Received: 5 May 2022 | Revised: 7 September 2022 | Accepted: 11 October 2022

DOI: 10.1111/1541-4337.13069

COMPREENSIVE REVIEWS IN FOOD SCIENCE AND FOOD SAFETY

Sustainability issues along the coffee chain: From the field to the cup

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Funding information
European Regional Development Fund; Fundação para a Ciência e a Tecnologia; Ministério da Ciência, Tecnologia e Ensino Superior; European Social Fund

Abstract
The coffee industry is one of the most important commercial value chains worldwide. Nonetheless, it is also associated to several social, economic, and environmental concerns that impair its sustainability. The present review is focused on these main sustainability concerns from the field to the coffee cup, as well as on the strategies that are being developed and/or implemented to attain sustainability and circular economy principles in the different chain segments. In this context, distinct approaches have been applied, such as sustainable certifications (e.g., voluntary sustainability standards), corporate sustainability initiatives, direct trade, relationship coffee concepts, geographical indication, legislations, waste management, and byproducts valorization, among others. These strategies are addressed and discussed throughout this review, as well as their recognized advantages and limitations. Overall, there is still a long way to go to attain the much-desired sustainability in the coffee chain, being essential to join the efforts of all actors and entities directly or indirectly involved, namely, producers, retailers, roasters, governments, educational institutions (such as universities and scientific research institutes), and organizations.

KEYWORDS
circular economy, coffee byproducts, coffee certification, coffee chain, sustainability, voluntary sustainability standards

1 | INTRODUCTION

Coffee is one of the most appreciated beverages in the world and is, therefore, one of the most produced and traded commodities (Murthy & Naidu, 2012b). As the coffee plant grows mostly in the area between the Tropic of Cancer (23.43695°N) and the Tropic of Capricorn (23.43695°S), also known as the "Coffee Belt" (Franca & Oliveira, 2019), its production is mainly supplied by developing countries. Indeed, it is estimated that in the "Coffee Belt" there are approximately 60 countries producing coffee (corresponding to a cultivation area of ~11 million ha), and of these, Brazil is the largest coffee producer, followed by Vietnam (ICO, 2021c). On the other hand, coffee consumption is significantly higher in developed countries, particularly in the European ones and in the United States (ICO, 2021e).

Coffee (as raw material) is a good example of a commodity frontier since it has moved across many places from its ancient home (Kefa, region of North Africa, now part of Ethiopia, 850 AD) (Beckert et al., 2021; Ludwig et al., 2014). It is also important to note that the division between "producer" and "consumer" country is not always clear since more and more producer countries are also consumers and vice versa, contributing to a more tightened production–consumption gap. As an example, Portugal is a well-known coffee consumer country but, in the last years, the production of this commodity has appreciably increased in two islands of the Azores archipelago (São Jorge and São Miguel) (Costa, 2020; Voz do Campo, 2020). Indeed, the edaphoclimatic conditions favor the growth of arabica coffee on these islands (Costa, 2020), and, indeed, with climate change and global warming, it might be possible that, in the future, coffee plantations will start to spread to other countries rather than those located in the Coffee Belt, such as in the Southern European countries.

According to the International Coffee Organization (ICO), coffee production has presented some fluctuations over the years, being always higher for arabica coffee (around 60% in the last years). Just as an example, in 2020/2021, about 10.13 million tons of coffee were produced, corresponding to a slight decrease of 0.1% compared to the previous year (ICO, 2022). On the other hand, coffee consumption has significantly increased, with worldwide coffee consumption estimated to be about 10.06 million tons in 2020/2021 (more 2.0% than in 2019/2020) (ICO, 2022). This continuous increase can be attributed to several factors. First, it is significantly related to the ease that the market has been offering to consumers to drink coffee at home, as there are new machines and formulations (instant coffees, single serve presentations—pods and capsules—and "Ready to Drink" preparations), which can be found elsewhere (supermarkets, coffee shops, and online shops) at very competitive prices (Kamiloglu, 2019; Panhuysen & Pierrot, 2020). Furthermore, there are also new market trends: (i) the out-of-home consumption is continuously growing as lifestyles change and as there are more coffee shops, population under the working age, and urbanization (Research & Markets, 2020); (ii) as aforementioned, the producing countries are increasingly consuming coffee (e.g., while in Brazil and Ethiopia the consumption of this commodity is already well deep seated and the increase is continuous but slower, in other producing countries such as Vietnam, India, Indonesia, Philippines, Uganda, and Colombia, the consumption has grown considerably in the last years due to urbanization and policies that encourage domestic coffee consumption) (ICO, 2021e; Sachs et al., 2019); and (iii) there is a growing demand for products with higher quality, namely, specialty coffees, as well as for single serve products, mainly in developed countries (Sachs et al., 2019). Finally, the consumption increase can also be associated with increased consumers' awareness on the positive health effects of moderate coffee consumption (Alves et al., 2009), which have been widely described and discussed in the literature and media.

In fact, the coffee industry has undergone several changes over time regarding coffee consumption and the global coffee culture, which have been called "coffee waves." The first wave corresponded to the era of exponential consumption growth (around the 1800s), where coffee was increasingly available and largely sold in bulk and as an undifferentiated commodity. The second wave began around 1970–1990 with the appearance and growth of Starbucks. This wave was characterized by the demand for better quality coffees and the social coffee experience, with a consumption increase of espresso coffees in coffeehouse chains. During this period, consumers were curious and wanted to learn about the different origin countries and to appreciate the best qualities of their coffees (International Trade Centre, 2021; Vicol et al., 2018). In addition, it was also in this wave that the coffee capsules, patented by Nespresso, appeared, which also allowed consumers to drink coffee with a significant increase in quality in their own homes (Boaventura et al., 2018). Finally, the third wave started in the late 1990s and early 2000s, and its focus goes beyond the countries of origin, that is, in this wave consumers seek greater specificity of origin (namely, the farm in which the coffee was produced), and want to know about the variety, the history of cultivation, the method of harvesting and processing, the roasting and brewing profile that gave rise to the final taste behind the cup of coffee they are drinking, and even the social, economic, and environmental conditions followed to obtain that coffee (Boaventura et al., 2018; International Trade Centre, 2021). Thus, consumers of this third generation are even more sophisticated and informed and have a particular interest in specialty coffees. In fact, as mentioned in the Fourth Edition of *The Coffee Guide*, the terms *specialty coffee* and *third-wave coffee* are closely related, as "third-wave coffee is an experience" and "specialty coffee is a product served within that experience" (International Trade Centre, 2021). Furthermore, in the third wave of coffee, face-to-face communication, "conviviality," and service itself are also fundamental, and coffee growers, roasters, and baristas are seen as respectful, knowledgeable, and skilled artisans that are responsible for the creation of a great cup of coffee and that know and are able to share the whole process and the story behind that cup (Boaventura et al., 2018; International Trade Centre, 2021; Manzo, 2015). Overall, the three coffee waves represent successive movements in the coffee industry and each one has melted into the next one, coexisting elements of all of them in the current coffee industry (Boaventura et al., 2018; International Trade Centre, 2021). Thus, over the years, besides coffee consumption has continuously increased, consumers have become more and more informed and exigent, which requires producers to be able to keep up with these market demands not only in terms of quantity but also in terms of quality.

Nevertheless, it is becoming extremely challenging to supply the current worldwide coffee demand due to several constraints that have been affecting the chain (ICO, 2021a). For example, climate change is significantly impacting coffee production, as this perennial crop is very sensitive to climate and requires warm temperatures (18–24°C) and abundant precipitation (Franca & Oliveira, 2019). Thus, continuous global warming, the increase of natural disasters, and other climate adverse conditions have led to a decrease in some coffee crops (ICO, 2021a; Pham et al., 2019). In addition, other factors unrelated to the coffee chain also significantly affected this sector, as was recently observed, for example, with the COVID-19 pandemic. A recent report published by ICO shows that COVID-19 negatively affected labor supply (due to illness, lockdowns, and travel restrictions), the poverty status of coffee farmers (due to income falls and inputs costs risings), the prevalence of child labor (due to the increase of poverty status and closures of schools as a result of lockdowns), and many other factors that hampered the production yields, exportations, and, consequently, revenues (ICO, 2020).

Besides that, considering that there are about 25 million smallholders worldwide, responsible for about 70%–80% of the total coffee production, and that around 125 million people worldwide depend on coffee for their livelihoods (International Trade Centre, 2021; Souza Pião et al., 2020), it is easy to understand that these mentioned factors can lead to significant negative impacts on the livelihood of these smallholders and farmworkers, who are often the less favored of the coffee chain, consequently impairing the whole chain (Pham et al., 2019; Sachs et al., 2019).

Furthermore, along with the increasing coffee production and consumption, a huge amount of different byproducts are also being generated (Figure 1) and, unfortunately, they are not being well managed—often ending up in landfills—resulting, consequently, in serious environmental problems (Janissen & Huynh, 2018).

In this way, the aforementioned examples show that the coffee chain sustainability is increasingly at risk, not only in environmental terms but also in social and economic ones. Therefore, it is essential to review which are the current problems in this chain, the strategies that have been used to overcome them, and the new actions that can be implemented.

The present review intends to present a comprehensive approach on the sustainability issues along the entire coffee chain: from the field to the cup. For that, different topics related to coffee sustainability were explored, addressing relevant and specific sustainability issues along each step of the coffee chain (i.e., production, processing, and consumption), to have a global vision of the entire process, the existing constraints, and the strategies that are being developed and/or implemented to achieve sustainability in this chain. Thus, and in brief, this review is structured in different sections. First, this current introduction to contextualize the topic under study. Then, Section 2 presents an overview of the methodology applied in this literature review. Section 3 describes and discusses the current social, environmental, and economic concerns throughout the coffee chain. And, finally, Section 4 is divided into three subsections focusing on the current strategies that have been applied in each stage (coffee production, processing, and consumption) to face such concerns and, thus, to achieve the desired sustainability of the coffee chain.

2 | METHODOLOGY

This literature research was performed using different electronic databases (Scopus, PubMed, Science Direct, and Google Scholar). In addition, several websites of interest (including those of organizations, institutions, and coffee companies' websites) related to the field of research were also accessed to find specific information.

First, in order to cover as much information as possible on the sustainability of the coffee chain, the term "coffee sustainability" was used in the aforementioned databases. The search was restricted by years (2000–2022), type of publication (research papers, reviews, and book chapters), and subject area ("Agricultural and Biological Sciences," "Business, Management and Accounting," "Chemistry," "Earth and Planetary Sciences," "Economics, Econometrics and Finance," "Energy," "Environmental Science," and "Social Sciences"), and the references were manually selected by taking into account the inclusion or mention of the term (or something related to it) at the title, abstract, or keywords, as well as their relevance in the field of this research. The selected references for this term were used throughout all chapters of the article. However, in addition to these criteria and this term, some more specific ones were used in some chapters, as described below.

Regarding the chapter that focuses on the current sustainability constraints of the coffee sector, the information present was fundamentally based on reports from institutions and organizations, although some of the selected research papers, reviews, and book chapters have also been used. For the chapter about the current sustainability strategies related to coffee production, besides the previous selected references and reports, more literature was searched with respect to the sustainable certifications adopted in the coffee sector. Thus, the term "coffee certifications" was used and the search was conducted as previously mentioned for the term "coffee sustainability." Nonetheless, the difference was that the subject areas herein used were "Business, Management and Accounting," "Earth and Planetary Sciences," "Economics,

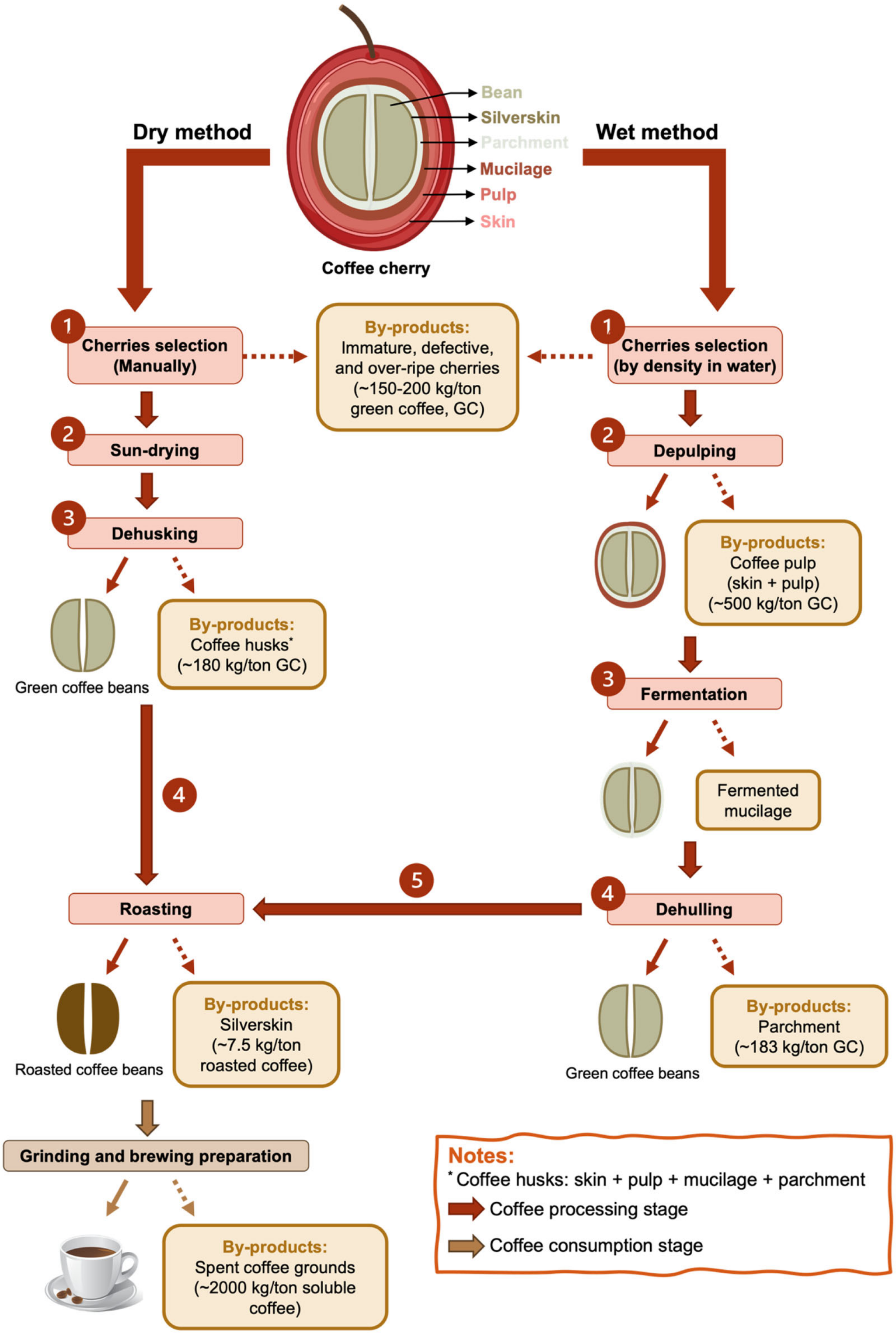

FIGURE 1 Coffee byproducts generated throughout the two major coffee processing methods and at the consumption stage. The indicated amounts were based on data presented in the literature (Alves et al., 2017; Benitez et al., 2019; Murthy & Naidu, 2012b; Mussatto et al., 2011; Ramalakshmi et al., 2007)

Econometrics and Finance," "Environmental Science," and "Social Sciences." Furthermore, for the chapter regarding the current sustainability strategies related to consumption, more information was also searched. In this regard, some coffee companies' websites were consulted, and the terms "coffee capsules," "coffee cups," and "coffee preparation AND sustainability" were searched on databases. The same selection criteria were applied, with the difference on the subject areas selected ("Business, Management and Accounting," "Earth and Planetary Sciences," "Economics, Econometrics and Finance," "Energy," "Engineering," "Environmental Science," "Materials Science," and "Social Sciences"). Finally, in the chapter addressing the valorization of coffee byproducts, a detailed bibliographic research was made in order to comprise as much information as possible regarding the current applications, strategies, and studies that are ongoing to add value to coffee byproducts. For that, the term "coffee byproducts" was searched and the criteria used for the selection of references were the same as described above, with the difference only in the selection of subject areas ("Agricultural and Biological Sciences," "Biochemistry, Genetics and Molecular Biology," "Business, Management and Accounting," "Chemical Engineering," "Chemistry," "Earth and Planetary Sciences," "Economics, Econometrics and Finance," "Energy," "Environmental Science," "Immunology and Microbiology," "Materials Science," "Medicine," and "Pharmacology, Toxicology and Pharmaceutics").

It is also noteworthy that throughout the reading and preparation of this manuscript, whenever a study or reference was found that was not in the applied inclusion criteria, but that could add value to this study, it was always critically analyzed, and some of them were also included in this review.

3 | SUSTAINABILITY CONCERNS IN THE COFFEE CHAIN

Although several definitions of sustainability can be found in literature, one of the most well-known, which has been the basis of many others (Al-Sobhi & AlNouss, 2018), was established in 1987 in the Brundtland Report, which defined sustainability as the "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development, 1987). This development requires a balance between environment, society, and economy, which are considered the three pillars of sustainability (Thomsen, 2013). Although independent, these pillars are closely linked because they influence each other (Geissdoerfer et al., 2017).

Social sustainability, fundamentally, aims to ensure social justice. Thus, an ethically social-sustainable society is the one that guarantees social equity for the poorest people (ensuring poverty reduction), human and worker rights, well-being, and quality of life (including health, education, and safety) of the current and future generations, preservation of culture, community involvement and development, and social responsibility (El-Haggar & Samaha, 2019; Thomsen, 2013).

Economic and financial sustainability ensures social and economic returns, as well as political involvement in these issues, to attain economic growth over the long term that may simultaneously improve the quality of life of society and the environment (El-Haggar & Samaha, 2019; Thomsen, 2013).

Finally, environmental sustainability would be ensured when society (primarily governments, companies, and other organizations) can stop the exaggerated use of natural resources (which, over the years, have been consumed at a speed that impairs their natural replacement) in order to guarantee their availability for future generations (El-Haggar & Samaha, 2019; Thomsen, 2013). The valorization of wastes that are usually discarded, giving them a new life, and closing the cycle in a zero-waste approach, can be here included. In addition to resource management, it is also crucial to avoid deforestation, preserve the natural habitats of endangered species, ensure good agricultural practices free of harmful inputs to the environment, and prevent pollution (El-Haggar & Samaha, 2019).

The 17 Sustainable Development Goals (SDGs) adopted by the United Nations comprehend these three interconnected spheres of sustainability and have been a good support to guide all countries, institutions, companies, and society in general, in the achievement and implementation of sustainable strategies and practices. Besides, as mentioned by the United Nations, "the 17 SDGs are integrated—they recognize that action in one area will affect outcomes in others and that development must balance social, economic, and environmental sustainability" (United Nations, 2021).

Currently, the coffee chain is facing several concerns in all the three sustainability domains. The social issues are closely related to the economic ones, and, in both cases, the central concern is focused on the players who have been less favored: the producers and their farmworkers. Although, in theory, it should be ensured that producers have gains that allow them to provide a decent standard of living for themselves, their families, and their workers (including food, education, health care, and decent housing), in practice this not always happens, and most coffee growers do not receive decent earnings (Sachs et al., 2019). In fact, considering the continuous increase in coffee consumption, it is difficult to understand why producers do not have more gains. Daviron and Ponte (2005) define this situation as the "coffee paradox," that is, "the coexistence of a 'coffee boom' in consuming countries and of a 'coffee crisis' in producing countries" and defend that this happens "because the coffee sold on the international market and the coffee sold as a final product to the consumer are becoming increasingly 'different'." As explained by the authors, the quality of a commodity (such as coffee) implies three different attributes: material, symbolic, and in-person service attributes. In brief, material quality is related to the physical characteristics of the product (e.g., aroma, taste, appearance, defects, color, cultivar, etc.) that can be measured directly by human senses or by technological devices; symbolic quality is based on reputation (e.g., the reputation of trademarks, geographical indications, and sustainability labels) and cannot be measured by human senses or technological devices; finally, in-person services quality attributes are based on the interpersonal relations between producers/providers and consumers and, besides implying affective work, may imply a physical transformation of that product (e.g., preparing and serving an espresso coffee). What is happening in the case of the coffee chain is that producers are receiving only for the material quality of the coffee they sell, while the profits from symbolic and in-person service quality attributes, which are the ones that provide higher incomes, are gained by the Northern actors (roasters, retailers, and cafés) (Daviron & Ponte, 2005). As a consequence, one of the main problems in the coffee production sector, which leads to many other concerns, is the poverty existing among farm owners, their workers, their families, and the community that lives on the income of this production. In fact, it is estimated that, in the coffee sector, approximately 50–100 million people are living below the extreme poverty line, and this includes not only coffee farmworkers but also farm owners (Browning & Moayyad, 2017). Unfortunately, due to the low and volatile earnings that farmers obtain from the sale of their coffees, and considering that these earnings (even though quite low) are higher only at harvest time, seasonal hunger—associated with malnutrition and lack of food security—still subsists in coffee-producing countries, as well as the limited access to health care, quality education, clean water, and sanitation (Panhuysen & Pierrot, 2020; Sachs et al., 2019).

Lamentably, another factor that has been contributing to the low farm gains and the poverty existing in the production sector—and which is related to the roasters' power mentioned above—is the limited participation of producers in the coffee value chain governance, such as in the negotiation of annual coffee floor prices and other policy decisions. In a recent review, Clay et al. (2018) show that several studies defend the importance of all stakeholders—including producers—to have an equal voice and accountability for a good governance and, consequently, for economic growth. In addition, some of them highlight that the lack of producers' participation results in the increased empowerment of the most influential actors (as also aforementioned), who might control policies to increase their own benefits, as well as in other corruption schemes that obviously harm the producers. Besides, as producers have no voice, they are not incentivized to invest in their coffee plantations leading to a poor farmer profitability, declining production, and long-term stagnation of the coffee sector. In this regard, Clay et al. (2018) interestingly showed that, when coffee prices are low, smallholders are the most productive producers and largeholders the least. The authors defended that this is because smallholders are pressured to produce to avoid poverty, while largeholders are driven only by the temptation of getting higher profit margins (Clay et al., 2018). In this way, there is a need for greater inclusion of producers in the value chain governance in order to adopt a floor price that considers the real costs of production and hence, to achieve higher prices that might enhance the motivation of largeholders to invest and to increase capacity production, and obviously, the quality of life of all producers (small, medium, and large ones).

Besides the inconstancy of coffee prices and the lack of voice, producers are also facing a continuous increase in production costs, such as the inputs, labor, and transport costs, which also enhances the poverty status. For example, the cost of fertilizers and pesticides has been continuously increasing, raising the financial pressure on producers and decreasing the incomes of their production (ICO, 2021b; Sachs et al., 2019).

In addition, and as a result of the extreme poverty of the production sector, working conditions in coffee production are not the most dignified and fair, and child and forced labor still exist (Panhuysen & Pierrot, 2020; Sachs et al., 2019). Thus, and unfortunately, much of the SDGs (e.g., SDG 1, No poverty; SDG 2, Zero hunger; SDG 3, Good health and well-being; SDG 4, Quality education; SDG 6, Clean water and sanitation; SDG 8, Decent work and economic growth) have not been accomplished in the coffee production sector and, as will be further discussed, we are still far from achieving them.

Furthermore, the SDG 5, which aims at gender equality, has not either been reached, representing another social (and even economic) concern in this value chain. Lamentably, although most of the existing workforce in coffee production are females, only a few women own lands. In detail, it is estimated that around 70% of the labor force in coffee production is provided by women but, of all coffee farms existing worldwide, only 20%–30% are headed by this gender (ICO, 2018a). This is largely due to patriarchal beliefs—where women only inherit lands if they are the only daughter or if there are no male members left in the family—and also to governmental land distribution programs that are gender biased, favoring males and giving to women less empowerment and access to resources (ICO, 2018a; Yeo, 2020). Nevertheless, due to these inequalities, the entire coffee chain (including consumers) loses, as it is estimated that women could increase agricultural yields by 20%–30% (FAO, 2011) and that an extra 30 billion cups of coffee could be created per year if gender equality is achieved (ICO, 2018b). Moreover, the increase of women empowerment could also improve the quality of nutrition, health, and education of their families and the community living from the coffee production incomes, as it is well described in the literature that females tend to spend more of their incomes on food, health care, and children access to education (Chiputwa & Qaim, 2016; Doss, 2013). Thus, the socioeconomic problems that hamper the reach of the various SDGs are directly correlated with each other, being essential to work in all of them.

Regarding the environmental issues, several concerns must be addressed and solved as fast as possible in the coffee chain because of the extreme situation in which our planet is, and to which this value chain also significantly contributes. Particularly, some of these concerns are deforestation, biodiversity loss, high carbon and water footprint, unsustainable production and consumption, and mismanagement of wastes. Thus, as will be further explained, it is also necessary to work toward the SDG 11 (Sustainable cities and communities), SDG 12 (Responsible consumption and production), SDG 13 (Climate action), SDG 14 (Life below water), and SDG 15 (Life on land) in order to achieve the desired environmental sustainability of this trade.

Deforestation is intimately related to other environmental concerns and might even be considered as a trigger for them, since it has been described as the second largest source of anthropogenic greenhouse gas emissions and a major contributor to climate change and biodiversity loss (IDH, 2020; Pendrill et al., 2019). Unfortunately, agriculture represents one of the main drivers of deforestation, particularly in subtropical and tropical regions, where it is around 86% (IDH, 2020). Although coffee has had a relatively low impact on global deforestation when compared to other crops (such as palm oil and soy crops), the increasing demand for this commodity and its sensitivity to climate change have led to the expansion and shifting of coffee cultures to new areas, enhancing the loss of forests (IDH, 2020; Panhuysen & Pierrot, 2020). Indeed, in some countries, particularly in Latin American and sub-Saharan Africa countries, deforestation resulting from coffee crops is already notorious and worrying (Takahashi & Todo, 2017). For example, in Peru, it is estimated that 25% of deforestation is related to coffee production (Panhuysen & Pierrot, 2020). Also, in Uganda, it is estimated that, since 1990, about 55% of natural forests have been eliminated and converted to agricultural land, and this deforestation seems to be highly correlated with coffee culture expansion, which has grown about 50% since the same year (Bunn et al., 2019). This expansion has often occurred into regions at higher altitudes (Panhuysen & Pierrot, 2020) mainly due to climate change. In fact, with the continuous increase of global warming, researchers have projected that by 2050, around 60% of current coffee production areas will no longer be suitable, particularly in mid-altitudinal areas (400–700 m above the sea level) (De Sousa et al., 2019). For this reason, an adaptation of the cultivated lands to higher altitudes (superior to 1800 m above the sea level) will be needed to compensate those losses (Adhikari et al., 2020; De Sousa et al., 2019). However, it is important to note that the higher the altitude required to continue cultivating coffee, the smaller the area available for that cultivation, thus enhancing deforestation. Furthermore, these higher altitude areas correspond to regions of high biodiversity—some of which are the last intact primary forests on the planet—which means that coffee crops expansion can be a threat not only for deforestation but also for biodiversity and ecosystem conservation (Panhuysen & Pierrot, 2020). Moreover, these transferences will also bring social and economic negative impacts in the whole coffee chain, as most smallholders will not be able to adapt to these changes due to their economic instability and, therefore, the living conditions of these communities can become even worse (Haggar & Schepp, 2012).

The modern agroecosystems in which coffee is produced have also been contributing to deforestation and biodiversity loss. Traditionally, coffee is produced under a varied and dense canopy of shade trees, where the biodiversity of fauna and flora is enormous (Perfecto et al., 2005; Takahashi & Todo, 2017). However, coffee plantations in these habitats result in lower production yields and, for this reason, these agroecosystems have been more and more replaced by sun-grown monocultures, which might attain three- to fivefold higher yields than the former (Takahashi & Todo, 2017). Nonetheless, it is important to note that over the long term it is unlikely that these sun-grown production yields can be sustained. In fact, these shifts to sun-grown monocultures require an increased use of inputs in the transition period (as soils degrade more quickly without the protection of the shade to fierce sun and heavy rain) and result in a significant increase in deforestation, biodiversity loss (namely, loss of tree species, birds, and arthropods), and also carbon footprint (once shade-grown coffee agroforestry systems can store seven to eight times more carbon than sun-grown monocultures) (Anil Kumar et al., 2019; Perfecto et al., 2005; Philpott et al., 2008).

In addition to deforestation and biodiversity loss, climate change has contributed to the increase of coffee diseases and pests (Sachs et al., 2019) due to the sensitiveness of this crop to temperature variations, water availability, humidity, and soil conditions (Adhikari et al., 2020; Sachs et al., 2019). Also, the occurrence of natural disasters (such as hurricanes, erratic and unpredictable heavy rains, and droughts) drastically affects harvest times, production yields, coffee quality, and, consequently, the coffee growers' incomes (ICO, 2021a; International Trade Centre, 2021; Samper & Quiñones-Ruiz, 2017). Besides that, and also as a consequence, more and more pesticides and fertilizers have been used, resulting in degradation and pollution of soils and water (Capa et al., 2015).

With respect to water management in the coffee chain, another important issue is the amount of wastewater (with high organic load and phytotoxicity) that is discarded during coffee processing, particularly in the wet method, which, likewise synthetic pesticides and fertilizers, contributes to pollution and may cause disease or death of fauna and flora (Janissen & Huynh, 2018; Rattan et al., 2015). Overall, the coffee chain has a high water footprint, with an estimate that the consumption of a 125-ml cup of coffee requires about 140 L of water (Hoekstra, 2008).

In addition, the coffee chain also contributes to another worrying footprint: the carbon footprint. In this regard, the concerns are focused not only on the production step but mainly on the processing and consumption stages. According to a study performed by Killian et al. (2013), the most critical points (responsible for 73% of total emissions in the coffee chain) are the use of fertilizers in production (20%, 0.960 kg CO_2/kg green coffee), the wastewater resultant from wet processing (8%, 0.374 kg CO_2/kg green coffee), and the electricity used in the preparation of coffee beverages using automatic coffee machines (45%, 2.150 kg CO_2/kg green coffee). Besides, the exportation, roasting, grinding, and purchasing processes, for example, are also points where high emissions are released. Overall, it is estimated that the entire coffee chain has a total carbon footprint of 4.82 kg CO_2 emission/kg green coffee, thus presenting a significant impact on the environment (Killian et al., 2013).

It is important to note that even the consumers assume an environmental negative role in this chain due to the ways they consume coffee: the continuous growth in the consumption of coffee capsules in recent years, particularly in Europe (the largest coffee consumer), together with the use of disposable cups, represents a huge environmental impact since they are made of materials that are difficult to recycle and, as mentioned above, capsule-based coffee machines consume high energy (Brommer et al., 2011; Killian et al., 2013).

Finally, another relevant environmental concern, already mentioned in Section 1, is related to the huge amounts of coffee wastes and byproducts that are generated from production to consumption (Figure 1). All these wastes pose serious risks to the environment, and this is not only because they are being generated in large quantities throughout the whole chain, but also because they contain some compounds that are toxic to plants, animals, and microorganisms that live in the soil and the water (Alves et al., 2017; Janissen & Huynh, 2018).

Overall, considering all social, economic, and environmental concerns presented in this section, it is clear that several efforts must be made to attain the much-desired sustainability of the chain. In this sense, several strategies have been studied and implemented, most of them based on the SDGs of the United Nations, as will be further discussed.

4 | SUSTAINABILITY STRATEGIES IN THE COFFEE CHAIN

With the increasing production and consumption of coffee worldwide, as well as with the abovementioned raising concerns, several strategies have been emerging to reduce the environmental impact of the coffee chain, to boost the economy of producing countries, and thus to ensure more favorable, fair, and dignified living conditions of producers and farmworkers. Nonetheless, various studies have wondered if sufficient efforts are being made by all stakeholders in this chain—particularly by coffee companies—to achieve the desired sustainability of the sector. Just as an example, in a study conducted by Bager and Lambin (2020), the sustainability efforts of 513 companies in the coffee sector were analyzed, and, unfortunately, the results were not as encouraging as it would be expected because one third of these companies reported that they do not perform any sustainability practice, one third reported a vague commitment to sustainability, and only a third reported a significant commitment. More concretely, more than half of the practices evaluated in the study were adopted by a small group of companies (18/513 companies), which reveals how sustainability is still underprioritized by most of companies. Moreover, producers and processors adopt the most sustainability practices, while cafés the least, and, in general, companies adopt more socioeconomic practices than environmental ones (with climate change and deforestation being the least addressed problems). This study also concluded that large companies tend to develop and follow their own sustainability measures, while smaller ones tend to adopt external sustainability guidelines, such as voluntary sustainability standards (VSS). In this regard, the authors also found that companies that work with nongovernmental organizations (NGOs) adopt significantly more sustainability practices than those that do not and even than those that claim to be sustainable, which highlights the importance of NGOs to increase the stringency in the adoption of these practices, as well as the existence of companies that, despite claiming that are sustainable, do not adopt many (or even any) sustainability practices or external standards. Thus, Bager and

Lambin also concluded that a broader change of all companies in favor of sustainability would be attainable if there were more transparency, more audits, more accountability, mandatory reports, among others (Bager & Lambin, 2020).

Even so, and fortunately, besides the sustainability efforts made by companies, several strategies have also been studied and adopted by governments and organizations, and the scientific community has also made several efforts in this field and has demonstrated huge interest in finding new ways to attain/improve sustainability in this chain.

From production to consumption, different types of approaches have been applied, such as sustainable certifications by NGOs, industries, and other entities; corporate sustainability initiatives by large companies; legislations by governments; and byproducts valorization and waste management by all entities, including the scientific community. In the following subsections, those strategies will be highlighted and their contribution to social, economic, and environmental sustainability will be discussed.

4.1 | Sustainability strategies related to production

As previously mentioned, most sustainability concerns in the coffee chain are concentrated in the production sector due to its social, economic, and environmental vulnerability. A potential solution to these concerns might be the improvement of coffee agriculture, which will require that coffee growers pursue modern agricultural policies, that is, technology and productivity packages, which include the use of drones, the introduction of machines in cultivation areas, the implementation of more efficient quality control plans, and the implementation of management techniques that ensure productivity and skilled labor (Caldarelli et al., 2019; Sachs et al., 2019). Thereby, it would be possible not only to increase economic stability and living and working conditions of coffee farmers but also to enhance biodiversity, coffee quality, and the availability of different coffee varieties to the consumers (Sachs et al., 2019). Nevertheless, it is important to note that all these requirements must be met not only by producers (who are unlikely to have the financial capacity to implement these measures) but mainly by governments, educational institutions (such as universities and scientific research institutes), companies/private sector, and organizations, that is, it requires a multisectoral cooperation (Caldarelli et al, 2019; Panhuysen & Pierrot, 2020).

In this sense, several strategies have been developed and implemented to face the current sustainability problems in the production sector, such as VSS and certification schemes, corporate sustainability initiatives, geographical indications (GI), and direct trade and relationship coffee concepts. In general, these initiatives can be considered to be part of the third coffee wave (mentioned in Section 1), as they are initiatives that promote and aim to produce specialty and sustainably coffee.

Of these strategies, the creation and implementation of VSS/certifications schemes has been the main strategy adopted in the last decades in order to reduce, at least in theory, the existent discrepancy between producing countries and different farmers (Souza Pião et al., 2020). In fact, the coffee industry is considered a pioneer in the implementation of standards and sustainability certifications since its growth in the global market was accompanied by several problems related to economic, social, and environmental sustainability (Dietz et al., 2018; Potts et al., 2014). Just as an example, in 2014, the production of certified coffee in countries such as Brazil, Colombia, Peru, Honduras, and Costa Rica corresponded to 30%–50% of total production (Potts et al., 2014).

In brief, VSS are nongovernmental initiatives with market-driven governance approaches (Grabs et al., 2016) that are based on a combined set of "voluntary predefined rules, procedures, and methods to systematically assess, measure, audit, and/or communicate the social and environmental behavior of a firm" (Dietz et al., 2018), always aiming and promoting the improvement of sustainability in the production and the rest of the market chain (Grabs et al., 2016). These VSS can be established by NGOs, industries, and sector associations, or even by numerous combinations of these stakeholders (e.g., collaborations between NGOs and industries), or by states and supranational institutions (although these last in minority) (Dietz et al., 2018). Nonetheless, it is important to note that the private policies of the different VSS must be in accordance with the public and government policies of each country (Grabs et al., 2016; Souza Pião et al., 2019). Although participation in VSS is not mandatory (because it is voluntary), it may become *quasi-legal* in specific situations (Dietz et al., 2018), and some studies have shown that the cooperation between public and private initiatives may present several advantages and synergies (Auld, 2010; Glasbergen, 2018; Grabs et al., 2016; Souza Pião et al., 2019). As defended by Glasbergen (2018), this is because public certification has a greater power of law enforcement, while private certification is more rigorous (Glasbergen, 2018).

Despite the multiplicity of VSS related to the coffee chain, and although their criteria vary significantly, they all have common objectives that go through achieving economic, social, and environmental sustainability goals (Panhuysen & Pierrot, 2020).

The most recognized and implemented VSS in the coffee sector are Organic, Fairtrade, Rainforest Alliance, and Common Code for the Coffee Community (4C).

Briefly, Organic certification is based on four principles (health, ecology, fairness, and care) and is mainly focused on the environment and good agricultural practices, avoiding or prohibiting deforestation and the use of agrochemicals, hormones, or genetically modified organisms, and replacing them by more environmentally friendly alternatives that aim to maximize the fertility of lands and the preservation of biodiversity, ecological balance, and animal well-being (European Commission, 2020a, 2020b).

Fairtrade certification, on the other hand, is mainly focused on ensuring social and economic stability of smallholders and their workers, aiming to democratically support smallholder cooperatives in developing countries by paying them a minimum price, but fair, for their services. With this certification, it is expected that labor rights are improved and that long-term trade relationships are established (Valkila, 2009). Nonetheless, this certification also has an environmental concern because it helps farmers to adapt to climate change, raising awareness and encouraging more environmentally friendly agricultural practices (Becchetti & Costantino, 2008; Fairtrade Foundation, 2020) and, in fact, it is estimated that 50% of Fairtrade coffee-certified farms are simultaneously Organic certified (Valkila, 2009).

The main focus of Rainforest Alliance certification (which recently has merged with UTZ certification) is the protection and conservation of biodiversity, always aiming to improve not only the future of nature but also the future of people. In other words, it aims to eradicate forest deforestation, implement best commercial practices to increase recognition and reward of those who invest in sustainability, raise awareness of farmers to use more efficient farming methods to deal with climate change, and manage land and crop so they are more prosperous, and, socially, ensure human rights (ICO, 2021d; Souza Pião et al., 2020).

Finally, 4C certification results from a multistakeholder collaboration between coffee producers, traders, industries, NGOs, the social sector, and the scientific community from all over the world, and is considered the gateway to other certifications as it works in the three areas of sustainability. Briefly, the 4C certification uses transparent sustainable farming practices in the production and is still responsible for ensuring these same conditions in the processing of coffee (Potts et al., 2014; Souza Pião et al., 2020).

Besides these VSS, large companies, such as Starbucks and Nestlé (Nespresso), have also developed and adopted their own standards and corporate sustainability initiatives, which are only applied to the coffee they sell (International Trade Centre, 2011). Starbucks' C.A.F.E. Practices and Nespresso's AAA Sustainable Quality program are the two best-known cases of corporate sustainability initiatives and, in brief, besides they are intended to improve social, economic, and environmental sustainability, just like the others VSS, both are also focused on improving product quality (Nestlé Nespresso SA, 2020; Starbucks Coffee Company, 2007).

Over the years, there has been a great scientific investment in order to understand the impact these certifications and VSS have had on the production sector. Nonetheless, most studies do not allow an objective conclusion of whether the application of certifications is beneficial in all that involves it. In the present review, an exhaustive overview of the impacts of standards and certification schemes on the coffee sustainability concerns previously discussed was carried out. The major advantages and limitations found in the literature are detailed in Table 1. It can clearly be observed that the studies are not often unanimous and that there are always pros and cons (Table 1). For example, despite some limitations, it seems that, in general, the environment is the one that most profits from VSS implementation. Regarding other important concerns of the coffee production sector, such as working and living conditions of producers and farmworkers, access to education and child labor reduction, gender equality, production yields, and coffee prices, several advantages and limitations are described in the literature, but it is difficult to balance and reach concrete conclusions. In fact, this happens because there are not enough solid methods to realize the evolution in farms before and after certification, because the attention given to the different VSS is not the same (some VSS are more studied than others), and also because often the analysis of voluntary coffee standards assessing various factors such as prices, product quality, and working conditions should not be generalized (since the studies are done under completely different conditions and are often not comparable) (Elliott, 2018; Loconto et al., 2014). To evidence this, in 2017, a review updated the information of the main published articles on the impact of certifications on the livelihood of small coffee producers (Bray & Neilson, 2017). The results were mostly positive, but the number of studies with neutral/mixed impact was the highest. It was also possible to observe that there are more studies on Fairtrade and Organic, although the conclusions are mostly neutral/mixed. In addition, there are not many studies on Rainforest Alliance and UTZ (now merged)—even though these seem to be the certifications that have the most positive results—neither in 4C (Bray & Neilson, 2017), which is currently the one holding the largest volume of produced coffee (Potts et al., 2014). Similar findings were also reported by Dietz et al. (2018). Furthermore, the authors reported that the positive or negative impacts of a certification scheme should not be measured by itself, but should be an assessment of the social, political, and economic context, among other factors of the country in which it is being studied

TABLE 1 Advantages and limitations of coffee certifications in relation to the key concerns of the coffee production chain

Key concern/goal	Known advantages	Known limitations
Working and living conditions of producers and farmworkers	- Several studies demonstrated that certification systems present benefits for farmers by reducing livelihood vulnerability, lowering production costs, increasing revenues, providing training in good sustainable agricultural practices, and improving food security (Bacon, 2005; Chiputwa et al., 2015; Elliott, 2018; Ho et al., 2018; Jena et al., 2012; Mitiku et al., 2017); - In general, certifications seem to improve the quality and quantity of coffee production as a result of farmers training. Furthermore, they also seem to strengthen organizational capacities and create market opportunities (Elliott, 2018; Glasbergen, 2018); - Chiputwa et al. (2015) showed that Fairtrade certification improves the living conditions of smallholder coffee farmers in Uganda by 30% and reduces the prevalence and gravity of poverty. Similar findings were shown by Ssebunya et al. (2019), where Fairtrade–Organic farms presented significantly greater improvements than Fairtrade farms, and both, in turn, performed significantly better than noncertified farms (Ssebunya et al., 2019); - Mitiku et al. (2017) found that Rainforest Alliance and Fairtrade–Organic certifications provide higher incomes and reduce poverty mainly due to higher prices (Mitiku et al., 2017); - Chiputwa and Qaim (2016) and Becchetti and Costantino (2008) found that certification schemes can improve the quality of farmers' diets (Becchetti & Costantino, 2008; Chiputwa & Qaim, 2016); - Dietz et al. (2019) found that Rainforest Alliance and UTZ certifications present positive effects on gross coffee incomes of Honduran farmers, while Fairtrade and 4C certifications has no effects and Fairtrade–Organic has negative effects (Dietz et al., 2019).	- In Nicaragua farms, although Fairtrade–Organic certification can create more jobs through the substitution of inorganic fertilizers by manual labor, the working conditions are not better than those of noncertified farms (e.g., there is no mechanical assistance to carrying heavy materials), and the producers and their workers are not well remunerated for producing organic coffee (Valkila, 2009); - Some studies showed that Fairtrade and Organic certifications does not present a significant impact on poverty reduction (Beuchelt & Zeller, 2011; Cramer et al., 2016; Jena et al., 2012; Mitiku et al., 2017; Valkila, 2009; Valkila & Nygren, 2010); - According to the results ascertained by Mitiku et al. (2017), in Ethiopia, the authors proposed that the effects of certifications schemes on poverty reduction, for example, strongly depend on the performance and organization of coffee cooperatives, as well as on the organization of the coffee supply chain and the quality of coffee (Mitiku et al., 2017); - The certifications in general do not seem to solve the problems of the living conditions of small farmers (Glasbergen, 2018); - In a study conducted by Dietz et al. (2019), it was found that only 10 of the 659 Honduran producers involved in their study were able to pay daily wages above the minimum salary to their farmworkers (Dietz et al., 2019).
Access to education and child labor reduction	- Some studies have shown that Fairtrade certification can improve school rates and access to education and, in some of them, the effects were found to be especially beneficial for girls (Akoyi et al., 2020; Gitter et al., 2012; Meemken et al., 2017; Naegele, 2020); - Some studies demonstrated that certification schemes invest in school infrastructures, although these investments are not always easily detectable (Akoyi et al., 2020); - In Akoyi et al. (2020) found that Fairtrade certification enhances the possibility of children to attain secondary school and to improve their school efficiency, although it does not have effects in child labor reduction nor in increasing incomes. Contrariwise, Rainforest Alliance certification was correlated with higher incomes and child labor reduction (Akoyi et al., 2020).	- A research conducted in Uganda and Ethiopia concluded that Rainforest Alliance certification slightly reduces girls' schooling and has no effect on boys' school outcomes, but has a significant effect on reducing child labor (Akoyi et al., 2020); - Meemken, Spielman, et al. (2017) found that Organic coffee certification does not have effects on child schooling outcomes (Meemken, Spielman, et al., 2017); - Dietz et al. (2019) found that one quarter of 4C-verified farms is still employing workers underage (Dietz et al., 2019).

(Continues)

TABLE 1 (Continued)

Key concern/goal	Known advantages	Known limitations
Gender equality	- The studies performed by Chiputwa and Qaim (2016) and Meemken and Qaim (2018) showed that sustainability certification improves gender equity (e.g., assets are jointly owned by male head and female spouse, or by female head; females receive training courses on coffee production and marketing; certified households participate in workshops on gender equality). However, the results found may not be generalized (Chiputwa & Qaim, 2016; Meemken & Qaim, 2018); - Chiputwa and Qaim (2016) found that the increasing involvement of females in decision-making through certification schemes is associated with improved nutrition of farmworkers and their families (Chiputwa & Qaim, 2016); - Some studies have shown that certifications increase female involvement in coffee production and access to markets, as well as women's control over income and wealth from production (Meemken & Qaim, 2018).	- Ssebunya et al. (2019) verified that there is still no gender equity in Fairtrade- and Fairtrade–Organic-certified farms from Uganda (Ssebunya et al., 2019); - Some standards (e.g., Organic) have specific requirements that may increase labor intensity, which, consequently, seem to increase the women's workload. However, for other standards (e.g., UTZ and Fairtrade), such evidence was not found, but more studies are still needed (Meemken & Qaim, 2018); - There is still no equal participation of women in farmer organizations and group meetings (Meemken & Qaim, 2018).
Production yields	- Several studies demonstrated that Fairtrade and Organic certifications may enhance production yields and quality of coffee produced in Africa (Bolwig et al., 2009; Chiputwa et al., 2015; Meemken, Spielman, et al., 2017), but these positive effects were not observed in other studies for coffee production in Latin America (Meemken, Spielman, et al., 2017) (see limitations beside); - In the literature review performed by Elliott (2018), it is described that UTZ and Rainforest Alliance certifications (before they have merged) present positive effects on productivity (Elliott, 2018).	- Some studies denoted that certified coffee farms attain the same or even lower yields than conventional ones (Haggar et al., 2017; Loconto et al., 2014; Lyngbaek et al., 2001) and indeed, for intensive Fairtrade–Organic coffee production, for example, a study found that the yields tended to be lower than the yields of farms with comparable intensity of production that used conventional methods (Valkila, 2009). In addition, Mitiku et al. (2017) showed that Organic certification provides lower yields, thus reducing farmers' revenues (Mitiku et al., 2017). Overall, these lower yields seem to be more noticeable with Organic certification (Elliott, 2018).

(Continues)

TABLE 1 (Continued)

Key concern/goal	Known advantages	Known limitations
Coffee prices	- Fairtrade and Organic certifications provide farmers more stable prices compared to those noncertified (Bacon, 2005; Chiputwa & Qaim, 2016); - Fairtrade–Organic coffee production can increase incomes for low-intensity coffee farmers, even though in a very modest way (Valkila, 2009); - Fairtrade–Organic coffee prices are generally better and more attractive, as the minimum price is guaranteed, and the coffee prices of conventional coffee tend to be lower and lower (Valkila, 2009); - Bolwig et al. (2009) showed that Organic certification contributes to higher revenues in Ugandan farms (Bolwig et al., 2009); - Ruben and Zuniga (2011) found that Fairtrade certification allows producers to get better prices, while Rainforest Alliance and Starbucks' C.A.F.E. Practices allow to achieve higher yields and quality (Ruben & Zuniga, 2011); - Mitiku et al. (2017) verified that, in Ethiopia, the cooperatives certified by Rainforest Alliance give the premium prices directly to farmers after selling their coffee to the international market, while Fairtrade cooperatives invest in the cooperative or community development rather than paying directly to producers, thus benefiting the farmers only indirectly (Mitiku et al., 2017).	- The prices of certified coffee and the premium prices paid to farmers for that coffee, both higher when coffee prices are higher on the market, have been dropping as the amount of certified coffee increases. Thus, the demand for sustainability can become, in the long run, a requirement that does not bring economic benefits to producers (Brando, 2019); - In general, certified farmers only receive slightly higher prices than uncertified ones, which are statistically insignificant, thus not representing relevant profits for those who are certified (Elliott, 2018; Glasbergen, 2018; Mitiku et al., 2017); - Sometimes coffee farmers do not receive any bonus (premium fee) for joining a certification scheme and, when they receive, the difference from noncertified is insignificant and, therefore, demotivating. In addition, farmers from different regions who join the same certification may receive different premiums (Glasbergen, 2018); - The profits of certification are not properly distributed: for example, a study has shown that Indonesian roasters receive the most gains (83%–95%), while farmers only receive a minority (1.4%–5.6%) (Glasbergen, 2018); in addition, Valkila et al. (2010) found similar conclusions in relation to Fairtrade-certified coffee (Valkila et al., 2010); furthermore, Naegele (2020) showed that the largest portion of the price paid by Fairtrade-certified coffee consumers goes to the roasting company, while the retailer is the one with the lowest profit that, according to the author, is even lower than the profits obtained by a conventional coffee maker, and the farmer only earns one sixth of the total value of the price paid by the consumer (Naegele, 2020); - Price premiums of Organic-certified coffee do not guarantee, in themselves, advantages to producers (Valkila, 2009). In addition, in the first years after the adoption of the Organic certification (conversion period), the farmers do not receive price premiums (and, in some cases, never receive), so farmers have to invest without being sure whether they will have a return, thus often suffering losses (Auld, 2010; Blackman & Naranjo, 2012; Loconto et al., 2014). Moreover, Minten et al. (2018) found that only less than one third of quality premium at the export level given by Fairtrade and Organic certifications goes directly to producers (Minten et al., 2018); - Jena et al. (2012) verified that Fairtrade certification in Southwestern Ethiopia does not guarantee higher coffee prices nor higher gross coffee revenues to farmers since cooperative members do not sell their coffee production to their proper cooperatives but rather to private traders, and also because there are no significant differences between the coffee prices of certified and noncertified cooperatives (Jena et al., 2012); - Snider et al. (2017) found that farmers that joined Starbucks' C.A.F.E. Practices experience more price fluctuations when compared to NGOs-led certifications: in years of high global coffee supply, producers are paid lower for their certified coffee (C.A.F.E. Practices) than for conventional coffee, and in years of low global coffee supply, the reverse occurs (Snider et al., 2017).

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TABLE 1 (Continued)

Key concern/goal	Known advantages	Known limitations
Environmental performance	- Some studies showed that certified production is linked to better biodiversity and biodiversity conservation (Elliott, 2018; Ho et al., 2018); - The most common positive environmental effects found in studies on the environmental performance of VSS are improved and/or reduced handling and improved waste and water management (Elliott, 2018); - Some literature reports that Organic certification is associated with a reduction in the use of agrochemicals (as well as the implementation of other environmentally friendly practices) and with an increase of biodiversity (Blackman & Naranjo, 2012; Haggar et al., 2017; Loconto et al., 2014; Panhuysen & Pierrot, 2020); - Rueda et al. (2014) showed that Rainforest Alliance certification positively contributes to shade-grown coffee plantations, to a greater diversity of tree species, and, consequently, to a healthier ecosystem. In addition, it also contributes to the promotion of more sustainable agricultural practices in smallholder farms (Rueda et al., 2014). Similar findings were described by Takahashi and Todo (2017), who demonstrated that forest coffee certification positively contributes to the prevention of forest degradation not only in the certified areas but also in their surrounding areas, and, in addition, it also guarantees the quality conservation of the forest and the surrounding ecosystem, contrary to what happens with noncertified coffee forest areas, whose quality decreased (Takahashi & Todo, 2017); - A study conducted by Ssebunya and his team (2019) concluded that a better environmental performance is achieved in Fairtrade- and Fairtrade–Organic-certified farms from Uganda (particularly in Fairtrade–Organic farms), when compared to those noncertified (Ssebunya et al., 2019); - Ibanez and Blackman (2016) observed positive environmental effects in Columbian certified farms (comparing to those noncertified) through a decrease in the use of nitrogen and phosphorus and an increase in the use of organic fertilizers. However, these positive environmental effects were not accompanied by significant economic returns (Ibanez & Blackman, 2016). In fact, similar findings were observed for Vietnamese farms (certified vs. noncertified) in a study conducted by Ho et al. (2018): the most important results showed that certified farmers have higher levels of eco-efficiency than noncertified ones, leading the former to reduce some environmental pressure factors (e.g., use of irrigation water). Notwithstanding, as in Columbian certified farms, the price premium derived from certification was shown to be not enough for all the necessary efforts (Ho et al., 2018); - Haggar et al. (2017) found that farms certified by Organic, Rainforest Alliance, Starbucks' C.A.F.E. Practices, and Utz better managed the wastewater resultant from coffee processing and reduced the use of water when compared to noncertified farms (Haggar et al., 2017).	- Hughell and Newsom (2013) found that Rainforest Alliance certification improved water quality in one of their studied areas, but not in the other, and that it had no impact on soil quality (Hughell & Newsom, 2013).

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TABLE 1 (Continued)

Key concern/goal	Known advantages	Known limitations
Incorporation of producers in organizations	–	- Bennett (2017) analyzed the governance structure of 33 Voluntary Sustainability Standards-Setting Organizations (VSSSOs) and concluded that more than 50% of these organizations do not intend to put farmers in senior governance positions. Only 25% guarantee that producers have votes/seats and only 18% give producers veto power (Bennett, 2017). Therefore, it is questionable what is the role of VSSSOs in the lives of marginalized farmers and whether their focus will be to guarantee them better living conditions, as they probably do not consider their opinions and ideas when making decisions.
Transparency of certifications	–	- The marketing channels are not well-organized, and oftentimes certified coffee is mixed and sold with conventional coffee or sold as conventional (and vice versa). Therefore, the traceability of coffee from its production to the final product is not being guaranteed and needs to be better developed (Brando, 2019; Glasbergen, 2018). In addition, companies should be transparent in the way they communicate to consumers. When the package contains only a small percentage of certified coffee, it should be clearly entered which percentage it contains, or the expression "contains sustainable coffee" should be clear in the label, giving the consumer information that not all coffee present is certified (Brando, 2019); - Excessive information and the different amounts of symbols on labels may cause confusion in consumers, especially in those who are not so well informed (Giovannucci & Ponte, 2005; Zander et al., 2015); - Smaller producers have difficulties in understanding or meeting some standards and the access to information and certifiers is not the same for the different regions of the world (Giovannucci & Ponte, 2005); - There is still a lack of transparency about, for example, the premiums that the producers may receive with certification, and, in many cases, the benefits of certification to the producers depend on the administrative competence and transparency of cooperatives to which they belong (Elliott, 2018); - Information on audits carried out on industry and company-led certification programs (4C, Starbucks' C.A.F.E. Practices, and Nespresso's AAA Sustainable Quality program) remains private, that is, results are unknown/unpublished, making it difficult to understand the real effectiveness of these certification schemes (Dietz et al., 2018; Verburg et al., 2019).

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TABLE 1 (Continued)

Key concern/goal	Known advantages	Known limitations
General feedback from smallholders	- Meemken et al. (2017) tried to understand the preference of Ugandan small coffee producers concerning the sustainability standards required by three certifications (UTZ, Fairtrade, and Organic) and they concluded that, in general, farmers are proactive in relation to sustainability standards, available for agricultural training, and appreciate special support for women. However, they do not like the productivity-enhancing inputs ban. Female farmers, compared to male ones, have a greater preference to follow standards. Many of these farmers see the standards they must follow as a possible future investment in their farms. Finally, they describe that there is gender heterogeneity in farm households (Meemken, Veettil, et al., 2017); - Elder et al. (2012) described that producers perceive and notice that Fairtrade certification is positively correlated with an increase participation of women in cooperatives decision making (Elder et al., 2012).	- High costs and long process required to adhere to certification (e.g., Organic in Nicaragua) do not attract smallholders to join a certification scheme (Valkila, 2009); - For some certifications (e.g., in Fairtrade certification), there is the need to form coffee farmer groups/organizations and to be further connected to cooperatives to get access to certifications (Elder et al., 2012; Glasbergen, 2018; Loconto et al., 2014; Valkila, 2009). The farmers may have higher benefits for organizing together—an advantage highlighted, for example, by Ssebunya et al. (2019) for Fairtrade and Fairtrade–Organic—but their relationship is often complicated, thus hampering the achievement of certification goals and good sustainability performance (Elder et al., 2012; Glasbergen, 2018; Valkila, 2009); - Some studies have shown that several smallholders are not interested in joining certification schemes since many standards are focused mainly on good agricultural practices and general food safety (Loconto et al., 2014); - Many smallholders, although knowing that they participate in a certification scheme, do not know the details of that certification, that is, although they are instructed about the standards they need to follow (and that they correctly apply them), they are not properly aware by the certifying entities they work with about the importance they have for achieving sustainability (Elliott, 2018; Glasbergen, 2018).
Consumers' knowledge and awareness about certifications	–	- Zander et al. (2015) described that consumers' knowledge in some European countries regarding the EU Organic logo is slightly reduced compared to others. In addition, there is also another concern that reveals that the percentage of respondents who recognized false logo as being the organic EU logo was as high as the percentage of respondents who identified the organic EU logo as being a logo that ensures that the product followed organic production standards. One explanation for the fact that respondents recognized the fake logo as the real one is that it contained the word "BIO," which can lead to the confusion of the interviewee and possibly the consumer. This reveals a lack of knowledge from some consumers and still lacks government initiative to increase awareness and logo promotion. However, in some cases, the lack of interest from some consumers is a reality (Zander et al., 2015).

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TABLE 1 (Continued)

Key concern/goal	Known advantages	Known limitations
General issues	- In general, private certifications increased the awareness about sustainability issues, although the changes in the value chain are still not very effective (Glasbergen, 2018); - Certification schemes also appear to have a positive impact on Southern governments, which have sought to align their policies with sustainability objectives, in addition to having been starting to implement their own public sustainability standards and certifications (Glasbergen, 2018); - Global Coffee Platform (GCP) together with the Sustainable Trade Initiative has created the concept of Coffee Sustainability Curriculum that allows public services to appeal to sustainability but giving farmers the freedom to choose whether to certify and verify and if they do it, also to choose which VSS they prefer (Brando, 2019).	- Several sustainability issues (e.g., climate change and deforestation) are still receiving little attention from most companies (Bager & Lambin, 2020; Elliott, 2018); - The impacts of certification schemes on production yields and quality levels appear to vary between different regions: while in Latin America higher prices are not always reflected in higher revenues (due to lower production yields), in Africa, certification schemes make it possible to obtain products with higher quality and more significant yields for farmers (Chiputwa & Qaim, 2016). Likewise, the impacts of certifications in livelihood conditions, for example, also seem to vary depending on different factors, such as regional context and type of VSS (Chiputwa et al., 2015); - Jena et al. (2012) showed that poor organizational structure impairs the delivery of certification benefits to farmers (Jena et al., 2012); - Elliott (2018) defended that "agroecological and labor standards will only be implemented and maintained if they improve productivity, or if there is a price premium large enough to cover the costs" (Elliott, 2018); - The poorest and most marginalized smallholders are hardly able to obtain certification without external support (Elliott, 2018); - Dietz et al. (2018) developed a coding system to evaluate the strength of different VSS across the environmental, social, and economic sustainability, as well as at compliance enforcement, and they found that about 60% of certified coffee is certified by the less strict VSSs, which corresponded to the industry-related and corporate VSSs (mainly 4C, but also Starbucks' C.A.F.E. Practices and Nespresso's AAA Sustainable Quality program). They explain the low scores for these corporate VSSs were due to the low regulatory requirements needed to be included in these programs (e.g., the majority of standards listed in the standards catalogs are not obligatory for certification). Overall, the authors defended that the rapid proliferation of VSS that has been taking place in the coffee chain seems not to be reflected in a more sustainable chain, as stricter VSSs (e.g., Fairtrade, Rainforest Alliance, and UTZ) are not proliferating as fast as industry-led VSSs (Dietz et al., 2018).

(Bray & Neilson, 2017). Thus, conducting investigations that evaluate and compare the different certifications and the effect they have on local society is not easy because there are no control groups and there are also many variables that researchers cannot control.

In this way, several efforts have been made to attain and develop a consistent methodology able to compare results of different certifications under different contexts that, therefore, can provide the real impact of such certifications. One of the most renowned initiatives that are currently ongoing is the Committee on Sustainability Assessment (COSA), which is a nonprofit global consortium created by several institutions that have joined together and aim to develop a consistent and scientifically rigorous methodology to better address the impact of sustainability programs/certifications on social, economic, and environmental issues (Loconto et al., 2014). Furthermore, the International Social and Environmental Accreditation and Labelling (ISEAL) is a global association that works with sustainability standard systems, including those operating in the coffee sector (e.g., Rainforest Alliance and Fairtrade), to help them understand the impact of their standards, manage a series of "Codes of Good Practice," and facilitate information exchange between them and other member organizations (Loconto et al., 2014; Potts et al., 2014). For impact assessment, the ISEAL created the "ISEAL Impacts Code" that provides to these standard systems general requirements for the development and implementation of monitoring and evaluation programs for each one. Hereby, it allows these certification systems to monitor and refine their theory of change by which they expect to achieve the desired impact (thus increasing their strength, effectiveness, and rigor), facilitates future external evaluations of standards activities, and creates data that can be used to measure and compare the impact of each one, promoting greater transparency of these systems (Loconto et al., 2014; Potts et al., 2014). In addition, Food and Agriculture Organization (FAO) has also been concerned in following and collaborating with these and other related initiatives and has also its proper impact assessment tool—the Sustainability Assessment of Food and Agriculture Systems (SAFA)—which, according to the proper organization, is "compatible and complementary to most existing initiatives" (FAO, 2021; Loconto et al., 2014). Some of the studies presented in Table 1 (e.g., Dietz et al., 2019; Haggar et al., 2017; Ssebunya et al., 2019) have already applied these and other methodologies/guidelines to assess the impact of certification schemes, but the great majority used their own methodologies. Thus, it may still take a few years until we can truly understand the real impact of certifications schemes.

In addition, also questionable may be the need for so many certifications that intersect with ideals and that often support the three dimensions of sustainability, as well as the need for each certification to have its own standards. It is understandable that depending on the certifications, the requirements may be more or less stringent for the implementation of these standards on farms, but some authors wondered if the economic interests behind certifications schemes do not overlap the environmental and social interests and if it would not be simpler to adopt a common standard, merging the different certifications to fight together for a common good (Bennett, 2017; Giovannucci & Ponte, 2005; Glasbergen, 2018). Nonetheless, other authors have explained that these certification schemes, which are designed and led in the Northern economies, have coevolved and coexist because (i) they have been initiated in certain consuming countries by certain stakeholders (e.g., Fairtrade initiated in the Netherlands by social movement activists and small alternative trade organizations, while 4C was founded in Germany by German development agency [GTZ] and multinational companies); (ii) they occupy different market segments (e.g., in the United Kingdom, consumers prefer Colombian coffee and Fairtrade certification, while in the Netherlands the Brazilian coffee and the UTZ certification [now merged with Rainforest Alliance] have a high demand); (iii) the adoption of these standards significantly varies between producing countries (e.g., countries where coffee producers are mostly smallholders organized in cooperatives, such as Mexico, tend to adopt Fairtrade, while countries with large estates, such as Brazil, tend to adopt UTZ); and (iv) the institutional and business intermediaries in producing countries have an important role as standards transmitters (Manning et al., 2012). In line with this, Reinecke et al. (2012) found that this ongoing coexistence of multiple standards has occurred due to the *convergence* of the "rules of the game" and the *differentiation* of specialized attributes that support the identity of each one. In addition, they defend that this "meta-standardization" allows the provision of different regulatory solutions and the transformation of business practices (Reinecke et al., 2012). Even though, it would probably be more advantageous if these organizations joined forces and worked together for a common good since many smallholders are more and more pressured by their "need" to adhere to more than one certification scheme (sometimes multiple certifications) in order to meet the requirements of their different buyers (Manning et al., 2012).

Furthermore, information on the impact of corporate and industry-led certifications is relatively scarce in the literature (Bager & Lambin, 2020), and the few existing studies reveal that the results of these programs are not as good as those promoted by NGOs (Dietz et al., 2018; Haggar et al., 2017). As mentioned in Table 1, industry-led certifications are less stringent than NGO-led ones on all sustainability issues but, currently, represent the largest share of certification schemes in the coffee sector (Dietz et al., 2018). Thus, it may be questionable whether certifications are effectively helping to make the coffee chain more sustainable, as the highest percentage of certifications (industry-led certifications) have a limited third-party verification and are not rigorous enough and some of them are not transparent about the results achieved with the implementation of their standards. In fact, it is already reported that the sustainability efforts of some companies are adopted only for a segment of the value chain, as the more vulnerable segments (the production sector, with all social, economic, and environmental sustainability problems) are not considered and remain at risk (Bager & Lambin, 2020; Samper & Quiñones-Ruiz, 2017). For this reason, many of these companies are being subject to accusations of greenwashing (Bager & Lambin, 2020) since they claim to be sustainable (for market differentiation purposes) but do not effectively implement sustainability measures. Moreover, as industry-led certifications are not endorsed by ISEAL, and as the results of the audits made in some of them (when allowed and adopted) remain private information (as mentioned in Table 1), the transparency of all sustainability standard systems and, consequently, the trust in those who effectively strive and comply with sustainability policies are compromised. In this regard, it is essential to develop and implement legislations that may control the sustainability efforts made by companies and that compel them to comply with sustainability issues and, indeed, in some European countries (e.g., France, United Kingdom, Netherlands, Germany), debates have been generated and laws have emerged to precisely control and ensure that the private sector/companies comply with sustainability issues and, thus, with the protection of human rights and the environment. For example, the Germany's Supply Chain Due Diligence Act (*Lieferkettensorgfaltspflichtengesetz,* LkSG) is a new German legislation that aims to protect and strengthen the rights of people along the entire global supply chains of companies. This Act will come into force in 2023 for any company that has at least one branch in Germany (regardless of whether it is German or not) and that has more than 3000 employees or, from January 2024, for companies that have at least 1000 employees (Leifker & Porschke, 2021; The Federal Government - G7 Germany, 2021). Companies will have to comply with certain human rights and environmental due diligence obligations, which include setting up a risk management system and determining responsible people within the company for supervising it, taking measures to prevent and remedy abuses, and documenting the company's compliance with due diligence obligations and disclosing such compliance in annual reports (that must be published on the company's website and remain available for download free of charge for 7 years). Nonetheless, those obligations can be higher or lower depending on if the operations are related to the own company, a direct supplier (highest standard of obligations), or an indirect supplier (lower standard of obligations). As a consequence, in the case of indirect suppliers (who are the ones who suffer the majority of human rights abuses and environmental damages), the Act only requires that companies develop and implement a plan for stopping or minimizing abuses when they have reason to believe that human rights or environmental damages have occurred, but not obliges to assure that the plan will be successful. Therefore, unless companies are proactive in including indirect suppliers (such as coffee producers or other suppliers operating in risk sectors) in their risk management actions, the problems of coffee producers (particularly in the coffee value chain) may not be solved with this legislation. In this way, although the LkSG possesses several positive aspects that might improve the sustainability status of supply chains (e.g., giving to companies the precise description of the due diligence steps that they should follow), it also possesses several weaknesses, which include not only the limited due diligence obligations regarding indirect suppliers but also the fact that the Act is only applied to large companies and lacks any provision of civil liability. For these reasons, this legislation should not be reproduced and used, for example, as a blueprint for European Union (EU) legislation. Instead, considering that other EU member states also possess their due diligence laws (e.g., the French *Loi de vigilance* in France and the Dutch Child Labour Due Diligence Act in the Netherlands), which, like the LkSG law, have advantages and shortcomings, the EU Commission should take advantage of the strengths of each one to develop an EU legislation that can be used by all member states in order to ensure that all companies comply with strict laws that make it possible to control and guarantee the sustainability of value chains, including the coffee value chain (Leifker & Porschke, 2021).

Finally, it is important to note that besides the VSS herein addressed (which are fundamentally certifications developed and regulated by the Northern countries), it is also necessary to focus on the standards from the South, as they are more and more emergent but still poorly addressed in the literature. According to Schouten and Bitzer (2015), these Southern standards have risen as a way for certain groups of stakeholders from producing countries (who feel underprivileged by the results of the Northern standards) to present their own visions of sustainability and reclaim the areas occupied by the Northern ones, as well as "to create cognitive and moral distance to Northern standards" (Schouten & Bitzer, 2015). Indeed, they are focused on national producers (the stakeholders that generally felt less beneficiated by the VSS) as their main audience, act at a national scale, support cognitive legitimation rather than self-interest and moral legitimacy, and use national laws and legislations to attain that legitimacy, and that is why they are increasingly trendy. Nonetheless, the effectiveness of these standards is still poorly known and needs to be better studied, as they are very recent, their implementation and enforcement can be difficult in states that have weak administrative structures, and their adoption and recognition may not be a viable business model in the international trade (Schouten & Bitzer, 2015). Some of the most known examples of Southern standards are the Indonesian Sustainable Palm Oil (ISPO), the Malaysian Sustainable Palm Oil (MSPO), the Soja Plus (from Brazil), and the Sustainability Initiative of South Africa (SIZE), but there are also some Southern standards in the coffee sector, such as the Indonesian standards for coffee production (IScoffee) and the Brazil's Certifica Minas Café standard (Hospes, 2014; Schouten & Bitzer, 2015). In addition, the "Símbolo de Pequeños Productores" (SPP) is another example in the coffee sector where small producers from Chiapas (Mexico) have joined together to create a symbol (SPP) as a way of vindicating their position in the market and facing other certification programs established in that region (Fairtrade) that were considered very bureaucratic and undemocratic (as the participation of small producers in the internal and external supervision processes were not equilibrated) (Tepox-Vivar & González-Cabañas, 2021). Currently, this symbol groups 120 organizations of small producers from 30 countries and is already present in 50 consumer countries, which denotes its expansion and relevance in the market. Nonetheless, the certification process of SPP is carried out by an independent certification system and, despite the certifiers are authorized by SPP Global (allowing the small producers to have more control in production, commercialization, and certification processes), the dependence on an external certifier can end up bringing the same disadvantages as other certifications. In addition, the lack of financial support and experience to position the label in the global market may hinder the feasibility, consolidation, and continuity of this initiative (Tepox-Vivar & González-Cabañas, 2021). In fact, Tepox-Vivar and González-Cabañas (2021) found that the new generations of smallholders from Chiapas' organizations already consider SPP as part of the multi-certification business strategy, just like the other certifications (Fairtrade and Organic certifications), thus evidencing some known limits of this Southern strategy.

Besides VSS and certification schemes, and in order to overcome their problems, in the last years, direct trade and relationship coffee concepts, as well as GI, have also emerged in the specialty coffee niche.

The direct trade and relationship coffee concepts are increasingly trending in the global specialty coffee sector and aim for a direct and informal connection between producer and roaster—without other players—based on personal interaction, mutual trust, and price transparency to attain high-quality coffees and to improve the lives of coffee farmers and their communities, thus promoting economic, social, and environmental sustainability (Edelmann et al., 2019; Guimarães et al., 2020; Vicol et al., 2018). These concepts have been promoted by small- and medium-sized specialty roasters that divulge and market their relationships with producer communities on their websites and social media, by exposing stories and photos of farmer interaction and presenting sustainability/transparency reports. Nonetheless, these interventions do not have any third-party audits and the claims and information provided by roasters are mainly unverifiable (Edelmann et al., 2022; Vicol et al., 2018). In addition, the studies assessing the impact of these models on farmers and their communities' livelihoods are relatively scarce in the literature, and the results are variable. Some studies have shown that, although these concepts may improve sustainability outcomes and provide opportunities for producers to upgrade (by enabling the transfer of ideas, knowledge, and capital), the farm-gate price achieved by farmers is not improved and the local elites within producer communities (who are able to accumulate wealth and consolidate their social position) are the ones who take the benefits, thus not contributing to equality within communities or to poverty reduction (Hernandez-Aguilera et al., 2018; Vicol et al., 2018). Furthermore, the roasters and development agencies do not pay due attention to livelihood contexts (namely, social and political ones), not adopting their upgrading interventions to those rural contexts, but have instead managed these interventions in the same way as in industrial contexts, which results, consequently, in the break of the relationships and, again, in inequality (Vicol et al., 2018). On the other hand, Edelmann et al. (2022) found that all actors can benefit from relationship coffee models if organizational, institutional, cognitive, social, and temporary geographical proximity are established. More concretely, by analyzing and comparing three case studies of relationship coffee models, the authors found that temporary geographical proximity, particularly the initial face-to-face contacts, generates social and cognitive proximity—as mutual trust, recognition, and shared knowledge about coffee quality is developed during personal visits and frequent communication—and further organizational and institutional proximity—as coordination through on- and offline networks are enabled and the sharing of norms and values about coffee production and quality can be strengthened, which consequently leads to more recognition, pride, self-esteem, and personal development for farmers. As a consequence, a higher coffee quality can be achieved and, subsequently, higher farm-gate prices. Nonetheless, although several benefits through this higher relational proximity have been described, the authors also highlighted several challenges that still need to be overcome. For example, to produce high-quality coffee knowledge, skills, and more effort are required, but sometimes it is difficult to achieve that even with these relationships because there are some factors that farmers cannot manage, such as climate conditions, required infrastructures that they cannot purchase, and exigent harvesting and postharvesting processes that they cannot assess by themselves (having to rely on external expertise). In addition, the required coordination and communication between farmers and buyers can be difficult to build as their knowledge bases, social capital, and language may diverge, thus being necessary to trust brokers to build these relationships (Edelmann et al., 2022). Indeed, as will be further explained, one possible solution to the limitations found in these relationships might be the presence and participation of social brokers (Quiñones-Ruiz, 2021; Reinecke et al., 2018). Finally, besides actors are more dependent on each other (as both producers and roasters adapt their work to the features and needs of each other), the producers, once again, depend on roasters and buyers to benefit from the higher coffee quality and higher prices (Edelmann et al., 2022; Vicol et al., 2018). Thus, it is necessary to develop a critical political economy of upgrading in rural development that enables the adoption of these initiatives adapted to each local context and to give more empowerment to farmers so that they can be more independent and transform power structures (Edelmann et al., 2022; Vicol et al., 2018).

In fact, as mentioned in Section 3, all producers (conventional, certified, or those who establish relationship coffee models or other strategies) are receiving only for the material quality of their coffees (Daviron & Ponte, 2005). Nevertheless, a strategy that could (and should) be implemented is related to their need to directly access final consumer markets and receive profits from their symbolic and in-person service quality attributes (that they need to develop and implement). It is known that the principal concern of roasters is to increase their profits and be competitive, so the profits of producers will always be dependent on the benevolence and gains of these powerful actors (Daviron & Ponte, 2005; Edelmann et al., 2022). However, producers must stop being seen as the dependent poor actors and must start taking their position in the market to be more competitive and have their own profits, power, and independence. For that, it is essential to make producers and cooperatives aware of the different quality attributes, the types of consumers (who are increasingly looking for specialty and high-quality coffees), the right prices they can earn for the right quality attributes, and the attributes of coffees from other origins so that they can provide individualized offerings to consumers. One symbolic attribute where producers may invest is related to the creation of GI, where they may sell a place, a story, ideas, and even a sense of exoticism (Daviron & Ponte, 2005). In addition, despite the geographical distance between producers and consumers, some in-person services quality attributes can also be developed and implemented, such as the establishment of café chains controlled by producer organizations, agrotourism networks, safari-and-coffee farm tours, and digital marketplaces for producer–consumer interaction (Daviron & Ponte, 2005; Edelmann et al., 2022). Furthermore, as defended by Edelmann et al. (2022), the introduction of brand names for farms or cooperatives (e.g., cooperative X coffee roasted by roaster XX) in consuming countries may create social and institutional proximity between coffee producers and consumers and, hence, increase the producers' profits for the symbolic quality of their coffees (and even for in-person services if they open coffee shops in consuming countries) (Edelmann et al., 2022).

Focusing on GI—defined by The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) as "indications that identify a good as originating in the territory of a Member, or a region or locality in that territory, where a given quality, reputation or other characteristics of the good is essentially attributable to its geographical origin" (Teuber, 2010)—they have also been considered an important tool increasingly applied by producers from developing countries, who join efforts and work collectively to access value-added markets. In fact, the collective action of producers in these initiatives is considered crucial for them to defend their intellectual property rights, define their specific rules for the use of the origin label and their own quality standards and social boundaries, and, hence, construct their symbolic quality, avoiding the appropriation of geographical names by large companies that are not linked to these areas and that eventually may damage the reputation of the quality of their coffees (Quiñones-Ruiz et al., 2015; Samper & Quiñones-Ruiz, 2017). Nonetheless, not only producers but also the government, donor agencies, private companies, and other value chain actors (e.g., international buyers) may organize themselves (in collective action) and apply for GI (Quiñones-Ruiz et al., 2020). Quiñones-Ruiz et al. (2020) analyzed four cases of Protected Geographical Indications (PGI) from Colombia, Thailand (two cases), and Indonesia, and, in each case, the actors involved in the application and, more particularly, their role in the GI registration process varied according to the regulatory framework of the studied countries. For example, while in the Colombian case the GI registration resulted from a producer-led effort (under the Federation in Colombia), in the Indonesian case the process was initiated by regional government organizations and international donor agencies, which organized themselves in a public–private organizational form (then transformed into a Foundation), and in the Thai cases, one was led by a private for-profit company and the other by a social foundation. As demonstrated by the authors, the different cases presented different pros and cons: as cons, for example, while in the Colombian case, the producers needed to convince the other value chain actors (e.g., international roasters and brand owners) to become users of the GI, in the Thai company-driven GI case, the multiple producers and processers existing in that geographical area, who produced similar quality coffee according to the Product Specification of the GI mark, were not allowed to use it, and, in the Indonesian case, there was low participation of producers and processors in the GI governance (even though they were organized in a consortium to also participate in that) and the Foundation that managed the GI was always strictly linked to local government elites; as pros, for example, in the two Thai cases, the material, symbolic, and in-service quality attributes of their coffees were promoted and sold in the country, generating value added in the own country, while in the case of Colombian and Indonesian GIs, the coffee was mainly exported. In all cases, as defended in the study, the process of institutionalizing required powerful and reasonably well-resourced actors to assume a leadership role and hence, a relatively little participation from actual producers themselves (Quiñones-Ruiz et al., 2020). Therefore, these initiatives may present the same challenges and limitations than others (namely VSS) because the lead actors (who are not always the producers, but instead other local or outside production region participators) are the ones who decide who can be involved and who design the user rules. As a consequence, the effectiveness and distribution of benefits can be directed toward their particular interests. In addition, when international roasters and brand owners are not involved in these initiatives, they may not be disposed to pay more for this seal, nor be concerned and willing to communicate to consumers the origin and quality behind the coffee they are selling (as according to the EU legislation for GI, it is not mandatory to include the GI symbol on the package of third-country GI products) (Quiñones-Ruiz et al., 2015, 2020).

In general, one of the major limitations common to all these mentioned initiatives is, once again, the lack of two-way transparency existing between producers and consumers, that is, the producers have no information about consumers and their demands and preferences (namely, the quality attributes that they seek and appreciate) and consumers have little or even no information about the material properties of the coffee they are drinking. This happens because roasters have dominated the coffee chain due to their strategic choices over the last years and due to the regulatory framework currently ongoing, which allows them to manage the existing asymmetry of information on quality (between producers and consumers) in their favor. As already mentioned, roasters buy coffee with complete material quality information but when they blended and roasted it, it is sold to consumers under a brand name, selling symbolic and even in-service quality attributes but not material ones. In fact, although the appearance of specialty markets has tried to change these quality conventions by empowering producers and pressing specialty roasters to provide more information to consumers, thus attempting to differentiate these products from the mainstream ones, the "rules of the game," the governance structure that result from them, and the economic power of roasters and brand owners support the prevalence and dominance of these powerful actors even in these specialty markets (Daviron & Ponte, 2005). Therefore, it is necessary to develop new regulatory tools that effectively promote transparency in product information and labeling (namely, the blend composition, the countries of origin, the proportions of arabica and robusta present in the blend, and the price that is paid to producers) (Daviron & Ponte, 2005). As an example, the fact that it is not mandatory to include the GI symbol on the package of third-country GI products according to the EU legislation for GI (as mentioned above) demonstrates how the regulatory framework still needs to improve.

Moreover, it is also fundamental to effectively enhance a more transparent and inclusive dialogue between all chain actors in order to reduce their diverging grasps of quality (Quiñones-Ruiz, 2020). In this regard, the notion of social brokerage has been highlighted by the scientific community as a conceptual framework that might facilitate, coordinate, and influence social relations across the value chain (Quiñones-Ruiz, 2021). In this way, social brokers can be seen as intermediary actors "who carry out the role of creating, managing or influencing linkage points in global supply networks, and who have the capacity to alter social relations" (Reinecke et al., 2018), and, hence, as "connecting, knowledgeable, observant, and trustful actors" (Quiñones-Ruiz, 2021) that "facilitate transactions between other actors lacking access or trust in one another" (Reinecke et al., 2018). These brokers may be, for example, supply chain managers, factory managers, national governments, labor rights NGOs, multistakeholder organizations, meta-organizations (e.g., ISEAL), civil society actors, or even researchers and scientists (Quiñones-Ruiz, 2021; Reinecke et al., 2018). In addition, they may mediate their social relations by playing roles as governance actors, connectors, translators, and/or boundary workers (see Reinecke et al., 2018). In fact, as an example, Quiñones-Ruiz (researcher and scientist), in her study, acted as a social broker as she was involved in encounters between Colombian coffee producers and Austrian buyers, which promoted and enhanced the social ties between these two types of actors (Quiñones-Ruiz, 2021). As mentioned by the author, her involvement in social brokerage included structural holes (since she was a connector since the beginning, in Vienna, and continued during all the process in the producing regions and, after, virtually with both producers and buyers), cultural brokerage (as a translator in both countries), and boundary work (as she knew the idiosyncrasies that separated and united both actors). This involvement allowed downstream actors (European roasters and buyers) to know producers and their coffees, to understand the specific farming conditions that lead to certain material qualities (some of them needed to improve their roasting and blending processes through the acquired knowledge), and to verbalize their wishes and their needs to communicate the efforts made by producers to end consumers. In addition, it allowed upstream participants (Colombian producers) to express their discomforts and feelings, obtain feedback from roasters after cupping, understand what roasters look for, and know the work made by roasters and retailers. In general, this research-based relational pathway allowed the sharing of knowledge and the discussion of different specific and essential topics for both actors and, consequently, the construction of social ties and trust between the actors, which, in addition to allowing social proximity and empathy, enhances business relationships (and eventual partnerships), which over time can be rethought or ended according to their experiences. In addition, it is important to note that the role of the author as a researcher and scientist (particularly a non-European one) also had a significant impact on this social brokerage, once, as a researcher, she actively observed and reflected on how the encounters developed and, as a scientist, she was seen by the participant actors as a trustful person that had a neutral role in all process. Thus, as defended by the author, researchers and scientists may also act as social brokers since they have not only academic knowledge, but also communication skills, empathy, and constant reflective loops that legitimate their position as neutral social brokers (Quiñones-Ruiz, 2021).

Overall, although we can be on a good path to achieve social, economic, and environmental sustainability, all sustainability initiatives addressed throughout this section must be better studied, controlled, and implemented, as they still seem to be unable to solve the sustainability problems existent in the coffee production sector and possess many flaws, particularly regulatory and governmental ones.

4.2 | Sustainability strategies related to processing

Regarding the coffee processing sector, which involves all processes from postharvesting to arrival at the consumer, the major concerns are focused on the environment, and, in this sense, some strategies have been implemented fundamentally by governments, companies, and the scientific community.

As mentioned, one of the major environmental concerns related to coffee processing is the huge amount of wastewater generated in the wet processing method, which contributes to a considerable water footprint and ecosystems destruction. One of the solutions to minimize this excessive water expenditure has been the use of the semi-dry (also called semi-washed or semi-wet) and mechanical methods (Alves et al., 2017). Moreover, some of the certifications/programs previously described (e.g., Organic, Rainforest Alliance, C.A.F.E. Practices) have been working toward the maintenance of water resources and wastewater management, and the impact has been positive (Haggar et al., 2017; Panhuysen & Pierrot, 2020). A review published by Rattan et al. (2015) highlights some methods that can be used for the treatment of coffee wastewater. The authors concluded that the combination of biological (e.g., anaerobic methods) and chemical methods (e.g., advanced oxidation process schemes, the $UV/H_2O_2/O_3$ process) can be very effective in reducing the high organic load, turbidity, and the color of the water (Rattan et al., 2015).

Concerning the pollution issues in general, several governments worldwide (particularly those who are part of the Organization for Economic Cooperation and Development and the EU) have applied a legal principle to reduce the environmental damages caused by companies: the polluter-pays principle (PPP). It requires that the polluting entities are held responsible for mitigating the damage caused by them, that is, the entity that profits from pollution must be responsible for paying the constraints caused to others suffering from their pollution (Ambec & Ehlers, 2016). Overall, when applying this principle to the coffee sector, it is expected that industries become more motivated to comply with the reduction of greenhouse gas emissions and waste/byproduct management, thus ensuring the protection of health and the environment.

4.2.1 | Valorization of coffee byproducts

Although sustainability and circular economy have been mainly addressed as two separate and independent areas of knowledge, there are several environmental, economic, and social benefits arising from the synergy between them (Pieroni et al., 2019). However, their implementation is still in the early stages of development and still few countries have adopted actions to apply its concepts (Ghisellini et al., 2016). A recently published study highlights examples of circular economy applications, but there are not many studies that focus on applying these concepts to a production chain as complex as coffee (Van Keulen & Kirchherr, 2021). An example of these scarce studies is the one conducted by Topi and Bilinska (2017), which aimed to apply circular economy scenarios in the coffee value chain and closed the cycle by using spent coffee grounds to produce high-quality compounds in a large case-study catchment area. They evaluated the cost and benefit of four different scenarios (defined based on the type of equipment, land, and/or process) and concluded that they all had environmental benefits by reducing the amount of organic material that goes to landfills, permanent land use, and gas emissions. One of the scenarios also brought social benefits—which make it better compared to others—once it involved additional jobs. Although this study has some limitations, it showed that it is possible to implement circular economy principles in the coffee chain (Topi & Bilinska, 2017).

As demonstrated for spent coffee grounds, the other byproducts generated throughout the chain (Table 2) can also be valued and used to improve environmental, social, and economic sustainability, as well as to apply circular economy principles. Examples of waste uses are presented in a simplified and condensed way in Table 3. However, some of these processes entail costs for companies, being important to assess the feasibility and applicability on a larger scale, and that is why many of these proposals for byproducts use have not yet been implemented in practice (Oliveira & Franca, 2015). In addition, it is important to point out that the potential use of a byproduct depends on its chemical composition and the concentration that the bioactive compound(s) is expected to have in the biotechnological application (Janissen & Huynh, 2018). For instance, the high organic load that these byproducts possess makes them considerably polluting due to the high amount of oxygen needed for their degradation. Thus, although one of their current applications is as fertilizers (Table 3), they should not be applied indiscriminately into the soil without prior treatment (Jiménez-Zamora et al., 2015). One successful example of their application in the agriculture sector as fertilizer will be presented in the Section 4.3: the project "Recycling is Food" from Nespresso®. Besides, some coffee byproducts—namely, coffee husks and pulp—are also already used in mushroom production, and several studies are investigating the potential for other byproducts to be used as well, including combinations of different byproducts to maximize the yields and quality of mushrooms (Da Silva et al., 2012; Del Castillo et al., 2019; Hikichi et al., 2017).

Another current application of coffee byproducts in the agriculture sector is as animal feed. Nonetheless, as happens with fertilizers, these byproducts cannot be directly used for animal feed due to the presence of some antinutritional factors (e.g., tannins and caffeine) associated with the reduction of feed intake, weight gain, and impaired feed conversion of cattle, swine, and poultry (Clifford & Ramirez-Martinez, 1991; Pandey et al., 2000). Because of that, their ingestion must be controlled up to safe amounts. As an example, coffee husks and coffee pulp are feasible to be incorporated in animal feed (Table 3), but their limits vary from 5% to 40% according to the animal intended to be fed (Oliveira & Franca, 2015; Salazar et al., 2008). Furthermore, several studies have also shown the potential of coffee byproducts to be used in other areas (Table 3), such as in the food, pharmaceutic, and cosmetic industries, energy production, incorporation in polymers and materials, production of enzymes, and many others, thus ensuring beneficial economic and environmental effects (Franca & Oliveira, 2019; Iriondo-DeHond et al., 2019).

Regarding applications in the food industry, there are already some available products on the market. A recent review highlights some of these applications. Of all coffee byproducts, coffee husks seem to be those with a higher number of commercialized products: there are some companies all over the world selling coffee husks beverages, while others suggest them as a source of anthocyanins, caffeine, chlorogenic acids, and dietary fiber (Iriondo-DeHond et al., 2020; Oliveira & Franca, 2015). Besides, coffee mucilage is also being used in the production of beverages, particularly functional beverages (Iriondo-DeHond et al., 2020). Natucafé, a Colombian company, created a coffee mucilage concentrate—also denominated coffee honey or Coffee Cherry Extract—which is rich in antioxidants (e.g., chlorogenic acids, caffeic acid, polyphenols, vitamins, etc.) and which, besides being used directly, was further used for the development (also by this company) of functional beverages claimed for strengthening the immune and cardiovascular systems, preventing aging and neurodegenerative diseases, and promoting the health well-being and energy in general (+Vital, 2020; Natucafé, 2016a, 2016b). Nonetheless, as far as we know, these products are not yet available in Europe and, according to Iriondo-DeHond et al. (2020), these are the only food products derived from coffee mucilage available for now. With respect to the other coffee

TABLE 2 Coffee byproducts and their chemical composition

	Husk	Pulp	Mucilage	Parchment	Silverskin	SCG
Protein	8%–11% (d.w.)	10%–12%	8.9% (d.w.)	3.1%	16%–19% (d.w.)	14%–17.5%
Lipids	0.5%–3% (d.w.)	2.5%	–	0.3%	1.6%–3.3% (d.w.)	13%–18% (d.w.)
Minerals	3%–7% (d.w.)	6%–10% (d.w.)	0.7%	0.5%–5.8%	7% (d.w.)	0.1%–1% (d.w.)
Carbohydrates	58%–85% (d.w.)	45%–89% (d.w.)	–	55.75%	44%	45%–89% (d.w.)
Reducing sugars	14% (d.w.)	12.4%	–	–	–	–
Cellulose	23%–35%	10%–33%	–	40%–60%	18% (d.w.)	6.8%–10.4% (d.w.)
Hemicellulose	13%–30%	15%–29%	–	25%–32%	13% (d.w.)	31.7%–41.7% (d.w.)
Lignin	23%–24.5%	26%–31.5%	–	23%–32%	29%	24% (d.w.)
Caffeine	1% (d.w.)	0%–2.5% (d.w.)	–	–	0.8%–1.25% (d.w.)	0.07%–0.5% (d.w.)
Phenolics						
Total	1.2% (d.w.)	1.5% (d.w.)	–	–	10.8–17.3 g GAE/100 g	16–19 g GAE/100 g
Tannins	5% (d.w.)	1%–9% (d.w.)	–	–	0%–0.12% (d.w.)	0%–0.12% (d.w.)
Others	5-Caffeoylquinic acid Quercetin-3-rutinoside Quercetin-3-glucoside Quercetin-3-galactoside Catechin Epicatechin Procyanidin dimers, trimers, and tetramers	5-Caffeoylquinic acid 5-Feruloylquinic acid Dicaffeoylquinic acids Rutin Cyanidin-3-rutinoside Cyanidin-3-glucoside Flavan-3-ols Hydroxycinnamic acids Flavonols Anthocyanidins			Caffeoylquinic acids Dicaffeoylquinic acids Feruloylquinic acids Coumaroylquinic acid Caffeoylquinic acid lactones	Caffeoylquinic acids Dicaffeoylquinic acids Caffeic acid Ferulic acid *p*-Coumaric acid Sinapic acid 4-Hydroxybenzoic acid

Note: Compilation of data presented by Alves et al. (2017), Ballesteros et al. (2014), Bessada et al. (2018), Campos-Vega et al. (2015), Esquivel and Jimenez (2012), Franca and Oliveira (2016), Gemechu (2020), Iriondo-DeHond et al. (2019), Janissen and Huynh (2018), Monente et al. (2015), Murthy and Naidu (2012b), and Pleissner et al. (2016).

Abbreviations: % (d.w.), percentage in dry weight; GAE, gallic acid equivalents; SCG, spent coffee grounds.

TABLE 3 Possible applications and potential effects of different coffee byproducts

By-product	Characteristic/Fraction/Chemical compound	Possible application/potential effects	References
Coffee with imperfections	Beans	Commercialization in Brazilian internal market It has economic return in Brazil.	Franca et al., 2005
	Oil	Production of biodiesel This study was a preliminary evaluation of this viability.	Oliveira et al., 2008
	Oil, caffeine, and chlorogenic acid	Extraction of oil and bioactive compounds This study was a preliminary evaluation of this viability.	Oliveira et al., 2006
Coffee husks	–	Incorporation in animal feed (up to 10%) Currently used strategy	Oliveira & Franca, 2015; Salazar et al., 2008
		Substrate for production of enzymes, organic acids, mushrooms, flavor, and aroma compounds These studies present strategies to optimize the process.	Da Silva et al., 2012; Murthy & Naidu, 2010; Pandey et al., 2000
		Production of briquettes	Suarez et al., 2003
		Production of coffee husk beverages Currently used strategy	Iriondo-DeHond et al., 2020
		Obtention of aqueous extract enriched in phytochemicals to be used as food preservative, food colorant, or in the incorporation of healthy yogurts	Iriondo-DeHond et al., 2020
		Production of biogas Currently used strategy For example, in Uganda, by the gasification of total coffee husks generated per year in the country (46.6 million tonnes), it might be produced 0.7% of their total energy consumed.	Miito & Banadda, 2017
	Minerals (mainly K)	Production of Silage	Couto Filho et al., 2007; Hoseini et al., 2021
	Organic matter and minerals	Production of soil fertilizer For example, the compost used by Dzung et al. (2013) improved soil fertility and increased crop productivity.	Dzung et al., 2013; Hoseini et al., 2021
	Organic matter	Subtract for composting and vermicomposting These studies present strategies to make application more effective.	Degefe et al., 2012; Rezende et al., 2012; Shemekite et al., 2014
		Production of biogas (biomethanation) In this article, they demonstrate that coffee husks treated with Mycotypha can be used for the production of biogas.	Jayachandra et al., 2011
	Carbohydrates	Production of biopesticides This study shows that coffee husks are effective in the production of mosquitocidal toxins.	Poopathi & Abidha, 2011
	Polysaccharides and fermentable sugars	Production of bioethanol For example, Gouvea et al. (2009) demonstrated that coffee husks fermentation by *Saccharomyces cerevisiae* has excellent potential for ethanol production.	Gouvea et al., 2009; Hoseini et al., 2021

(Continues)

TABLE 3 (Continued)

By-product	Characteristic/Fraction/Chemical compound	Possible application/potential effects	References
	Fiber	Incorporation in polyethylene composites The experimental results of this article demonstrate the feasibility of incorporating coffee husks into high-density polyethylene composites.	Huang et al., 2018
	Cellulose, hemicellulose, lignin, and proteins	Production of biosorbents These studies showed the feasibility of using coffee husks as biosorbents for the removal of various heavy metals and dyes from wastewater.	Ede et al., 2014; Franca & Oliveira, 2019; Hoseini et al., 2021
	Cellulose and hemicellulose	Incorporation in environmental-friendly materials This preliminary study demonstrates that it may be possible to apply coffee husks as board or building insulation, in civil construction.	Bekalo & Reinhardt, 2010
	Large amount of volatile matter, small amounts of fixed carbon and ash	As solid biofuel	Oliveira & Franca, 2015; Saenger et al., 2001
	Phytochemicals and antioxidant dietary fiber	Ingredient for human food This study allowed us to evaluate and conclude that the conversion of these coffee subproducts into food ingredients is safe, healthy, sustainable, and low cost.	Iriondo-DeHond et al., 2019
	Anthocyanins (cyanindin-3-rutinoside and cyanidin-3-glucoside), caffeine, polyphenols, and chlorogenic acid	Obtention of bioactive compounds	Murthy & Naidu, 2012b; Oliveira & Franca, 2015; Prata & Oliveira, 2007; Tello et al., 2011
Coffee pulp	–	Incorporation in animal feed (up to 10%) Currently used strategy	Oliveira & Franca, 2015; Salazar et al., 2008
		Subtract for composting and vermicomposting These studies present strategies to optimize the process.	Pandey et al., 2000; Raphael & Velmourougane, 2011
		Production of solid biofuel This review article highlights studies demonstrating the use of coffee pulp as a cost-effective and sustainable source of solid biofuel.	Oliveira & Franca, 2015
		Production of mushrooms It is already used.	Aguilar et al., 2019; Rodríguez Valencia, & Jaramillo López, 2004
		Ingredient in the development of high-fiber salty cookies Moreno et al. (2019) found that cookies enriched with dry coffee pulp had a higher preference and acceptability by consumers than the control cookies. The enriched cookies possessed higher bioaccessibility, as well as higher antioxidant capacity and fiber content.	Moreno et al., 2019
	Organic matter	Production of biogas These studies present strategies to optimize the process.	Calzada et al., 1984; Pandey et al., 2000

(Continues)

TABLE 3 (Continued)

By-product	Characteristic/Fraction/Chemical compound	Possible application/potential effects	References
	Proteins, polyphenols, vitamins, and minerals	Obtention of flour and honey Ramirez Velez and Jaramillo Lopez (2015) patented a method for concentrating and conserving the coffee pulp and the mucilage to obtain an industrially processed honey and/or flour rich in proteins, polyphenols, vitamins, and minerals, which might be further used for several purposes (e.g., human and/or animal consumptions, drugs, and cosmetics).	Ramirez Velez & Jaramillo Lopez, 2015
	Carbohydrates	Production of bioethanol These studies assess viability and provide optimization strategies for bioethanol production.	Gurram et al., 2015; Kefale et al., 2012; Menezes et al., 2014
	Lignocellulosic composition (cellulose and lignin)	Removal of Cr (VI) in wastewater This study aimed to use coffee pulp as bioadsorbent in the removal of Cr (VI) in synthetic wastewater. The authors highlight its low cost and high efficiency.	Aguilar et al., 2019
	Reducing sugars, proteins, and pectin	Substrate for polygalacturonase production The article states that coffee pulp is a good substrate for the production of pectic enzymes (polygalacturonase); this fermentation leads to total caffeine consumption, which can also make this technique effective for the removal of antinutritional factors and allow coffee pulp to be incorporated into animal feed.	Frómeta et al., 2020
	Caffeine and polyphenols	Obtention of bioactive compounds	Esquivel & Jimenez, 2012; Murthy & Naidu, 2012b
	Antioxidants and phenolic compounds	Production of Cascara beverage This study aimed to use dehydrated coffee pulp for the production of a beverage marketed in Switzerland (Cascara) rich in bioactive compounds such as caffeine and polyphenols.	Heeger et al., 2017
	Anthocyanins	Production of natural colorant Preliminary study of anthocyanins extraction and characterization that suggests future application as colorants	Murthy et al., 2012
	Tannic acid	Potential raw material to produce gallic acid The study aimed to optimize the production of gallic acid, through tannins existing in coffee pulp by *Penicillium verrucosum*.	Bhoite et al., 2013
Mucilage	–	Functional beverage rich in antioxidants It is already used.	+Vital, 2020; Iriondo-DeHond et al., 2020; Natucafé, 2016a, 2016b
		Incorporation in foods as an unrefined source of pectin, antioxidants, and flavonoids Proposed by ICO	Rathinavelu & Graziosi, 2005
	Carbohydrates	Production of biogas (H_2)	Hernández et al., 2014

(Continues)

TABLE 3 (Continued)

By-product	Characteristic/Fraction/Chemical compound	Possible application/potential effects	References
	Pectin	Production of biodegradable electrosprayed pectin films	Valdespino-León et al., 2021
	Proteins, polyphenols, vitamins, and minerals	Obtention of flour and honey Ramirez Velez and Jaramillo Lopez (2015) patented a method for concentrating and conserving the coffee pulp and the mucilage to obtain an industrially processed honey and/or flour rich in proteins, polyphenols, vitamins, and minerals, which might be further used for several purposes (e.g., human and/or animal consumptions, drugs, and cosmetics).	Ramirez Velez & Jaramillo Lopez, 2015
	Fermentable sugars and polysaccharides	Production of bioethanol To the best of our knowledge, it has no industrial application yet, but Orrigo et al. (2018) successfully scaled up bioethanol production from sugars fermentation using 5-L bioreactors.	Orrigo et al., 2018; Woldesenbet et al., 2016; Yadira et al.
Parchment	–	Production of a hydrogen rich fuel gas	Domínguez et al., 2007
		Production of fillers of polyurethane composites	Funabashi et al., 2003
	Fiber	Application in thermoplastic composites	Wang et al., 2019
	Cellulose and hemicellulose	Production of particleboard	Bekalo & Reinhardt, 2010
	Lignocellulosic material	Precursor in the production of activated carbons	Nabais et al., 2008
	Antioxidant dietary fiber	Ingredient for human food This study allowed us to evaluate and conclude that the conversion of these coffee byproducts into food ingredients is safe, healthy, sustainable, and low cost.	Iriondo-DeHond et al., 2019
Silverskin	–	Used as firelighters It is already used.	Costa et al., 2014
		Soil fertilization and composting It is already used.	Costa et al., 2014
	Dietary fiber	Bread-making	Pourfarzad et al., 2013
		Prebiotic capacity	Borrelli et al., 2004; Jiménez-Zamora et al., 2015
	Dietary fiber and phytochemicals	Ingredient for human food	Iriondo-DeHond et al., 2019
		Incorporation in flakes, biscuits, bread, and snacks	Ateş & Elmacı, 2018; Garcia-Serna et al., 2014; Mussatto et al., 2011
		Incorporation in cookies (until 5%)	Garcia-Serna et al., 2014; Gocmen et al., 2019
	Cellulose, hemicellulose, lignin, starch, pectin, and proteins	Substrate for fungus growth	Machado et al., 2012

(Continues)

TABLE 3 (Continued)

By-product	Characteristic/Fraction/Chemical compound	Possible application/potential effects	References
	Antioxidant compounds (chlorogenic acids, caffeine, etc.)	Anti-inflammatory effect	Shin et al., 2015
		Antiaging effects	Furusawa et al., 2011; Iriondo-DeHond et al., 2016
		Dermocosmetic ingredient	Jiménez-Zamora et al., 2015; Rodrigues et al., 2015, 2016
		Production of an antioxidant beverage	Martinez-Saez et al., 2014
Spent coffee grounds	–	Used as a leachate absorbent	Ching et al., 2011
		Production of fillers of polyurethane composites	Funabashi et al., 2003
		Used in incorporating a stabilized green material for road construction	Kua et al., 2017
		Ingredients rich in antioxidants and dietary fiber for incorporation in bakery products (e.g., bread, cookies, breakfast cereals, etc.)	Iriondo-DeHond et al., 2020
		Food preservative	Iriondo-DeHond et al., 2020
		Adsorption of contaminants (e.g., heavy metal ions and dyes)	Iriondo-DeHond et al., 2020
	High calorific power (around 5000 kcal/kg)	Production of pellets	Silva et al., 1998
		Used as a fuel for the boiler in coffee industry	Silva et al., 1998
	High amounts of carbon and low adsorption capability	Production of carbonaceous fuel	Vakalis et al., 2019
	Organic compounds	Production of biogas	Luz et al., 2017
	Organic matter	Used as a leachate absorbent	Ching et al., 2011
	High nutritional characteristics	Incorporation in animal feed	Iriondo-DeHond et al., 2020; San Martin et al., 2021
	Compounds with basic and polar property (caffeine and amino acids)	Production of activated carbon for catalysts	Kante et al., 2012; Ngaosuwan et al., 2016
	Good physical, mechanical and thermal properties.	Used in clay brick production	Eliche-Quesada et al., 2011
	Granulated and insoluble material	Manufacture of recycled glass by incorporation of spent coffee grounds into geopolymers	Arulrajah et al., 2017
	Exhibited a remarkable anode performance and excellent capacity retention	Fabrication of a lithium-ion battery	Eliche-Quesada et al., 2011
	Dietary fiber	Source of dietary fiber	Murthy & Naidu, 2012a
	Cellulose, hemicellulose, lignin, starch, pectin, and proteins	Substrate for fungus growth	Machado et al., 2012
	Carbohydrates (mannose and galactose)	Production of bioethanol	Burniol-Figols et al., 2016; Iriondo-DeHond et al., 2020; Kwon et al., 2013; Rocha et al., 2014

(Continues)

TABLE 3 (Continued)

By-product	Characteristic/Fraction/Chemical compound	Possible application/potential effects	References
	Sugars, protein, and aroma compounds	Production for new alcoholic beverages	Lopes et al., 2019; Sampaio et al., 2013
	Oil	Extraction of oil	Al-Hamamre et al., 2012
		Production of biodiesel	Iriondo-DeHond et al., 2020; Kwon et al., 2013; Oliveira et al., 2008; Park et al., 2016; Rocha et al., 2014
		Production of bio-hydrotreated fuel	Phimsen et al., 2017
		Incorporation in skincare products Marto et al. (2016) developed a sunscreen containing 35% of oil extracted from spent coffee grounds that possessed important lipophilic antioxidant compounds protecting against UVB radiation and which was already industrially scalable. It demonstrated to be suitable and promising for topical use since it presented an excellent balance between UV protection, rheological, mechanical, efficacy, safety, and stability assessments, and, overall, the spent coffee oil has improved the sunscreen performance.	Marto et al., 2016
	Nitrogen, phosphorus, and potassium	Used as agricultural fertilizer	Cruz et al., 2014; Gomes et al., 2014
	Caffeine	Topical anti-photoaging agent	Choi et al., 2016
		Ingredient to produce energy drinks	Brazinha et al., 2015
	Antioxidant compounds (chlorogenic acids, caffeine, etc.)	Recovery of bioactive compounds	Panusa et al., 2013
		Source of new beverages	Machado et al., 2018
		Extract powder can be integrated in food as an ingredient or additive	Bravo et al., 2013
		Source of CGAs in functional foods or supplements	Monente et al., 2015
	Melanoidins	Prebiotic, antimicrobial, and antioxidant capacity	Jiménez-Zamora et al., 2015
	Triglycerides	Production of bioplastics	Williamson & Hatzakis, 2019
	Phytosterols	Source of phytosterols	Nzekoue et al., 2020
	Dark color, unique visual and aromatic properties	Used in 3D Printing Architecture It is already used.	Rael & Fratello, 2018

byproducts, to the best of our knowledge, there are still no available food products on the market, but several efforts have been made to incorporate them in foods or beverages, such as biscuits, bread, yogurts, and so forth. Indeed, very recently, the European Commission has authorized the commercialization of the "dried pulp of *Coffea arabica* L. and/or *Coffea canephora* Pierre ex A.Froehner cherries and their infusion" as a food that can be used as an ingredient in infusions (including ready-to-drink beverages) and flavored drinks intended for the general population (Official Journal of the European Union, 2022). In addition, many products containing this and other byproducts are already patented, aiming—due to their chemical composition—the formulation of functional foods to prevent several diseases and to promote the maintenance of health and well-being (Iriondo-DeHond et al., 2020).

The same happens in pharmaceutical and cosmetic fields with several promising studies demonstrating potential applications of coffee byproducts—particularly due to their antioxidant, antiaging, anti-inflammatory, antimicrobial, anticellulite, and prebiotic effects, and protection against UVA/UVB radiation—but very few products are commercially available to date (Bessada et al., 2018; Santos et al., 2021).

Regarding the application of coffee byproducts in environmental-friendly polymeric materials, several studies have demonstrated their potential to produce and be incorporated in polymers and composites, particularly due to their richness in cellulose and hemicellulose (Bekalo & Reinhardt, 2010; Huang et al., 2018; Wang et al., 2019). Moreover, a recent review highlighted the potential of almost all coffee byproducts to be used not only directly, that is, through the incorporation of these byproducts into polymer composites, but also indirectly, through the isolation of interest compounds (e.g., phenolic compounds) that may be introduced into polymer matrices to enhance their resistance against oxidation, bacteria, and fungi (Hejna, 2021). Moreover, these byproducts can also be transformed into other materials (e.g., polyols) that may act as intermediates of polymeric materials such as polyurethanes, polyesters, and epoxy resins (Hejna, 2021). Nonetheless, as much of the other applications herein addressed, these are not yet implemented in industries, and more efforts and studies are still needed.

In what concerns to energy production, several potential strategies have been described in the literature for all byproducts. Just as an example, in a recent review, Mata et al. (2018) presented a biorefinery approach for recycling spent coffee grounds and concluded that most of the potential treatments to this byproduct have limited scope and the final products have low economic value (Mata et al., 2018). In turn, another recent study that assessed the potential of coffee-derived fuels showed that, in comparison with hydrocarbon diesel, coffee biodiesel contributes to an 80.5% reduction in CO_2 emissions during its life cycle. Another advantage is that coffee biodiesel can generate 3.45 MJ of energy, consuming only 1 MJ in its entire life cycle (Kamil et al., 2019).

In general, as can be noted in Table 3, similar uses have been suggested for different byproducts because, in the end, they have similar characteristics, or their chemical composition does not differ too much. In this way, they might be combined, for example, to increase the amount of residue treated. The most important will be to use byproducts rationally and consciously and adapt their use to the purposes for which they are best intended, using clean and sustainable technologies and procedures and ensuring minimal residual wastes in all this process.

In this sense, making the coffee production chain more sustainable also implies extracting and concentrating the bioactive compounds that these byproducts contain by methods that spend less energy, are cheaper, and minimize the use of organic solvents or even replace them with green solvents with nontoxic, nonvolatile, recyclable, and biodegradable characteristics, especially when the conventional methods are dangerous to the environment. For this reason, in recent years, the methods for bioactive compounds extraction have been optimized (Torres-Valenzuela et al., 2020). Recently, Yoo et al. (2018) showed the effectiveness of using deep eutectic solvents that have advantages such as low or no toxicity, nonflammable, nonreactive with water, and simple preparation for the isolation of bioactive compounds existing in spent coffee grounds (Yoo et al., 2018). In another study, Torres-Valenzuela et al. (2019) also showed the efficacy of extracting bioactive compounds from this byproduct using supramolecular solvents (Torres-Valenzuela et al., 2019). Other examples are the supercritical fluid extraction technique (e.g., using supercritical CO_2) (Andrade et al., 2012) or a multifrequency, multimode, modulated ultrasound technology using only water as solvent (Puga et al., 2017).

An important advantage that stands out in the valorization of the coffee byproducts is that the great majority of them can be easily collected from producers and coffee industries, and this can be the key to the various problems on the farms. By taking advantage of marketing their byproducts, coffee growers can create jobs for a longer time and, consequently, allow their workers and families to establish themselves and create decent living conditions (Klingel et al., 2020). Thus, coffee growers can become an integral part of the solution and be active in the change, no longer as waste generators but instead as traders of their byproducts.

An exception to the presented advantage is the spent coffee grounds, as they result from domestic coffee preparation and are usually dispersed among consumers' homes and commercial establishments. Therefore, innovative ways to gather higher amounts of spent coffee grounds should also be highlighted. With this aim, in the city of Athens, in Greece, a preliminary concept called "COFFEE BIN," which is a garbage bin that serves to collect spent coffee grounds, was created. This container arose since there are not always appropriate places for the deposition of spent coffee grounds. The idea was to put these "COFFEE BIN" next to areas of high population density and close to coffee shops. Thus, more quantity could be collected and reused, in this case, to produce carbonaceous fuels or Biochar. This concept to date was only theoretical (it was not yet implemented), although the study served to help instigators to scale the "COFFEE BIN" (Vakalis et al., 2019). Moving from theory to practice, Bio-bean is a company founded in 2013 in the United Kingdom that transforms the spent coffee grounds collected in various parts of the United Kingdom, in a circular economy approach. The final products are coffee logs, coffee pellets, and natural flavors that can be used easily in the food industry, and in the incorporation of beverages. In addition, this company is still focused on creating new value-added products based on bio-oils and bioplastics (bio-bean Limited, 2020).

Overall, the potential and/or already practicable applications of the wide variety of coffee byproducts described in this section demonstrate the impact they may have not only on environmental sustainability but also on economic and social sustainability.

4.3 | Sustainability strategies related to consumption

Nowadays, the coffee industry has different types of consumers (arising from the different coffee waves) that have raised several concerns. In this way, different sustainability strategies have been developed (at an environmental level, but also at social and economic ones) in order to solve the problems resulting from the various forms of consumption and to improve/take advantage of trends arising from the different coffee waves. Hereafter, these different strategies will be presented and discussed.

The increasing consumption of coffee capsules has been a target of concern since their environmental impact is very high (not only due to the high energy expenditure of capsule-based coffee machines but also due to the materials that constitute the packaging) (Brommer et al., 2011). Consumers search for these products for their convenience, quality, easiness, and speed of preparation, as they can drink the beverage in comfortable places, as in their own home, in a clean way, just needing a coffee machine that supports capsules (Gandia et al., 2018). Therefore, it is necessary to rethink strategies that continue to be convenient for the consumer but are more sustainable.

Currently, there are several types of coffee capsules on the market, but the most common are those made of plastic and/or aluminum (Cincotta et al., 2020). The plastic capsules are mainly composed of polypropylene (PP), which is an inexpensive material that withstands high temperatures and maintains coffee quality, but not as much as desired because it is not a very effective barrier against oxygen inlet. To counterbalance this fact, PP capsules often have a top coating of aluminum foil/polyethylene bilayer (Mount, 2009). However, due to the complexity of these materials, recycling is not always carried out, and the capsules are often improperly discarded. It is estimated that in 2050 there will be 12,000 million metric tons of plastics in landfills and natural environments, with coffee capsules being an emerging plastic residue (De Bomfim et al., 2019). Thus, recycling these materials is urgent to minimize their environmental impact.

On the other side, aluminum is considered the best material for maintaining coffee quality as it protects and prevents the entry of light, gases, and moisture (Cincotta et al., 2020). Nevertheless, it is expensive and leads to complex waste at the end of its service life, which requires advanced recycling processes. In this case, the responsibility does not depend only on the companies but mainly on the consumers. In addition, and in line with this idea, Nespresso® has also a campaign called "Recycling is Food" in which it is possible to deliver used coffee capsules at indicated locations. Later, the metal is recycled, and the spent coffee grounds are used to produce a 100% organic agricultural compost that serves to facilitate the growth of rice, which is after donated to the Food Bank, an institution that aims to combat food waste by sending free distribution to deprived people (Banco Alimentar Contra a Fome, 2020; Nespresso Nestlé Portugal, 2020).

Besides plastic and/or aluminum-based capsules, in recent years, a new concept of more environmentally friendly capsules has emerged: the biodegradable and compostable capsules. These capsules are frequently described as "0% plastic, 0% microplastic, and 0% aluminum" because they are made based on plant materials (e.g., sugar cane, cassava, corn, and sugar beet) that by fermentation give rise to bioplastics/biopolymers, such as polylactic acid (PLA), polyesters (e.g., polybutylene succinate, polybutylene adipate terephthalate, and polycaprolactone), and polyhydroxyalkanoates (PHA) (BICAFÉ, 2015; DELTA CAFÉS, 2021; Eunomia & European Commission, 2020; THE GREEN RING, 2021; TORRIÉ, 2021).

The 100% biobased PLA is one the most common biodegradable plastics on the European market, followed by polyesters. However, these bioplastics are only biodegradable in an industrial context (under specific conditions of temperature, oxygen levels, and moisture for the biodegradation by the microorganisms), and not in home composting containers in the time that would be assumed according to the parameters required by the standard EN 13432, the European standard that regulates and proves the compostability of bioplastics in an industrial context. To accomplish this standard, at least 90% of biodegradation must occur within 6 months (Eunomia & European Commission, 2020). There are already several coffee industries selling biodegradable capsules made of these bioplastics that are fully degraded at industry composters in less than 6 months. However, the available industrial composting facilities are still limited and the final destination of these capsules after use causes some confusion in the consumers, which sometimes put them in their home composters (Eunomia & European Commission, 2020).

On the other hand, the 100% biobased PHA are both industrially and home compostable, not presenting, therefore, the limitations of PLA and polyesters. There are some coffee capsules made by 100% biobased PHA, such as the coffee capsules commercialized by the World Wide Fund for Nature (WWF) in the United Kingdom (WWF, 2020), but, in general, these bioplastics are still poorly used commercially due to their high costs (Eunomia & European Commission, 2020). Even so, although the capsules made with these bioplastics are not yet as widespread in the market as aluminum and plastic capsules, and although their packaging technology still needs to be improved, their potential and advantages are much greater than their disadvantages, since their decomposition timeline is much lower when compared to aluminum and plastic (CapsulePack, 2020; Eunomia & European Commission, 2020).

In addition to biodegradable and compostable capsules, there is still another very innovative and promising alternative: the Droops Coffee Maker. This is a machine that uses coffee capsules that are coated with 100% natural materials, which are also dissoluble (made with coffee beans, algae, salt, and water). Depending on its constitution, it may give rise to different types of coffee beverages, which is quite interesting since several products with distinct characteristics can be developed in order to satisfy the different tastes of consumers (Droops Coffee, 2019; Global Coffee Report, 2019). Nonetheless, while this alternative is not available on the market, coffee pods, that is, commercial prepackaged doses in which coffee powder is placed between two thin layers of paper and is sealed hot with low-density polyethylene (which allows to remain it hermetically stable), seem to be the most eco-friendly way of preparing a coffee beverage using a single dose (Restuccia et al., 2015; Tavares & Mourad, 2020).

With regard to the types of containers used to drink coffee, disposable cups are more and more delivered in coffee shops or automatic vending machines for their practicality. However, these cups represent another major concern related to coffee consumption as many of them are not recycled or reusable, also ending up in landfills. Indeed, large amounts of CO_2 are generated with the use of these types of cups, which can be made of plastic or paper. However, the latter are not composed exclusively of paper, as they also have a thin layer of polyethylene that allows its impermeability. Although these cups have a paper layer, they are often not recycled because it is not technically easy due to the difficulty in separating the paper from the polyethylene layer: it would require specialized labor and equipment that does not exist in many countries, in addition to the entailed high logistic costs. Furthermore, when it is possible to return disposable coffee cups, their subsequent use is not usually possible due to contamination with organic compounds and other materials (Poortinga & Whitaker, 2018). To address this problem, Kosior and Mitchell in their recent study highlighted the possibility of creating a new composite containing resins, the paper cup, and agents that interconect all materials, thus forming a molding resin that can be used for various applications (Kosior & Mitchell, 2020). Although these biodegradable cups seem like a good alternative to plastic and regular paper cups, it turns out not to be very viable for two reasons: first, in the majority of the cases, the consumer is not sufficiently sensitized and tends to confuse the place of deposition of biodegradable cups with common cups; second, this can lead to an increase in landfill waste because the consumers can think that it is not harmful to the environment to dispose them into the ordinary garbage (Poortinga & Whitaker, 2018). Therefore, the most sustainable option and what is seen as the alternative to the issues raised are the reusable coffee cups. Some coffee shops offer their own-brand selection and there are also many different types of these products on the market. Although the production of reusable multi-use cups may have a greater environmental impact, it is important to note that this impact will be lower the greater is the use of that same cup.

Changwichan and Gheewala (2020) analyzed the lifecycle of three different types of cups: a single-use cup with a biological basis (polylactic acid), a single-use cup with a plastic basis (polypropylene and therephthalate of polyethylene), and a third multi-use stainless steel alternative. The results suggested that the multi-use stainless steel cups have the best environmental performance compared to the others studied. As these cups can be made of recycled stainless steel, they can have a lower environmental impact, encourage a circular economy, and can be recycled endlessly. The authors also concluded that bio-based cups produced from sugarcane have a lower impact on global warming than petroleum-based plastics, but higher than multi-use stainless steel cups if these are used a considerable number of times to justify their environmental impact (Changwichan & Gheewala, 2020).

Moreover, another study carried out by Poortinga and Whitaker (2018) intended to demonstrate whether easy-to-adopt awareness-raising measures would have an impact on promoting the use of reusable coffee cups. The authors concluded that combining awareness with environmental mentions and providing alternatives (e.g., charging for disposable cups and discounting for those who did not use them [although discounts were not effective]) increased the use of reusable cups, thus demonstrating that these awareness campaings can be important in helping consumers to make greener choices (Poortinga & Whitaker, 2018).

Besides the strategies abovementioned, which are fundamentally environmental driven, the third coffee wave (already discussed and presented in Section 1 and briefly mentioned in Section 4.1) can be seen in itself as an opportunity and a strategy with regard to coffee consumption, as this era has opened up many opportunities not only for consumers, retailers, and cafés, but also for producers, in terms of how coffee is valued and consumed, and can therefore present important social and economic strategies for various actors in the chain. For example, the specialty coffee shops where specialty baristas can sell the material, sensory, and in-service quality attributes of the product is a good strategy that has increased over the years, not only in the Northern countries but also in the Southern (Boaventura et al., 2018; Quiñones-Ruiz, 2021). In addition, as mentioned in Section 4.1 (dealing with strategies related to production), the producers must develop/use their symbolic and in-person service attributes to generate an added value for their coffees and to get closer to consumers by roasting and selling their own coffee beans and by promoting, for example, coffee tours and taste experiences to consumers (Boaventura et al., 2018; Daviron & Ponte, 2005; Edelmann et al., 2022). In fact, this is already happening in the third coffee wave, with specialty and sustainable coffee consumers searching for the specificity of the origin and the whole experience behind the coffee cup. Nonetheless, it is important to note that these consumers (who are third-wave consumers) still represent a niche of the coffee market because, as previously mentioned, the three coffee waves coexist, and the third-wave elements are melted with the others (namely, with the mainstream market from the second wave). Thus, it is still necessary to increase the knowledge of "all" consumers about the coffee they are drinking. As happened in the wine industry, it is necessary to improve the culture of mainstream consumers regarding, for example, the types and origins of coffee, their taste characteristics and roasting profiles, what particular coffees go better with milk, what kind of coffee matches better with a dessert type, and so forth (Daviron & Ponte, 2005; Quiñones-Ruiz, 2020). Moreover, as defended by Daviron and Ponte (2005), "the ICO, international NGOs, aid agencies and producing country governments should build alliances and promote initiatives aimed at cultivating consumers rather than more coffee" (Daviron & Ponte, 2005). Thus, on the one hand, the large companies (e.g., Starbucks and Nespresso) could invest in coffee taste sessions and workshops in their stores, for example, and, on the other hand, producing countries, together with organizations, could join efforts and promote initiatives (e.g., agrotourism) that allow all consumers (and not only the "*coffee aficionados*") to learn basic information about the types and origins of coffee, basic language, and tasting techniques. By this, producers may co-create valuable experiences with intermediary actors and final consumers and, hence, develop cooperation relationships throughout the whole value chain (Boaventura et al., 2018). Furthermore, the internet phenomenon also allows greater contact (albeit virtual) between producers and consumers since, for example, consumers can buy products online or maintain contact with producers (Edelmann et al., 2022). This, together with wide-ranging information campaigns in the media and the opening of producer-controlled coffee shops on their farms and consuming countries, for example, may have a positive impact on producers, once more informed consumers can be able to distinguish the material qualities of coffee, look for particular kinds of coffee, are disposed to pay more for its particularities, and, hence, can bring value added to the coffee chain. These are just some strategies that are already part of the third coffee wave and that must be taken into account by all the actors involved to scale up this segment of the coffee industry and conduct the whole value chain into a new era. In fact, according to the International Trade Centre, we might be already in the fourth coffee wave, which "represents the best that the third wave brought to the coffee movement, while borrowing elements from second-wave culture. It seeks innovations in quality that can generate commercial opportunities to reach more people and achieve greater impact" (International Trade Centre, 2021). Indeed, as already discussed in the article, the big companies (the second-wave brands) have already started to join the specialty market and sell high-quality products at more accessible prices, attaining a wider commercial distribution. Likewise, specialty brands are also becoming more "marketable," selling more commercial options, such as capsules, instant coffee, and ready-to-drink beverages. These strategies of both actors (mainstream and specialty brands) may greatly increase socioeconomic benefits, particularly for producers, as more coffee (sustainable and with higher quality) at a fair price can be sold (International Trade Centre, 2021). However, it is essential that these strategies are effectively accomplished, and that the entire process, in addition to being socioeconomically sustainable, is also environmentally sustainable and respects the production capacity of our planet, or otherwise it can bring irreparable damages to the entire value chain.

Overall, we can notice that several strategies regarding the consumption stage are being studied and implemented to reduce their negative impacts on the environment and also to take advantage of the most positive aspects from the different coffee movements coexisting in the coffee industry, but the success of all of them is quite dependent on consumers' awareness, which must be assured and increased.

5 | CONCLUSIONS

In the present review, different topics related to coffee sustainability from production to consumption were explored. It was possible to clearly distinguish the three areas of coffee sustainability, without forgetting that they are intimately related, and a change in one can influence the others.

Moreover, this comprehensive review highlights how complex it can be to study the sustainability status of the coffee chain since the governance structure is predominantly dominated by roasters and big companies, which take advantage of the gaps existing in the current legislation or even the lack of it and hence define the rules of the game in their favor. In fact, the "coffee paradox" does not seem to have an easy resolution, precisely due to the control of information by the roasters, which results in a lack of two-way transparency (and even misinformation) between producers and consumers regarding the quality attributes of coffee they are producing/consuming. Therefore, although several strategies have been developed throughout the chain (from production to consumption) to face the sustainability problems of the coffee industry, and despite some advantages arising from these strategies are already known, it is still necessary that governmental structures (from both producing and consuming countries) join efforts to strictly regulate and control all initiatives and to increase the transparency of all processes or, otherwise, the big actors will continue to exert their power in all of them. Through this, producers will be able to take their position in the market as active, independent, and important actors in the chain and will thus be able to take profits from all qualities (material, symbolic, and in-person services) of their products. In addition, they will also be able to manage the byproducts generated in order to integrate them into circular economy scenarios and thus increase even more their yields, achieving social, economic, and environmental sustainability.

The valorization of the different coffee byproducts can also improve the three areas of sustainability and contribute to the circular economy of the coffee chain. Waste discharges to the environment could be significantly reduced, contributing to economic profits, and new jobs could be created. However, there is still a long way to go until all wastes are used in a profitable way and economic viability studies are largely needed to confirm if the strategies proposed based on laboratorial studies can be implemented in the real world.

Furthermore, regarding consumers, it is possible for them to be more informed and, thus, to contribute to the significant improvement of this value chain (e.g., through the adoption of more sustainable consumption practices and the search for specialty and sustainably produced coffees). However, it is important to emphasize that, although great efforts are needed on the part of governments to properly regulate all steps in the chain, the role of nongovernmental institutions, producers, roasters, supply companies, consumers, and the academic community is also fundamental because the ideas go all in the same direction and actions are expanded. Only with the union of all the parts involved it will be possible to guarantee social, economic, and environmental benefits for all.

AUTHOR CONTRIBUTIONS

Juliana A. Barreto Peixoto: Investigation; Methodology; Formal analysis; Writing – original draft; Writing – review & editing; Visualization. **Joana F. Silva**: Investigation; Formal analysis; Writing – original draft; Visualization. **M. Beatriz P. P. Oliveira**: Funding acquisition; Project administration; Writing – review & editing. **Rita C. Alves**: Conceptualization; Investigation; Writing – review & editing; Funding acquisition; Project administration; Supervision.

ACKNOWLEDGMENTS

Juliana A. Barreto Peixoto thanks to FCT/MCTES (Fundação para a Ciência e Tecnologia and Ministério da Ciência, Tecnologia e Ensino Superior) and ESF (European Social Fund) through NORTE 2020 (Programa Operacional Região Norte) for her PhD grant (ref. SFRH/BD/07329/2021). Rita C. Alves thanks to FCT for funding through the Scientific Employment Stimulus- Individual Call (CEECIND/01120/2017 contract). This work was supported by the project PTDC/SAU-NUT/2165/2021 – COBY4HEALTH – Can coffee by-products decrease the risk of metabolic syndrome? A comprehensive approach to reduce waste and valorize health benefits, funded by FCT/MCTES. This research was also supported by the following projects: SYSTEMIC "an integrated approach to the challenge of sustainable food systems: adaptive and mitigatory strategies to address climate change and malnutrition" - Knowledge hub on Nutrition and Food Security, UIDB/50006/2020 and UIDP/50006/2020, funded by FCT/MCTES; and AgriFood XXI I&D&I (NORTE-01-0145-FEDER-000041) cofinanced by ERDF, through NORTE 2020.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Peixoto, J. A. B., Silva, J. F., Oliveira, M. B. P. P., & Alves, R. C. (2022). Sustainability issues along the coffee chain: From the field to the cup. *Comprehensive Reviews in Food Science and Food Safety*, 1–46. https://doi.org/10.1111/1541-4337.13069