countries' responses to the COVID-19 pandemic in the education sector by analyzing the impact of school closures and learning losses worldwide. Following this line, UNESCO launched the Global Education Coalition to support educational recovery and assist countries in developing the best distance learning practices [104].

6 Efficient Environmental Practices in Education

6.1 Appropriate Use of the Email

Information and communication technologies have brought significant changes to society in various sectors, and education has not been the exception. These have become tools that help develop the student learning process in a didactic way, where technology is involved with education [30, 50, 51].

One of the most widely used services is email. In this line, Alvarez-Risco [19] proposes first, select and discard the inbox, i.e., delete emails that have no use, second is to sort; for this, you can use folders in the case of Outlook or labels in Gmail to be stored within these, so they will no longer be in the inbox. The third is to clean, that is to say, to be aware of the viruses that can arrive using the mails; the fourth is to standardize, develop habits so that the inbox shows what is answered, and have discipline be constant in all these steps.

6.2 Efficient Use of Laptops/Computers

It is a fact that traditional means are not indispensable to conduct classes; even the student's physical presence in the classroom is unnecessary. Technological devices have allowed classes to continue to be transmitted virtually, either live or recorded. One of the most indispensable devices is the laptop or computer. It is recommended to turn off the monitor, in case of a computer, when you are not using it, avoid opening many programs at the same time; reduce the brightness of the screen; unplug external devices such as USB and memory cards when you finish using them; and do not place the devices near sources of heat or cold.

6.3 Appropriate Use of Cloud Storage

Cloud storage appeared to reduce paper waste, saving files and having access to them from any device via the Internet, which has become an efficient tool in virtual learning environments as it provides students access to their educational materials anywhere and at any time. Cloud computing makes it possible to share, comment, visualize, and edit files in real time with other users, reducing the need for social gatherings. As well as in emails, it is recommended to use cloud storage appropriately to get the most benefit from it. Apart from organizing files in folders to better manage them, it is essential to periodically review the files that are no longer needed and delete them. The latter reduces the carbon emissions generated by cloud data centers [71].

7 Post-pandemic World Planners

Also, new practices seemed strange at first; however, it is part of everyday life. Likewise, according to Filimonau et al. [52], the return to classes brings with it the mandatory use of masks, an increase in the carbon footprint due to the limited capacity of public transportation, an increase in the use of water for disinfection, greater use of disposables, and greater use of classrooms or laboratories due to the fact of having more use of the facilities because the capacity in a class is reduced.

7.1 Use of Masks

Awareness of the use of single-use disposables was beginning to be raised in the world. However, with COVID-19, many of the practices to avoid the use of disposable have decreased. A clear example is masked as a form of protection against the virus. Selvaranjan et al. [96] showed that one person uses 5 masks per week. The authors mentioned that a biodegradable mask would be an option to reduce plastic waste. With the replacement of polypropylene with organic materials with similar chemical, mechanical, and physical properties, it can be inferred that the cost is higher due to the innovations that these masks would have.

7.2 Social Distancing on Public Transport

Because of the new restrictions about the social distancing on public transport, the carbon footprint would increase because more buses are needed and more use of petroleum or gas. In some cases, the student prefers to use cars to spread the virus, which means a higher carbon footprint per student. Consequently, the role of sustainable virtual education is fundamental to generating awareness about the efficient management of the carbon footprint without significantly affecting the environment [96].

7.3 Increased Water Use for Disinfection

Another variable that would affect the carbon footprint is the increase of water because it is frequently used for disinfection, according to Selvaranjan et al. [96]. So, what actions should universities take to have a minimum impact on climate change? On this point, it is pretty interesting to follow correct water management, and it is worth noting that SDG 6 mentioned the following: "the sustainable management of water and sanitation and the objective is to increase the efficiency of water use in every sector and guarantee the sustainable harvest and allocation of water resources to face scarcity of water…" In this sense, virtual education can lead to virtual training programs on efficient water use for all members of the various university communities. In this way, it is possible to face the fact that today it is necessary to consume more significant amounts of water resources.

7.4 Packaging and Other Solid Waste

Solid waste may be another problem for the environment while going back to face-to-face classes, as more single-use disposables are used to minimize the spread of the virus. Especially in campus dining services, some protocols are added to prevent COVID-19 contagions. For instance, it might be useful to give students packaged food and disposable utensils as they are easier to disinfect before using them. However, these practices might lead to an increase in carbon footprint per student. The implementation of more sustainable management according to the reverse logistics can improve the safety of the packaging, being recyclable, and more facilities to transport. Also, it can mean a significant improvement to regain value from the product or dispose of it, reducing waste.

7.5 High Energy Consumption

There is social distancing in shopping malls, public transportation, restaurants, and others in the new reality; this restriction probably continues in the case of face-to-face education. Because of that, there is student capacity per classroom; with this, the frequency of teaching increases, which means frequent use of university facilities and laboratories, affecting the energy consumption in the buildings. According to Versteijlen et al. [110], virtual learning consumes considerably less energy than campus-based education, which leads to lower carbon emissions in approximately 84%. In this sense, education centers that shift to online or hybrid learning rather than solely face-to-face education achieve energy efficiency and meet their sustainability goals.

7.6 Hybrid Education

After the pandemic, education became entirely virtual in the first months. However, with more people vaccinated and the level of the ones affected by the virus is reducing, many countries are adopting a mix between online and in-person education. It is also known that even though some systems could apply online learning quickly, they struggled in meeting the needs of all the population. For example, in developing countries such as Peru, people in remote areas with little to no Internet access could not study in proper conditions. We can conclude that the pandemic exposed what was lacking in the educational system. Caird and Roy [34] propose a design called blended learning, which is "the design of learning experiences that draw on a combination of face-face, distance, or online delivery methods, learning technologies, delivery multimedia, and pedagogical methodologies to achieve a mix of learning outcomes in educational or training contexts" (p. 4).

One of the objectives of this design is to be able to "support sustainable development, including the social, economic, and environmental dimensions of sustainability and protect global environmental resources to meet the needs of the present and future generations" (p. 4).

Blended learning is widely known as hybrid learning too, and it has become so widespread this year that it may be the new normal. However, an important aspect to consider is that while hybrid education allows a lower environmental impact to be had and contributes to the reduction of the carbon footprint, classes should be planned in such a way that the articulation of the face-to-face and online classes so that they can be part of the same teaching process and not as two parallel educations.

8 Closing Remarks

Education generates a carbon footprint as well as other sectors. In virtual education, to find this footprint, scope 1 refers to the direct emissions produced by the educational center; then scope 2 to the indirect energy emissions; and scope 3 to the other indirect emissions that may be generated, which is a higher percentage of participation unlike scope 1 and scope 2. Also, universities have started talks and activities to raise awareness about climate change to students, but around 44% have not yet received any information on the subject. So, the work is still in process.

Even though there is an approach to hybrid or blended learning, it is yet to have an empirical test to prove its effectiveness in reducing carbon footprint. There need to be further studies that can bring a solution and balance to an effective educational method that includes technology and broader access to education. There would be more accessibility to people who live in rural areas in developing countries with blended learning. However, it would also affect the environment because of the transportation pollution for mobility and energy consumption.

Several practices are not complex and that can be converted into new habits to have a more significant impact on the carbon footprint, such as the proper use of email, managing through labels or folders; the efficient use of laptops, with actions such as lowering the brightness, disconnecting all USB ports that are not used in the device; the efficient use of hybrid education, a point that has demonstrated the large gap in education that exists.

Many countries are preparing for the return to face-to-face classes and with it, a new reality that students face from the moment they leave home until they return. The use of permanent masks, social distancing in public transportation, increased use of water for disinfection, more significant solid waste, higher consumption in university facilities, among others, are changes that students are subjected to do. Therefore, it is a new challenge for universities to determine what actions can be taken to minimize their carbon footprint.

By way of conclusion, it is possible to mention that there are huge innovations, in terms of sustainable education, in both the face-to-face and virtual contexts. Obviously, throughout the present research work, it was noted that most theoretical and practical applications had been carried out in traditional education, that is, face-to-face education. However, many initiatives could be seen for the virtual context, widely expanded due to the COVID-19 conjuncture. In addition, face-to-face activities can serve as a source of inspiration to develop projects that promote a sustainable and focused virtual education, as proposed by the research, in carbon footprint and circularity. In addition, it is exciting that both types of sustainable education mentioned above follow international principles for sustainable development education, which represent a fundamental basis on which great projects can be achieved that benefit student, teachers, communities, and, in general, the public environment and its inhabitants.

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