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Can coffee production be a sustainable chain?

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Can coffee production be a sustainable chain?

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"Recomeça...

Se puderes,

Sem angústia e sem pressa.

E os passos que deres,

Nesse caminho duro

Do futuro,

Dá-os em liberdade.

Enquanto não alcances

Não descanses.

De nenhum fruto queiras só metade"

Miguel Torga

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ABBREVIATIONS AND SYMBOLS

BIO-base polybutylene succinate	**Bio-PBS**
Biologic	**BIO**
Carbon dioxide	**CO2**
Carbon monoxide	**CO**
Coffee and Farmer Equity	**C.A.F.E.**
Common Code for the Coffee Community	**4C**
Corporate Social Responsibility	**CSR**
Dry weight	**d.w.**
European Union	**EU**
Food and Agriculture Organization of the United Nations	**FAO**
Food System	**FS**
Gallic acid equivalents	**GAE**
Genetically Modified Organisms	**GMOs**
Global Coffee Platform	**GCP**
Good agricultural practices	**GAP**
Good management practices	**GMP**
International Coffee Organization	**ICO**
International Federation of Organic Agriculture Movements	**IFOAM**
International Organization for Standardization	**ISO**
Italian National Consortium for the Recovery and Recycling of Aluminum	**CIAL**
Organic Crop Improvement Association	**OCIA**
Polluting-paying principle	**PPP**
Polypropylene	**PP**
Private Sustainability Standards	**PSS**
Room-temperature drying	**RTD**
Scientific Certification Systems	**SGS**

Spent coffee grounds	**SCG**
Sustainable Agriculture Network	**SAN**
Sustainable Development Goals	**SDGs**
Sustainable food system	**SFS**
United Kingdom	**UK**
Voluntary Sustainability standards	**VSS**
Voluntary Sustainability Standards - Setting Organizations	**VSSSOs**

ABSTRACT

The Earth is currently at risk since some human actions have been threatening our own survival in future years. It is therefore urgent to find strategies to make future life on earth so viable as it is now. Coffee is one of the most consumed beverages in the world and is also one of the most traded goods. However, this much-appreciated product can also be a source of environmental, social, and economic concerns.

This dissertation highlights the main steps of the coffee production chain and its sustainability issues, discussing what is already being done in this field and what can be improved. The only assurance that consumers have that efforts are being made in terms of sustainability is through certifications. In this context, certifications are distinguished, their concepts are clarified, and effectiveness and/or weaknesses are also discussed. In order to understand how the concepts of circular economy can be applied in the coffee production chain, several studies were reviewed, showing that it is possible to add value to the by-products of this industry, and significantly reduce their impact on the environment. Solutions that are already being implemented and that demonstrate the concerns of companies and the beginning of consumer awareness of these sustainability-related issues are also presented and discussed.

In conclusion, as the coffee chain is complex and with so many points spread throughout the process from producer to consumer, it is not simple to make it fully sustainable, but all small efforts can result in great benefits for the most disadvantaged populations, for our planet and for future generations.

Keywords

Coffee chain, certification, voluntary sustainability standards, coffee by-products, sustainability, circular economy

RESUMO

A Terra está atualmente em risco, já que algumas ações humanas têm ameaçado a sua sobrevivência. Por isso, é urgente encontrar estratégias para manter a vida futura na Terra tão viável como é agora. O café é uma das bebidas mais consumidas no mundo e é, também, uma das mercadorias mais comercializadas. No entanto, este produto tão apreciado é uma fonte de preocupações ambientais, sociais e económicas.

Esta dissertação apresenta os principais passos da cadeia produtora do café e as questões de sustentabilidade que levanta, discutindo o que está a ser feito e o que pode ser melhorado. As certificações são a única garantia que os consumidores têm dos esforços em termos de sustentabilidade que estão a ser feitos. Nesse contexto, faz-se a distinção entre certificações, sendo esclarecidos os seus conceitos, mas também são discutidas a eficácia e/ou fraquezas dessas tomadas de posição.

Foram revistos vários estudos para entender como os conceitos de economia circular podem ser aplicados na cadeia de produção do café, mostrando que é possível agregar valor aos subprodutos desta indústria, e reduzir significativamente o seu impacto no meio ambiente. São ainda apresentadas e discutidas soluções que já estão a ser implementadas e que demonstram a preocupação das empresas e o início da consciencialização dos consumidores sobre as questões relacionadas com a sustentabilidade.

Em conclusão, sendo a cadeia de produção do café complexa, com diversos pontos que vão do produtor até ao consumidor, não é simples torná-la totalmente sustentável. No entanto, todos os pequenos esforços podem resultar em grandes benefícios para as populações mais desfavorecidas, para o planeta e para as gerações futuras.

Palavras-chave

Cadeia de produção do café, certificação, padrões voluntários de sustentabilidade, subprodutos do café, sustentabilidade, economia circular

1. Introduction

Although in the 20th century there was still availability of affordable and cheap energy, if climate instability continues (caused by fossil fuel burning and release of CO_2 into the atmosphere), in the 21st and next centuries, agriculture, as we know it today, will be unlikely to exist. Besides, civilization will collapse and consequently disappear [1]. A recent study refers to the environmental problems that threaten our planet's climate and ecosystems as a "Planetary emergency" [2] and, in September 2019, the World Health Organization (WHO) said that climate change is "one of the world's most urgent health threats" [3]. Based on this, it is urgent to think in strategies that provide more varied and nutritious food but simultaneously answer to the sustainability principles.

According to the Food and Agriculture Organization of the United Nations (FAO), a Food System (FS) covers a wide range of people and their activities related to all forms of food production. It comprises other small subsystems such as: agricultural system, waste management system, supply system of inputs, etc. In addition, a FS interacts with other systems such as trading, energy, and health systems. A positive change in any of them will benefit the others [4].

A sustainable food system (SFS) is a food system that provides food security and nutrition to all, without compromising the needs of future generations in social, environmental, and economic terms [4], being one of the main supports of the United Nations' Sustainable Development Goals (SDGs) [4].

Until 2030, SDGs have, among others, the aim of transforming FSs and agriculture, making them more productive, more inclusive of poor and marginalized populations in the agricultural work, environmentally sustainable and more resilient to climate change, maintaining ecosystems and ensuring soil quality, to be possible to eradicate hunger, improve nutrition and achieve food security [4, 5].

Coffee is one of the most popular and most consumed beverages in the world and is therefore one of the most produced and transacted commodities [6, 7]. It is mostly supplied by developing countries, growing, and being harvested and post-harvest processed on small farms where families are the main workforce. Often, they do not use sophisticated machinery to facilitate this process [6]. Therefore, it is necessary to find solutions to help homeowners, workers, and their families to have a better life.

The coffee production chain is also a high source of by-products which are often not well managed and end up in landfills [8]. However, they have very interesting bioactive compounds that should not be squandered but transformed into value-added products,

applying the principles of circular economy. This could involve a better environmental and economic balance and perhaps may ensure new forms of food in the future.

In this work, we propose to clarify the concepts related to sustainability in the coffee production chain, understand what is already being done to make it more sustainable, distinguish the objectives of the different certifications in the sustainability field, and understand in what extent the coffee chain can be considered sustainable.

2. Coffee in the World

2.1. Production

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" [9, 10]. In this area, there are approximately 60 tropical countries (approximately 11 million ha). Coffee production is mainly carried out by small farmers. In total, it is estimated that there are 25 million of farmers [11, 12].

According to the International Coffee Organization (ICO), in 2018, 174 897 000 of 60 kg bags were produced, and there was a production increase of 7.0% compared to 2017/2018. The production is higher for arabica coffee, corresponding to approximately 60% in 2018, while for robusta it corresponded to ~ 40%. Brazil is the largest coffee producer, followed by Vietnam [13].

Coffee is a perennial culture very sensitive to climate. It grows mainly in regions where temperatures are warm (between 18 and 24 °C) and with abundant precipitation [10]. A small change in temperature can modify the quality of coffee because lower temperatures favor the delay in ripening and consequently higher concentration of aroma precursors in the beans [14]. A study performed with arabica coffee (the species most sensitive to temperature) in Nicaragua predicted that, by 2050, it will have to be an adaptation of the cultivated lands to an altitude 300 m higher than those currently practiced (Läderach et al. 2017). The authors also predict that, due to climate change, farmers who work at low altitudes will not be able to produce high-quality coffee and, therefore, they will have to abandon their crops. In addition, the adaptation of land to higher altitudes will bring drastic changes in forests and natural resources. Farms will have to develop effective strategies to address this impact of climate change [11]. A recent systematic review states that there may be a positive impact in suggesting those adaptations, including the transfer of farms to places that are more adapted to climate, irrigation, and agroforestry, and consider that research to support coffee production in a sustainable way is needed [15]. Another recent study [16] aimed to find an alternative to counteract the constraints caused by climate change and realized that the lower canopy produced high-quality coffee beans with greater quality, increasing the intensity of aroma, and the amounts of sucrose, trigonelline and caffeine in the bean. The combination of these investigations may be the solution to deal with climate change: on the one hand, choosing to transfer crops to higher altitude zones and, on the other hand, apply the slower development of grains in low canopy. Finally, a recent review [17] suggests that another solution for adapting to climate change could be the implementation of certification processes, as will be further discussed.

2.2. Consumption

Coffee is one of the most appreciated beverages in the world [18]. In recent years, there has been a significant and global increase of its consumption due to the ease that the market offers to consumers to drink coffee at home, as there are new machines, formulations, and market trends [19]. As coffee has active pharmacological properties, many studies have been carried out to understand which are its benefits for consumers, and there is scientific evidence which prove that a moderate consumption of this beverage has a positive effect on several diseases[20].

According to the International Coffee Organization (ICO), the European continent is the largest consumer of coffee. In 2019/2020, 168 492 000 bags (60 kg) were consumed worldwide and, of the total value, 56 287 000 bags (60 kg), approximately 33%, were consumed in Europe [21].

3. Coffee processing methods

To better understand the coffee processing methods and the resulting by-products, it is necessary to know the coffee fruit morphology. The coffee cherry is composed of two elliptical-shaped beans (endosperm), each surrounded by a thin coat called silverskin (integument) which, in turn, is lined with an advanced layer called parchment (endocarp). Between the parchment and the pulp (mesocarp), there is another layer called the mucilage (pectin layer), and the outer layer that covers the pulp is the skin (exocarp or epicarp) [18, 22, 23] (Figure 1).

Harvesting is the first step of processing. The color of the exocarp is what determines the state of maturity of the fruit - when they are not mature yet, they have a green color. When they reach maturity, they acquire colors such as red-violet, orange, deep red, or yellow, depending on the genotype. To avoid contamination by fungi or other microorganisms, the post-harvesting process should begin as soon as possible after harvesting [23]. The dry or the wet method can be used, but there are other procedures like semi-dry or mechanical methods that are used in more specific situations. The process selection depends mainly on the producer countries, their economic possibilities, water availability, and coffee types [18, 22].

The dry method is simpler and requires lower costs [22]. It is mainly used for robusta and lower quality arabica coffees [18]. Different types of drying can be employed. For example, small producers apply mostly solar drying, while room-temperature drying is used mainly by coffee industries because it is faster and simpler compared to other methods [24]. Coffee composition, including the percentage of bioactive compounds, can be influenced by the drying method used. Thus, the procedure should also be selected based on the intended purpose and profitability of the final product [24]. Regardless of the drying method, green coffee beans are dried until they reach a moisture content of less than 12% (a) in Figure 1), which allows by-products to be easily detached from the fruit when it is mechanically peeled. The resulting by-product of this processing type is the coffee husks (CH), which is a mixture of dry skin, pulp, mucilage, and parchment [22] (Figure 1).

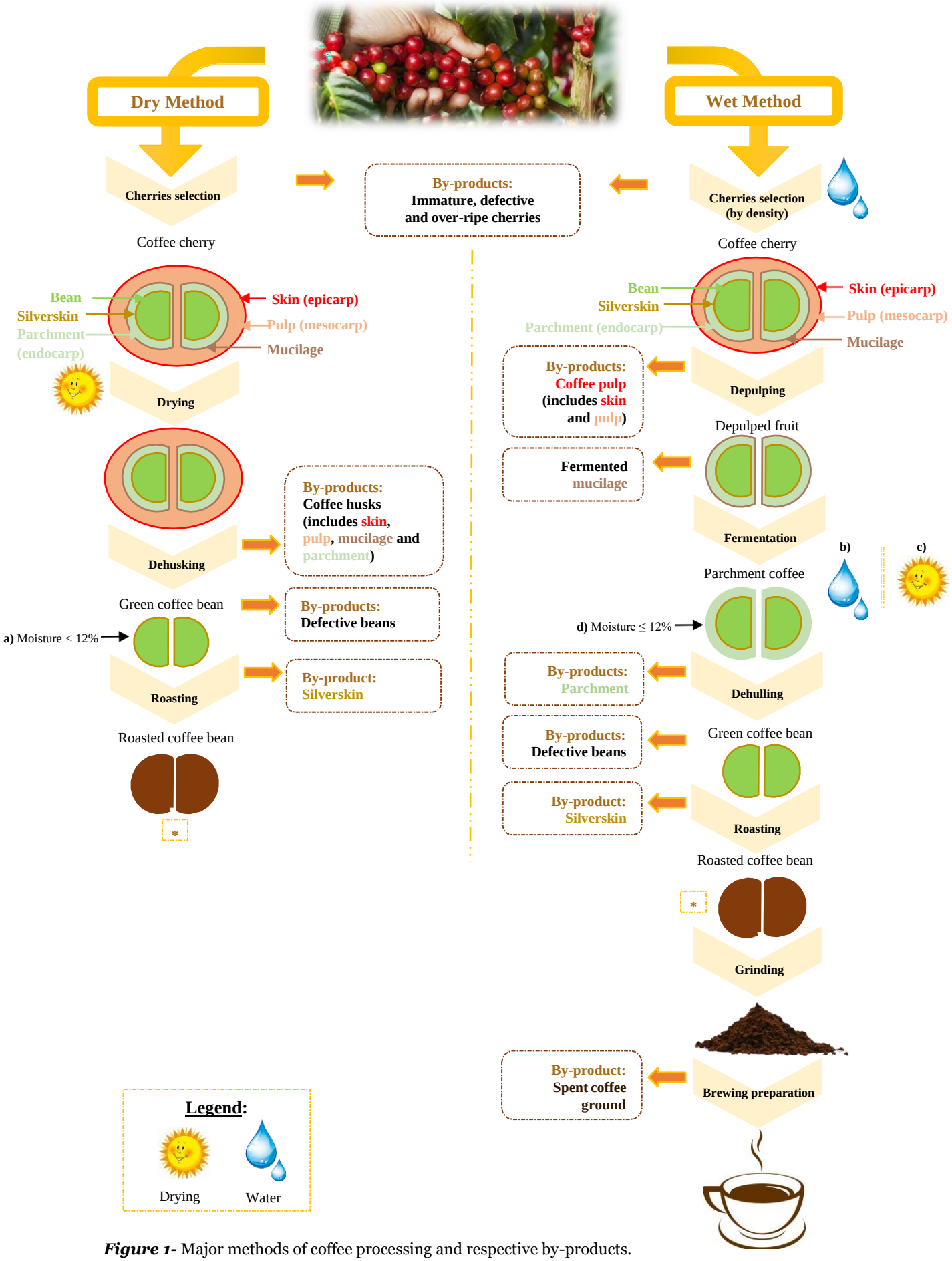

Figure 1- Major methods of coffee processing and respective by-products.

The wet method is more complex and needs more machinery as well as available clean water. Therefore, it is mainly used to process higher quality coffees. Although more expensive, this method brings greater economic advantages because wet-processed coffee has more aroma and acidity, organoleptic characteristics highly appreciated by consumers [18, 23]. In this method, the beans need to be fully ripe, so coffee is preferably harvested manually or with machinery that allows the separation of the mature fruits from others that are not in such good conditions. When this is not possible, the first step of the wet method is to place all coffee cherries in water and have a density separation. A by-product is here obtained: defective and immature coffee fruits [18, 25]. The next phase of this process is depulping, in which the skin (epicarp) and the pulp (mesocarp) are removed from the fruit by a mechanical process, resulting in another by-product: coffee pulp [18, 22]. Around the beans, there is a layer of mucilage, rich in polysaccharides (pectin), which will be degraded throughout fermentation [26]. The fermented coffee is then washed with clean water and subsequently dried until it reaches 11-12% moisture (b), c) and d), respectively in Figure 1). The following phase is the removal of the parchment by mechanical dehulling. In these conditions, the processed coffee beans, which still contain silverskin, are able to be packaged and exported by producing countries [10].

Roasting is the subsequent part of coffee processing. Developed countries are usually the most coffee-consuming countries, and they have usually local roasting industries where the imported raw coffee is roasted [27]. This is a fundamental step in coffee processing because it causes physical and chemical changes on the bean that make coffee a unique product [28]. This stage needs to occur close to the consumer because the roasted coffee characteristics, like color, aroma, and taste would not resist to international exchanges [18, 23].

Roasting processing occurs in three distinct stages:

- In the first step (drying process), with a temperature lower than 150 °C, the grains release water, and volatile substances. Although the temperature is still low to cause pyrolysis, several reactions occur that cause aroma release and the change of beans color from green to yellow, due to the beginning of the formation of Maillard reaction intermediaries [22, 29].
- The second step (roasting) occurs at temperatures between 150 °C and 230 °C. During this phase, the beans suffer important chemical reactions, like Maillard reactions, degradation of trigonelline and chlorogenic acids, pyrolysis reactions, among others. These confer physicochemical characteristics to the roasting coffee different from those of the green beans, like brown color, aroma, and a friable

texture [22, 29]. For instance, during Maillard reactions, melanoidins (that present biological activity) are formed and sugars are caramelized by caramelization reactions [29, 30]. In addition to the chemical compounds formed and degraded during the roast, gases such as CO and CO_2 are released. CO_2 is formed in larger amounts, and there is a direct relationship between these gases release and the roast degree. One of the biggest inconvenience of CO and CO_2 release during roasting is the exposure to which the workers can be subjected, with the risk of developing respiratory diseases [31, 32].

- The last step of the roasting process is cooling, with fresh air or water jets, that prevents coffee beans from burning [22, 33].

Throughout roasting, the only by-product that is obtained is chaff, which is constituted by the silverskin (the thin layer that coats the bean) and a small fraction of dust resultant from roasted beans friction [10]. Silverskin disjoints from the bean during the thermal processing due to the bean's size expansion. It is a high-quality by-product because it contains bioactive compounds with great commercial interest [18].

After roasting, coffee is packaged (with or without being ground) and stored. The preparation of the beverage is the final step of this whole process and consists in the dissolution of the coffee constituents in water [22]. The coffee beverage can be prepared by several ways: through pressure, decoctionare or infusion, and it depends on the culture of the country where it is prepared [18, 22]. After brewing or industrial soluble coffee preparation, a new by-product emerges: the spent coffee grounds (SCG). This is the last by-product obtained in the coffee production chain and the one that is obtained in biggest amounts. It is a fairly moist solid residue, with dark brown color and a residual aroma of roasted coffee [18, 34]. Its chemical composition will depend on the coffee roasting degree, grinding degree, and the conditions of beverage preparation, such as extraction time, temperature, and water-to-coffee ratio [10, 18, 35]. As SCG is a high-produced by-product obtained in the consumer countries, there is a great interest by researchers to analyze it and understand its potential for further applications [36].

4. Sustainability in coffee chain

The definition of sustainability is not as objective as it seems to be, because there are several definitions for the same term [37]. According to the International Organization for Standardization (ISO), the ISO 14000 family correspond to standards that provide information to companies and organizations that wish to manage their environmental responsibilities [38] In ISO 14001:2015 “Environmental management systems - Requirements with guidance for use” it is possible to find one of the many possible definitions of sustainability: the balance between the environment, society, and the economy in order to meet its own needs without compromising the future generations. So, the sustainable development will only be achieved when that equilibrium is accomplished [39]. Sustainability is divided into three major spheres: economic, social, and environmental. Although independent, they are closely linked because they influence each other [37]. Society's expectations regarding companies' application of sustainable development concepts, demonstration of transparency, and accountability for acts that do not meet these principles, have led to an increased legislation that effectively achieves these objectives [38].

4.1. Social Sustainability

Social sustainability, fundamentally, aims to ensure social justice. Thus, an ethically social-sustainable society guarantees social equity for the poorest people, ensuring poverty reduction, community involvement, and, thus, achieving a significant social impact. It also ensures human and worker rights and the preservation of culture [40]. Applying this concept to the coffee production chain, it is important to ensure social equality and better working conditions for farm owners, their workers and their families, and the community that lives on the income of this production.

4.2. Environmental Sustainability

Over the years, too much natural resources have been consumed at a speed that impairs their natural replacement. An ethically sustainable society is the one that can stop the exaggerated use of natural resources. In addition to resource management, it is also necessary to preserve the habitat of several animals, guaranteeing their safety and well-being, to ensure good agricultural practices and free of harmful inputs to the environment,

avoiding and preventing pollution that, ultimately, will lead to a mitigation of natural disasters [40].

In this way, environmental concerns about coffee production emerge as they cause deforestation in large areas promoting devastating consequences for ecosystems [41].

The coffee processing chain is inevitably a source of wastes and these have high associated environmental impacts. Unfortunately, many of these wastes still end up in landfills rather than being treated and used in agriculture or for many other purposes [8]. Fernandes and his team showed the environmental implications of disposing coffee wastes on the environment and concluded that leached and solubilized-containing coffee wastes can bring risks to human and environmental health, as they contain compounds that have mutagenic potential and have toxicity to aquatic organisms [42]. According to this evidence and despite all the efforts made by researchers, companies, and producers, there is still much to do, especially to respond to the principles of sustainability [18].

In 2005, the concern on this subject grew, so ICO (2005) has published and distributed a document entitled “Use of coffee by-products and alternatives uses for low-quality coffee”, which aimed to alert coffee producers about the different utilities that coffee by-products can have. This also aimed to sensitize the members of ICO and to divulge the advanced scientific work in the area [18].

Currently, the European Union, through Directive 2008/98/EC on waste (Waste Framework Directive) aims to regulate waste management, considering the product life cycle. The main objectives of this directive are to make the member countries of the European Union closer to a "recycling society", allowing to reduce the environmental impacts caused by waste and increase the economic value that their recovery can have, always ensuring the conservation of natural resources. Furthermore, this Directive establishes an order of priority that must be respected in order to achieve an environmental improvement in resource management, with prevention being the basis of the pyramid; then, preparing for reuse, recycling and other recoveries (e.g., energy recovery); and finally, the top of this pyramid is disposal [43]. In this view, Member States will be responsible for encouraging compliance with this waste flow hierarchy always in a controlled manner with the aim of achieving the best overall environmental result [18, 44].

There is a high controversy regarding coffee production in high quantities. There are authors who argue that the expansion of tropical agricultural commodities (such as coffee farms) could be a threat to biodiversity. However, others argue that encouraging the creation and implementation of sustainable agricultural landscapes can be a part of the solution for biodiversity conservation [45].

Another issue is the amount of water that is spending during the coffee processing, and several efforts have been made in recent years to find alternatives to the concerns that conventional processing methods arise, for example, the use of excessive and unnecessary water amounts. Indeed, the wet method requires a high amount of water compared to the dry one, and in order to minimize this excessive water expenditure and to overcome some limitations that the dry method has, the semi-dry (also called semi-washed or semi-wet) method arose [10]. In addition, different methods to treat wastewater from coffee processing have been discussed in the literature [46].

4.3. Economic Sustainability

Economic and financial sustainability involves ensuring social and economic returns, financial sustainability, and political involvement in these issues [40].

To improve coffee agriculture, it will be necessary for farmers to pursue modern agriculture policies, *i.e.,* 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, such as pest control plans, management techniques that ensure productivity and skilled labor. However, all these requirements must be met not only by producers but also by governments, educational institutions such as universities and scientific research institutes, *i.e.,* multisectoral cooperation [47].

5. Sustainable certifications for coffee

Sustainability does not require verification or certification, as farmers may ensure good management practices (GMP) and/or good agricultural practices (GAP), without certification. However, this is the only way that gives confidence to roasters, retailers, and consumers. Certification protects both suppliers and buyers, as there is a specific demand for certified products [48]. Certification is a concept applied to the cultivation, marketing, and quality of the final product [49].

The coffee industry is generally considered a pioneer in terms of implementation of standards and sustainability certifications because initially its growth in the global market was accompanied by several problems related to economic, social, and environmental sustainability [41, 50].

In recent years, certifications and standards have been created - the voluntary sustainability standards (VSS) or also recently called private sustainability standards (PSS) [51] - which made it possible to eliminate the heterogeneity existent between producing countries and different farmers. VSS have a combined set of "voluntary predefined rules, procedures and methods to systematically assess, measure, audit and/or communicate the social and environmental behavior and/or performance of a firm" [41, 52]. VSS are non-governmental initiatives that promote sustainable approaches to production and the rest of the market chain [53]. Although the participation of VSS is not mandatory by law because it is voluntary, it may become *quasi-legal* in specific situations [41]. The standard systems in Global Coffee Industry have become an important aid targeting sustainability in various sectors such as producers, buyers (businesses and consumers), factory owners, farmers, and others [53].

International Organization for Standardization (ISO) defines certification as "the provision by an independent body of written assurance (a certificate) that the product, service or system in question meets specific requirements". In this way, certification is an useful way to show the customer that a certain product meets their expectations because it has credibility [54].

For the coffee certification process, a standard or code is required, which dictates how it should be produced and marketed, where it is grown or which characteristics the final product should present. Subsequently, when the certification process is complete, it should be verified by an external entity through an audit system to confirm that the practices follow the standards. Finally, the certification logos are used on product labelling to inform the consumer about this whole process [49].

The private sustainability schemes were initially formulated to pay attention to environmental and social issues, but they do it according to their own models [55]. Certified coffee production that meets sustainability criteria has grown in producing countries such as Colombia, Kenya, and Ethiopia, allowing prices between buyers and sellers to be fairer for both [47]. 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 [50].

Some examples of VSS that can be applied to the coffee chain are Organic, Rainforest Alliance along with UTZ Certified, Fairtrade, and Common Code for the Coffee Community Association (4C), [50, 53]. Despite the multiplicity of VSS related to this chain, they all have common objectives that go through achieving economic, social, and environmental sustainability goals, although their regulations vary significantly [41]. In addition, it is also important to note that there is a specific EU certification, mandatory for pre-packaged organic products, in the EU which is called "Euro-Leaf" [56]. And finally, beyond VSS, there are also corporate sustainability initiatives, like Starbucks' C.A.F.E. Practices and Nespresso's AAA Sustainable Quality programs [57].

Certification in accordance with these practices allows companies to make visible their commitment to social responsibility, thereby giving credible information to the consumer about the quality of products and how they are produced. This is all possible due to the labels on the products of the adherent marks proving the certification [58]. However, increasing stamps and labels on products can sometimes make consumers fatigued when purchasing the product. For this reason, if companies who act in accordance with sustainable practices wish to provide that information to consumers, they must invest in resources, through their labels, to be credible and demonstrate their Corporate Social Responsibility [41]. This concept is extremely complex and sometimes controversial because it involves many distinct definitions, however, briefly and applied to the present context, one can say that Corporate Social Responsibility (CSR) is the environmental, social, and ethical responsibility that companies must have in society, in addition to the profits they have from their business [59].

The global coffee crisis, in 2001, had a serious impact on the global market, as there has been a decline in prices. It was when many coffee growers rethought their production schemes and the explosion of sustainability standards applied to the coffee sector occurred [50, 60, 61].

Despite the scientific investment in realizing the role of the implementation of VSS in the coffee production chain, it is still early to draw conclusions about their impact. This is

because there are not enough solid methods to realize the evolution in farms before and after certification and often analyses of voluntary coffee standards that assess various factors such as prices, product quality, and working conditions should not be generalized because studies are done under completely different conditions and are often not comparable [62].

In the following sections, the differences between each VSS will be explained, as well as the way they act as certifying entities and what has been done in recent years to ensure the applicability of sustainable aspects in the coffee production chain.

5.1. Voluntary Sustainability Standards (VSS)

5.1.1. Organic

The incorporation of high amounts of chemical compounds and organic matter into the soil are considered sources of pollution [63]. Besides, many synthetic chemicals routinely used in agriculture are toxic to the environment and surrounding biodiversity [64].

When synthetic chemical compounds, such as herbicides, pesticides, and fertilizers, began to be used, it allowed soils to become fertile and increase their productivity. However, currently, it is not the case because soils are saturated and do not have the capacity to naturally degrade the synthetic compounds, leaching the soils and leading to the contamination of hydrothermal resources, which a large environmental concern. In addition, it is necessary to pay attention to the growing consumer concerns about consuming healthier foods free of synthetic chemicals, resulting in new agricultural practices. As a result, new farming practices have been implemented [65].

Coffee cultivation is mainly practiced by small farmers, under conditions of few economic resources, in tropical regions and on land establishing an intimate relationship with the surrounding biodiversity, thus the conditions are met necessary for the cultivation of coffee to adopt sustainability standards to become possible [50].

International Federation of Organic Agriculture Movements (IFOAM - Organics International) and Organic Crop Improvement Association (OCIA) are two certifying entities of organic farm farms, where coffee plantations are inserted, but both have differences [17, 66, 67]. Still, IFOAM is the standard-setting body reference used worldwide for organic agriculture, including organic coffee production. The definition of organic agriculture is based on the four Principles of Organic Agriculture (Principles of Health, Ecology, Fairness, and Care) and is defined as [68-70]:

> *"Organic Agriculture is a production system that sustains the health of* ***soils, ecosystems,*** *and* ***people****. It* ***relies on ecological processes, biodiversity and cycles adapted to local conditions****, rather than the use of inputs with adverse effects. Organic Agriculture combines* ***tradition, innovation,*** *and* ***science*** *to benefit the shared environment and promote* ***fair relationships*** *and a good* ***quality of life*** *for all involved."*

When the first certified organic coffee farm (Mexico, 1967) came up, it only guaranteed the production of chemical-free coffee. Subsequently, initiatives to implement organic certification in coffee farms argued that improving soil health would be the way to ensure people's environmental integrity and health [50].

Organic farming is practiced according to some rules, these are: prohibition of genetically modified organisms (GMOs) and their derivatives, limitation to the use of agrochemicals (artificial fertilizers, herbicides, and pesticides), the prohibition of the use of ionizing radiation, the prohibition of forest deforestation for growing crops, a ban on the use of hormones and the use of antibiotics is only allowed when necessary to ensure the health of the animal. Producers must also adopt measures that allow them to obtain fertility in their land, such as practicing soil rotation, they must cultivate nitrogen fixing plants, and still maintain free and green crops. To control the impact of weeds and pests, they must adopt techniques that naturally control them and choose more resistant plants. In addition to these measures, farmers must adopt measures to control soil erosion, they must use water and energy resources responsibly, they must guarantee the preservation of biodiversity, preserve ecological balance, and must pay attention to animal behavior so that they can respect it [71, 72].

Organic coffee production is, therefore, based on the use of organic fertilizers instead of inorganic ones, replaces the use of pesticides and fungicides by more environmentally friendly alternatives, and allows refuge for wildlife. In addition, coffee plantations retain carbon dioxide from the air and reduce the speed of water flow, thus ensuring the protection of the surrounding river basins [60].

Although Organic is the oldest VSS, there is no such marked growth in sales of this type of coffee compared to the rest [50]. In 2016 this trend continues to be evident because organic coffee is the one that is less produced compared to coffees certified by the rest of VSS [57].

5.1.1.1. The “Euro-Leaf” or UE Organic

IFOAM Organics Europe is the entity that supports organic certification in Europe. Thus, it helps in the formulation of European policies based on the four principles of organic certification [73].

The organic certification in Europe is represented by the logo called “Euro-leaf”. It is a green symbol with the stars of the European Union that forms an outline of a leaf. This symbol is always accompanied by the code of the certifying entity, detached by home adherent country, and still refers to whether agriculture is practiced in Europe or not. A product containing the EU organic logo complies with strict conditions and has previously been certified organic by a competent authority. This product must have at least 95% organic ingredients and the remaining 5% must follow very tight conditions. There are other rules, exceptions, and prohibitions on the use of this logo that can be found on the European Commission's website [56, 74].

Until 1 January 2021, the Council Regulation (EC) No 834/2007 *on organic production and the labeling of organic products*, that determine whether products can be sold as organic in the EU, will be in force. After that date, the Regulation (EU) 2018/848 on organic production and labelling of organic products will repeal the previous one [73].

The European Union organic logo gives consumers information on which products are guaranteed to be produced according to organic farming practices and helps farmers spread their products in the EU. The legislation is prepared to include products that are produced in the EU or those imported, as is the case of coffee. [56, 75].

5.1.2. Rainforest Alliance

Although many of the coffee crops exist in protected areas, many of them are legal because they are certified by the Rainforest Alliance [69]. It is a certification that aims to improve the future of people and nature, making businesses more accountable [76].

In recent years, the Rainforest Alliance has undergone several changes that are reflected today, and which must be clarified. Until 2017, the Rainforest Alliance used the standards formulated by the SAN but, in that year, an agreement was signed that allowed Rainforest Alliance to own the certification system. Thus, the Rainforest Alliance used The Rainforest Alliance 2017 Sustainable Agriculture Standard and The Rainforest Alliance 2017 Lists for Pesticide Risk Management standards until 2020/2021 [77].

In January 2018, another major change occurred in this VSS, as Rainforest Alliance became the owner of UTZ Certified. This coalition has a greater impact, allowing farmers to have better living conditions and also the protection of the places where they live and work [78].

The new Rainforest Alliance 2020 standard "*2020 Sustainable Agriculture Standard*" has four areas of activity (farm requirements, assurance, supply chain requirements, supporting resources) and in which more targeted standards are applied for these areas of activity [79]. These new standards formulated by the Rainforest Alliance already encompass the principles of the UTZ Certified [78].

The Rainforest Alliance works primarily to promote more sustainable agricultural practices, and land and crop management so they are more prosperous, and thus eradicate forest deforestation; implement best commercial practices to increase recognition and reward of those who invest in sustainability; teach farmers to use more efficient farming methods to deal with climate change; and, socially, ensures human rights [80]. By joining UTZ Certified, this VSS will allow consumers to have sure that their products have been sustainably obtained from their origin to the supermarket [81].

This recent merger shows the trend that the market is adopting to reduce the number of VSS available, and thus may be an asset for producers to choose which certification they want to implement on their farms [52]. Any citizen can ally himself with this cause and search for brand products working in partnership with the Rainforest Alliance. For that, consumers should look for the "green frog" seal on the labels [82].

5.1.3. Fairtrade

Fairtrade arose to respond to the decline and inconstancy of coffee prices. Its aim is to democratically support smallholder cooperatives in developing countries, so they are paid the minimum price, but fair, for their services. Incentives for social development are given, there is attempt to improve labor rights, and long-term trade relationships are established, which allows to give more financial stability to small farmers [60]. Fairtrade standards also have an environmental concern because they help farmers to adapt to climate change, teaching them how to reduce the impacts, and encouraging a more environmentally friendly agriculture [83, 84].

In sum, Fairtrade combines social, economic, and environmental factors. In this way, it is responsible for providing a safety network to farmers such as lower income prices, aids in paying school fees, helps to acquire fertilizers, and teaches them how to work in order to

take care of the environment and obtain products with higher quality, which will allow them to be reliable suppliers, thereby improving business relationships. This makes them more independent and less vulnerable to coffee price variations because a minimum price for their products is guaranteed (Fairtrade Minimum Price). The independence that farmers acquire makes them able to decide their own future because they have financial security for that since they receive a Fairtrade Premium which is an extra incentive award that allows farmers to invest in improving quality and production. This ensures not only improvements in their lives since it brings them the ability to invest and expand their farms but also in those of their families and communities, as they are able to guarantee food security [83, 85].

For a farm to be certified by Fairtrade, it is not necessary to practice organic farming, however, this certification encourages coffee growers to "work towards organic practices where socially and economically practical". In addition, it is estimated that 50% of Fairtrade coffee certified farms are simultaneously certified by Organic Production. Hence, sometimes the name Fair Trade Organic Coffee appears [60].

5.1.4. Common Code for the Coffee Community (4C) Association

This certification is considered as the gateway to other certifications because the sustainability standard used by this certification aims to reduce the existing barrier to the entry of products into the supply chain. In addition, 4C encompasses the producer, environment, and the market. That is, 4C works in the three areas of sustainability aims to ensure better social, economic, and environmental conditions because they use transparent sustainable farming practices in the production and are still responsible for ensuring these same conditions in the processing of coffee [50, 52, 86, 87]. The coffee produced according to these standards has shown the highest growth, so this association is the one that holds the largest volume produced [50, 57].

5.2. Corporate sustainability initiatives

Corporate guidelines - or Buying Standards - establish similar or sometimes the same objectives of the previous certifications, which agree on improving sustainability and allow companies to ensure the quality of their own coffees. That is, these codes of conduct are applied only to the coffee they sell [48]. Starbucks' C.A.F.E. Practices and Nespresso´s AAA Sustainable Quality program are the two best-known cases of corporate sustainability initiatives.

5.2.1. Starbucks' Coffee and Farmer Equity (C.A.F.E.) Practices

SCS (Scientific Certification Systems) is an entity responsible for providing environmental certification, sustainability, and guarantees the quality of the food of companies that establish partnerships with it, because it is responsible for auditing, ensures process integrity, testing, and develop standards [88, 89]. In this way, SCS has teamed up with Starbucks and Conservation International and created coffee and farmer equity (C.A.F.E.) standards, which ensures that Starbucks is providing its consumers a sustainable coffee. C.A.F.E. follows four key sustainability guidelines: product quality; economic responsibility; social responsibility; environmental leadership [90].

5.2.2. Nespresso's AAA Sustainable Quality Program

A collaboration between Nespresso and Rainforest Alliance allowed the creation of the Nespresso AAA Sustainable Quality Program. The Nespresso AAA program has in common with other certifications many of the principles they implement, but, in addition to respecting environmental and social standards, it also guarantees product quality as well as high productivity, thereby helping coffee growers to produce high-quality coffee in a more sustainable way [91].

5.3. Advantages and limitations of sustainability certifications

There are still not many studies that allow an objective conclusion about whether the application of certifications is beneficial in all that involves it. Opinions are often not unanimous and there are always post and cons. It is relevant to discuss, according to the available literature, if it is beneficial to certify a farm and what will be the impact of this on the lives of farmers and all those around them.

On the one hand, it is good that there are certificates that give consumers confidence, but on the other hand, excessive information, and the different amounts of symbols on labels can cause confusion in consumers, especially in those who are not so well informed. Consumers' awareness should be increased, if possible, with actions between companies and their customers, in order to increase trust and closeness. In general, even when the product is more expensive, the informed consumer shows interest, otherwise, the companies would not invest in the certification of their products.

Several studies have been carried out to prove the importance and benefits of implementing certifications. A study conducted by Valkila (2009) reports that on Nicaraguan farms, working conditions in the production of Fairtrade organic coffee have several limitations [60], which meets the problems reported by Haight (2011) in this certification [92]. Another study conducted by Ssebunya and his team (2019), in which the main objective was to compare the performance of organic and Fairtrade certified farms with smallholder farms in Uganda that are not certified, concluded that a better sustainability performance is achieved in certified farms [58]. In turn, a research conducted in Uganda and Ethiopia aimed to understand the impact of VSS on social sustainability, concluded that Fairtrade certification facilitates the enrolment of children in school and improves their school achievement, while the Rainforest Alliance certification slightly reduces girls' schooling and has no effect on boys' school outcomes, but has a significant effect on reducing child labour [51]. In turn, Meemken et al. (2017) tried to understand what the preference of Ugandan small coffee producers in relation to the sustainability standards required by the three certifications: UTZ, Fairtrade, and Organic. The authors 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 a gender heterogeneity in the farm households [93].

According to Millard (2017), while companies increase their investments in sustainability, they should also invest in civil society organizations. Sustainability standards bring benefits because they are the simplest way to communicate, guide, and verify sustainability. However, empirical evidence applied to a continued sustainability development is very limited and may jeopardize its credibility. The Global Coffee Platform in conjunction with the Sustainable Coffee Challenge can be the key to this issue because they look at all entities in the coffee sector as collectively responsible for sustainability and will facilitate the collection and processing of data from a more consistent form [94, 95].

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 farmers that are not impaired are those certified by Fairtrade because this certification has a pre-established premium price, which is not dependent on the price of coffee in the global market. Thus, the demand for sustainability can become, in the long run, a requirement that does not bring economic benefits to producers. In this way, a reformulation of the institutions is necessary, and this is being

done with the help of the Global Coffee Platform [49]. Global Coffee Platform (GCP) together with the Sustainable Trade Initiative, have 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 [49].

Despite the encouraging results presented above, not everything is so clear and perfect. Another important issue is the voice that the farmer must have in the construction of these organizations, that is, it would be beneficial for him to be part of his leadership. In fact, as many of these certifications aim to support the farmer and check the way he practices agriculture, it makes perfect sense to include these small farmers in the head of the Voluntary Sustainability Standards - Setting Organizations (VSSSOs). However, a lot has still to be done in this field. Indeed, Bennett (2107) analyzed the governance structure of the 33 VSSSOs that certifies not only coffee but also cocoa, and tea and concluded that more than 50% of these organizations do not intend to put farmers in the senior governance positions. Only a 25% guarantee that producers have votes/seats and only 18% give producers veto power [96]. It is there questionable what is the role of VSSSOs in the lives of marginalized farmers, whether their focus will be to guarantee them better living conditions, but they probably do not consider their opinions and ideas when making decisions.

Another question that can be addressed is: is there the need for so many certifications that intersect with ideals and that often support the three dimensions of sustainability? And that they all have their own standard? 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 wouldn't it be simpler to adapt a common standard and that all VSSSOs fight for a common good? Or are economic interests also overstating environmental and social interests?

A study by Thong Quoc Ho and his team aimed to assess eco-efficiency benefits between sustainability-certified (certified organic farms) and conventional farms in Vietnam, which is the second largest coffee-producing country. And the most important results were that certified farmers have higher levels of eco-efficiency than non-certified ones, which leads the former to reduce some environmental pressure factors. However, the price premium derived from certification is not enough for all the necessary efforts [97].

To prove this hypothesis, a relatively recent article, with a strong and suggestive title “Smallholders do not Eat Certificates”, reinforces that certifications do not seem to solve the problems of improving the living conditions of small farmers. In addition, they state that

the most important thing about private certification was a change of awareness about sustainability issues rather than an effective change in the value chain. The authors also emphasize the idea of combining public and private sustainability standards in order to harmonize the applications of standards, since public certification has a greater power of law enforcement, but it is not as rigorous as private certification [55].

In 2017, a review was published to update the information of the main published articles on the impact of certifications on the livelihood of small coffee producers. The results were mostly positive, however, 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 and UTZ while these seem to be the certifications that have the most positive results. Furthermore, the authors report 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, economic context, among others factors of the country in which it is being studied [98]. Thus, conducting studies 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.

Another relevant issue is whether the coffee price premiums that the certifications promise actually to reach the producer, i.e. whether the price paid by the buyer goes through the entire supply chain and actually reaches the coffee grower [49]. A recent study by Naegele (2020) states 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 [99].

Besides, the buyer should be assured that the coffees they buy are being certified and checked on farms. The answer to this question should be simple and goes through traceability from production to the final product in the cup, which despite everything is an area that, according to Brando (2019), still needs to be developed [49].

Zander et al. (2015) described that consumers' knowledge in some European countries regarding the EU Organic is slightly reduced compared to other logos. In addition to this result, 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-raising and logo promotion. However, in some cases, the lack of interest from some consumers is a reality [100].

But what is the commitment of companies to the sustainability practice? Are they already taking more sustainable attitudes or not? Bager and Lambin (2020) analyzed the sustainability efforts of approximately 500 companies in the coffee sector. The results were not as encouraging as it would be expected because one-third of these companies have no commitment to sustainability, one-third have a vague commitment and only a third have a significant commitment to sustainability. This study also concludes that large companies tend to adopt their own sustainability measures, while smaller ones tend to adopt VSS. Thus, they concluded that there are companies that are effectively focused on change, but there is still a long way to go, and it would be attainable a more widespread change of all companies in favor of sustainability if there were more audits, more accountability, mandatory reporting, among others [101].

Another topic that deserves attention is the amount of sustainable coffee that a package or cup contains. It is usually assumed that all the coffee that constitutes them is certified, but that not always happens. So, 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 [49].

In general, we can be on a good path when it comes to maintaining sustainability, and certifications can actually help to make this possible as they provide farmers the rigor to do that in the best possible way, also increasing consumers’ trust. However, more studies are still necessary to raise awareness among the scientific community and consumers. Moreover, it is also necessary to understand which is the difference between the consumption of certified and uncertified coffee. These studies should include economic, social, and environmental issues for raw material producers, as well as the health benefits for consumers.

6. Other sustainability issues

6.1. Circular economy

The concept of circular economy emerged a few years ago, in 1966, with Boulding: the economy and the environment should coexist in the balance because Earth is a closed and circular system, with low assimilative capacity. In this way, the environment and economy must maintain a balance between themselves. The introduction of the concept was only made in 1989 when it was described the possibility to use natural resources as raw materials for production and consumption, thus influencing the economy, but still paying attention to the residues that come out of the process [37].

Considering their research and evaluation of all definitions of circular economy, Geissdoerfer and collaborators (2017) created their own concept and defined Circular Economy as:

> *"A regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling."* [37]

Another assertive and practical definition of circular economy is from the European Parliament:

> *"The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing, and recycling existing materials and products as long as possible... In practice, it implies reducing waste to a minimum".*

In sum, the aim of circular economy is to keep a product still within the economy even if its lifetime has come to an end, designing strategies to give them a "new life" [102].

In 2018, the ISO/TC 323 Circular Economy standard was created, which allows the development of structures and support tools and guidelines so that the entities involved can enhance their contributions to a sustainable development [103].

There is scientific evidence to prove that the implementation of the Circular Economy leads to improved well-being in view of the recovery of environmental integrity and that it could be the solution to reduce the environmental impacts of economic systems. However, its implementation is still in the early stages of development and still few countries have adopted actions to apply its concepts [104].

Although Sustainability and Circular Economy have been mainly addressed as two separate and independent areas of knowledge, there are business opportunities that benefit from the synergy between them [105].

A recent study applied circular economy scenarios in the value chain of coffee. Topi and Bilinska (2017) closed the coffee value chain 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 and concluded that they all have environmental benefits because they reduce the amount of organic material that go to landfills, permanent land use, and gas emissions. One of the scenarios brings social benefits, which make it better compared to others, as it involves additional jobs. In economic terms, they are all viable despite the differences between them. In spite of the limitations that the study presents, it was possible to conclude that other more viable alternatives can also be considered. However, it showed that it is possible to adapt circular economy principles to the coffee value chain [106].

6.2. The polluter-pays principle

The polluting-paying principle (PPP) exists since 1987, but over the past two decades, it has evolved considerably, becoming a world-renowned legal principle [107]. It requires that the polluting entities be 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 [108, 109]. According to the Theory of Justice (Fleurbaet, 2008), a polluter can be accountable for their negative impact on society or be rewarded if they contribute to a less polluted society [109]. Ambec and Ehlers in 2016 presented general mathematical models that allow us to understand whether the entity in question is a polluter, a pollution victim, or both [109].

Briefly, this principle calls on producers to comply with waste management principles according to Directive 2008/98/EC on waste, thereby ensuring the protection of health and the environment. Thus, this may be the perfect motto to bring processing companies the incentive to use the waste that is generated during processing. If this happens, waste is used, by-products are valued and economically monetized, companies do not have to pay for generated wastes and the environment will certainly gain from this conscious practice.

7. Coffee by-products and their bioactive compounds

As described in Section 3, several by-products are generated along the coffee chain, which usually are discarded, with several complications for the environment. However, they can be transformed into added value products and used for several applications [8, 18].

Table 1 shows the amounts (kg) of each by-product obtained to produce 1 ton of coffee (green or roasted) in order to understand which are mostly formed since this will be related with the consequences for the environment.

Some differences were observed between the results obtained by different authors, probably due to the extraction methods and test conditions used by the different research groups [110]. Besides, the chemical composition of the by-product can also vary according to the species and geographical origin of coffee. For instance, a recent study conducted by Bessada et al. (2018) was able to discriminate silverskin from different geographical origins based on the chemical composition of the samples [111].

Table 1- Amount (kg) of each by-product formed per ton of obtained coffee (green or roasted).

By-product	kg/ton green coffee	kg/ton of roasted coffee	Reference
Coffee with imperfections	150-200	-	[112]
Coffee husks	180	-	[7, 113]
Coffee pulp	500	-	[7]
Parchment	183	-	[114]
Silverskin	-	7.5	[18]
Spent coffee grounds	650	2000*	[115]

*2 ton of wet SCG per 1-ton soluble coffee produced.

In turn, Table 2 shows the nutritional composition and the most relevant bioactive compounds of the most promising coffee by-products that can have a special interest for pharmaceutical, food, and cosmetic industries [18].

Table 2- Coffee by-products and their chemical composition[a].

	Coffee by-products					
	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.)	-	0.5-5.8%	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

[a] Compilation of data presented by: [7, 8, 18, 22, 25, 110, 116-121].
Legend: GAE - Gallic acid equivalents; % (d.w.)- % in dry weight; % - % weight/weight in fresh.

Coffee with imperfections represents 150-200 kg per ton of green coffee that is produced [112]. When damaged by insects or microorganisms, they usually appear blacker or darker than normal beans. They can also exhibit visible stains or be simply pieces of immature cherries. Although they are low-quality beans, they can be used for different purposes since, for example, they are richer in compounds such as trigonelline, caffeine and chlorogenic acids comparing with the regular beans [18, 25, 122]. Instead, the oil levels are usually lower in the defective beans, although the fatty acids profile is not very different from non-defective beans [122]. The protein content is inferior to that of regular beans, but the content in free amino acids, namely asparagine, can be higher. The total mineral content is also higher than in the healthy beans, being potassium the major one [18]. In the case of immature coffee beans, these have an increased content of chlorogenic acids (35% d.w. higher contents of 5-caffeoylquinic acid compared to non-defective beans). Besides, as the maturation state has not been reached, they also present lower sugar and sucrose contents [18].

Coffee husks are the by-product obtained during the dry method of post-harvesting processing (180 kg/ton of green coffee) [7, 113]. They have moisture content [22], and a high percentage of carbohydrates (58-85% d.w.) mainly constituted by fiber [7, 18, 22]. This by-product also contains phenolic compounds (1.2% d.w.), being 5-caffeoylquinic acid the major one [18, 123]. In general, the high amount of secondary metabolites such as phenolic compounds and caffeine (~1% d.w.) stands out [124]. Coffee husks also contain tannins (5% d.w.) [18] and anthocyanins (especially cyanidin 3-rutinoside) [125].

Although the composition of coffee husks is very similar to that of coffee pulp, it is advisable to see them as separate entities because they are obtained by different processing methods (dry and wet methods, respectively) and coffee husks have in their composition other parts of the cherry that coffee pulp does not have (i.e., include parchment). Indeed, the coffee pulp is the by-product generated after depulping in the wet method of post-harvest processing (500 kg/ton of green coffee) [7]. It is mostly rich in carbohydrates (45-89% d.w.) and has large amounts of fiber, namely cellulose [7, 18, 22]. In lower amounts are minerals (6-10% d.w.), essentially potassium, and tannins [7, 22]. In addition to these compounds, as for coffee husks, chlorogenic acids, caffeine, and anthocyanins (cyanidin 3-rutinoside as the major one) have also been described [18, 22].

Mucilage is not a very studied by-product, because it is usually included in coffee husks (dry processing) or fermented during wet processing (with its texture changing from slippery and viscous to fluid and watery). However, it can also be mechanically removed in some situations (Alves et al., 2017). It is mainly composed of moisture, protein (8.9% d.w.),

sugars (4.1% d.w.), which are essential for the fermentation process, and ash (0.7%) [25, 126].

Parchment is the last by-product of wet processing. About 183 kg are obtained for each ton of green coffee that is produced [114]. It is very rich in cellulose (40-60%), hemicellulose (25-32%), lignin (23-32%) and ash [25, 121].

Silverskin is the by-product that is formed in the smallest amount along the coffee processing chain (~ 8 kg/ton of roasted coffee) since it corresponds to a small fraction of the cherry. However, it is the major by-product of roasting companies [18]. It has a low moisture content, and more than half of its constitution is fiber. It has also significant levels of protein (16-19% d.w.) and phenolic compounds (10.75-17.3 g $GAE/_{100g}$), being 5-caffeoylquinic acid the most representative one [18, 22, 118, 121].

And finally, but not the least (because it is the by-product that is formed in greater amounts throughout the processing chain), the spent coffee grounds represent 650 kg per 1 ton of green coffee produced or 2 ton of wet SCG per 1 ton of soluble coffee produced [115]. In this by-product, the high amounts of fiber, namely hemicellulose (31.7-41.7% d.w.), and protein (14-17.5%) stand out [7, 18].

In sum, the distinct by-products of coffee have different physical and chemical characteristics. However, they have something in common, the composition of polysaccharides and phenolic compounds are similar in all of them. Due to the diversity of compounds found in each by-product, it is possible to use them in several areas. Thus, researchers need to look for viable strategies to turn them into products of added value and economically profitable [10].

7.1. Potential of coffee by-products to be value-added products

Coffee by-products pose serious risks to the environment because they are generated in large quantities and contain some compounds that are toxic to plants and microorganisms that live in the soil. It is important to point out that the potential use of a by-product depends on its chemical composition and the concentration that the bioactive compound(s) is expected to have in the biotechnological application [8]. The high organic load that these by-products have makes them considerably polluting due to the high amount of oxygen needed to degrade them. Thus, they should not be applied indiscriminately into the soil as a fertilizer, without prior treatment [127]. Moreover, due to the presence of anti-nutrient factors, they cannot be directly used for animal feed. Instead, their ingestion must be controlled up to safe amounts. For example, the coffee pulp can be used in feed but only at

a limit of 10% [124, 128]. Thus, the use of such by-products should be meticulous and conscious.

As previously reported, coffee processing by-products are rich in bioactive compounds, and these can be used in several areas, such as food, pharmaceutical, or cosmetic ones. Besides these areas, they can also have different applications [10]. Researchers and the scientific community have been trying to adapt the concepts of sustainable development to the coffee production chain and by-products thereof. Techniques of valorization, reuse, and recycling of these by-products have been investigated with the aim of implementing the (bio)entrepreneurship in this industry [18, 129]. Some 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 by-products reuse have not yet been implemented in practice [129].

There are several reasons that lead researchers to focus on the use of by-products generated along the coffee chain, namely the environmental issues, the increasing amount they are generated due to the increasing consumption of coffee, and also because their chemical constituents have physiological effects [121]. The applications suggested by the different researchers (Table 3) show the potential of coffee by-products to be used as functional food ingredients and for pharmacological and cosmetic uses, as well as in other activities, such as energy production and incorporation in polymers and materials, ensuring beneficial economic and environmental effects [10, 120]. Table 3 also shows some projects developed in recent years by researchers in this field. As mentioned before, there has been indeed an effort by the scientific community and companies to find ways to exploit these by-products, but there is still a need to search for new and innovative alternatives. Similar uses have been suggested for different by-products because, in the end, they have similar characteristics, or their chemical composition does not differ too much. In this way, they can be combined to increase the amount of residue treated. The most important will be to use by-products rationally and consciously and adapt their use to the purposes for which they are best intended, using clean and sustainable technologies and procedures, ensuring that there is minimal residual waste in all this process.

Making the coffee production chain more sustainable also involves to extract and concentrate the bioactive compounds that these by-products contain by methods that spend less energy, are cheaper, and minimize the use of organic solvents or even replace them with green solvents with non-toxic, non-volatile, recyclable, and biodegradable characteristics, especially when the conventional methods are dangerous to the environment. And for this

reason, in recent years, the methods for bioactive compounds extraction have been optimized [130]. Recently, Yoo et al. (2018) showed the effectiveness of using deep eutectic solvents that have advantages such as low or no toxicity, non-flammable, non-reactive with water, and simple preparation, for the isolation of bioactive compounds existing in SCG [131]. In another study, Torres-Valenzuela et al. (2019b) also showed the efficacy of extracting bioactive compounds from this by-product using supramolecular solvents [132]. Other examples are the supercritical fluid extraction technique (e.g., using supercritical CO2) [133] or a multi-frequency multimode modulated ultrasound technology using only water as solvent [134].

Table 3- Possible applications or potential effects of different coffee by-products.

By-product	Characteristic/ Fraction/ Chemical compound	Possible application/ potential effects	References
Coffee with imperfections	-	Commercialization in Brazilian internal market	[135]
	Oil	Production of biodiesel	[136]
	Oil, caffeine, and chlorogenic acid	Extraction of oil and bioactive compounds	[137]
Coffee husks	-	Incorporation in animal feed (up to 10%)	[129, 138]
		Substrate for production of enzymes, organic acids, mushrooms, flavor, and aroma compounds	[124, 139]
		Production of briquettes	[140]
	Minerals (mainly K)	Production of silage	[129]
	Organic matter and minerals	Production of soil fertilizer	[141]
	Organic matter	Subtract for composting and vermicomposting	[142-144]
		Production of biogas (biomethanation)	[129, 145]
	Carbohydrates	Production of biopesticides	[146]
	Polysaccharides and fermentable sugars	Production of bioethanol	[147]
	Fiber, mineral, and sugar content	Obtention of flour and honey	[148]
	Fiber	Incorporation in polyethylene composites	[149]
	Cellulose, hemicellulose, lignin, and proteins	Production of biosorbents	[10, 150]
	Cellulose and hemicellulose	Incorporation in environmental-friendly materials	[129, 151]
	Large amount of volatile matter, small amounts of fixed carbon and ash	As solid biofuel	[129, 152]
	Phytochemicals and antioxidant dietary fiber	Ingredient for human food	[120]
	Anthocyanins (cyanindin-3-rutinoside and cyanidin-3-glucoside), caffeine, polyphenols, and chlorogenic acid	Obtention of bioactive compounds	[7, 125, 129, 153]
Coffee pulp	-	Incorporation in animal feed	[129, 138]
		Subtract for composting and vermicomposting	[124, 154]
		Production of solid biofuel	[129]

	Organic matter	Production of biogas	[124, 155]
	Fiber, mineral and sugar content	Obtention flour and honey	[148]
	Carbohydrates	Production of bioethanol	[156-158]
	Lignocellulosic composition (cellulose and lignin)	Removal of Cr (VI) in wastewater	[159]
	Reducing sugars, proteins, and pectin	Substrate for polygalacturonase production	[160]
	Minerals nutrients (mainly K)	Production of silage	[129]
	Caffeine and polyphenols	Obtention of bioactive compounds	[7, 25]
	Antioxidants and phenolic compounds	Production of Cascara beverage	[161]
	Anthocyanins	Production of natural colorant	[162]
	Tannic acid	Potential raw material to produce gallic acid	[163]
Mucilage	Carbohydrates	Production of biogas (H_2)	[164]
	Pectin	Production of biodegradable electrosprayed pectin films	[165]
	Fiber, mineral, and sugar content	Obtention flour and honey	[148]
	Fermentable sugars and polysaccharides	Production of bioethanol	[166, 167]
Parchment	-	Production of a hydrogen-rich fuel gas	[168]
		Production of fillers of polyurethane composites	[169]
	Fiber	Application in thermoplastic composites	[170]
	Cellulose and hemicellulose	Production of particleboard	[151]
	Lignocellulosic material	Precursor in the production of activated carbons	[171]
	Antioxidant dietary fiber	Ingredient for human food	[120]
Silverskin	-	Used as firelighters	[172]
	Dietary fiber	Bread-making	[173]
		Prebiotic capacity	[127, 174]
	Dietary fiber and phytochemicals	Ingredient for human food	[120]
		Incorporation in flakes, biscuits, bread, and snacks	[115]
		Incorporation in cookies (until 5%)	[175, 176]
	Cellulose, hemicellulose, lignin, starch, pectin, and proteins	Substrate for fungus growth	[177]
	Antioxidant compounds (CGA, caffeine, …)	Anti-inflammatory effect	[178]
		Anti-aging effects	[179, 180]

		Dermocosmetic ingredient	[127, 181, 182]
		Production of an antioxidant beverage	[183]
Spent coffee grounds	-	Used as a leachate absorbent	[184]
		Production of fillers of polyurethane composites	[169]
		Used in incorporating a stabilized green material for road construction	[185]
	High calorific power (around 5000 kcal/kg)	Production of pellets	[186]
		Used as a fuel for the boiler in the coffee industry	[186]
	High amounts of carbon and low adsorption capability	Production of carbonaceous fuel	[187]
	Organic compounds	Production of biogas	[188]
	Organic matter	Used as a landfill leachate absorbent	[184]
	High nutritional characteristics	Incorporation in animal feed	[189]
	Compounds with basic and polar property (caffeine and amino acids)	Production of activated carbon for catalysts	[190, 191]
	Good physical, mechanical and thermal properties.	Used in clay brick production	[192]
	Granulated and insoluble material	Manufacture of recycled glass by incorporation of SCG into geopolymers	[193]
	Exhibited a remarkable anode performance and excellent capacity retention	Fabrication of a lithium-ion battery	[192]
	Dietary fiber	Source of dietary fiber	[194]
	Cellulose, hemicellulose, lignin, starch, pectin, and proteins	Substrate for fungus growth	[177]
	Carbohydrates (mannose and galactose)	Production of bioethanol	[195, 196]
	Sugars, protein, and aroma compounds	Production for new alcoholic beverages	[197, 198]
	Oil	Extraction of oil	[199]
		Production of biodiesel	[136, 195, 200]
		Production of bio-hydrotreated fuel	[201]
	Nitrogen, phosphorus, and potassium	Used as agricultural fertilizer	[202, 203]
	Caffeine	Topical anti-photoaging agent	[204]
		Ingredient to produce energy drinks	[205]
	Antioxidant compounds (CGA, caffeine, …)	Recovery of bioactive compounds	[206]

		Source of New Beverages	[34]
		Extract powder can be integrated into food as an ingredient or additive	[207]
		Source of CGAs in functional foods or supplements	[208]
	Melanoidins	Prebiotic, antimicrobial, and antioxidant capacity	[127]
	Phytosterols	Source of phytosterols	[209]
	Dark color, unique visual and aromatic properties	Used in 3D Printing Architecture	[210]

While the great majority of coffee by-products can be easily collected from producers and coffee industries, SCG, in particular those resulting from domestic coffee preparation, are usually dispersed among consumer's homes and commercial establishments. Therefore, innovative ways to gather higher amounts of SCG should also be highlighted. Whit this aim, in the city of Athens, in Greece, there was a preliminary concept called "COFFEE BIN" which is a garbage bin that serves for the collection of SCG. This crate arose since there are not always appropriate places for the deposition of SCG. 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" [187]. Moving from theory to practice, Bio-bean is a company founded in 2013 in the United Kingdom, which transforms the SCG collected in various parts of the UK, in a circular economy approach. The final products are coffee logs, coffee pellets, natural flavours that can be used easily in the food industry, and in the incorporation of beverages, and this company is still focused on creating new value-added products based on bio-oils and bioplastics [211].

In a recent review, Mata et al. (2018) presented a bio-refinery approach for recycling SCG, concluding that most of the treatments that can be applied to this by-product have limited scope and the final products have low economic value[212]. In turn, another recent study that assessed the potential of coffee-derived fuels shows 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 the fact that coffee biodiesel is able of generating 3.45 MJ of energy, while it only consumes 1 MJ in its entire life cycle [213].

8. Measures adopted by some countries and companies to enable the sustainability convention

Several strategies to reduce the environmental impact, to boost the economy of producing countries, and thus ensure more favorable living conditions have been adopted by large coffee retail companies around the world. Below, some practices that have already been implemented with success will be highlighted, as well as others that were not so viable. The social, environmental, and economic contributions of companies will also be discussed.

In Europe, there has been a high growth in the consumption of coffee capsules in recent years. 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 for that a coffee machine that supports capsules [214, 215]. However, the environmental impact caused by capsule-based coffee machines is very high, since it consumes more energy, as well as materials that constitute the packaging [216].

There are several types of coffee capsules on the market, but today the most common are plastic and/or aluminum-based [217]. The plastic capsules are mainly composed of polypropylene (PP) which is a cheap material that withstands high temperatures, 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 [218]. However, due to the complexity of these materials, recycling is not always carried out, being these wastes often discarded. It is estimated that in 2050, 12,000 million metric tons (Mt) of plastics will become waste in landfills or in the natural environment and coffee capsules are an emerging plastic residue [219, 220]. Thus, recycling these materials is urgent to minimize environmental impact. A study by Domingues et al. (2020) aimed to evaluate several parameters to understand whether NESCAFÉ® DOLCE GUSTO® coffee capsules would be good materials to be reused. They concluded that the internal filter and the capsule body are two interesting sources for obtaining polypropylene in a more conscious way because it arises from the reuse of existing material [221]. This study shows that the scientific community is interested in understanding how plastic coffee capsules can be found new.

Aluminum is considered the best material for maintaining coffee quality as they protect and prevent the entry of light, gases, and water vapor [217]. But it is expensive and leads to a complex waste at the end of its service life, which requires advanced recycling processes to reuse this metal. A partnership that began in 2018 between Nespresso and CIAL (Italian National Consortium for the Recovery and Recycling of Aluminum) implemented the

concepts of Circular Economy and aims to collect and recycle 100% of aluminum capsules an unlimited number of times [222]. In this way, it is possible to recycle/reuse coffee capsules, if they are placed in the indicated locations. In this case, it is a responsibility that does not depend only on the companies but mainly on the consumers.

Nespresso®, one of the best-known brands of coffee, has joined the sale of its coffees in aluminum capsules. The company argues that coffee reaches fresher to the consumer, and as aluminum is a recyclable material will allow to give this waste a new life [223]. And so, Nespresso® has a campaign called “Recycling is Food” in which it is possible to deliver the coffee capsules used at indicated locations. Later the metal is recycled, and the spent coffee grounds are used to produce an agricultural compost 100 % organic that will serve to facilitate the growth of rice that will be donated to the Food Bank. This institution has as main objectives to combat food waste by sending free distribution to deprived people [224, 225].

In 2019, a more environmentally friendly coffee capsule appeared in the Portuguese market. These were described as "0% plastic, 0% microplastic and 0% aluminum", because they were made on the basis of cane sugar, cassava, and corn, materials that by fermentation give rise to a compound, succinic acid, which is a path of the formation of a BioPBS – Bio-based polybutylene succinate (polybutylene succinate of biological origin), the principal component used to create this capsule [226]. However, these capsules showed to be only biodegradable in an industrial context and not in home-composting containers in the time that would be assumed according to the parameters required by the European Union standards. These state that at least 90% of biodegradation must occur within 6 months. In this case, it was not clear how long these capsules take to degrade because they are not only constituted by this bioplastic (BioPBS), but they do not meet the required time [227, 228]. We also highlight a successful case, Novell's compostable coffee capsules that are certified by EN 13432, which is the European standard that regulates and proves the compostability of bioplastics in industrial context, so these capsules in industrial composting conditions are degraded up to 20 weeks [228, 229].

Indeed, brands are trying to keep up with market trends and to get their products on the front line in terms of sustainability guarantees, but is this being done in the right way? What will be the price that consumers will have to pay for these attempts that often fail at some point, in a theory created by companies, without the consumer having the knowledge to go down what is right or wrong?

There is another very innovative and promising alternative, this is called The Droops Coffee Maker, a machine that uses coffee capsules that are coated with 100% natural

materials that are also dissolvable (made with Coffee beans, Algae, Salt, and Water) and that are at the base preparation of the beverage and depending on its constitution may give rise to different types of coffee beverages [230, 231]. In the meantime, coffee pods, i.e., commercial prepacked doses in which coffee powder is placed between two thin layers of paper and is sealed hot with low density polyethylene that allows them to remain hermetically stable, seems to be the most eco-friendly way of preparing a coffee beverage using an unidose [232, 233].

Another important aspect that should be considered throughout this production chain is how the drink reaches the consumer and what is the eco-friendliest way to do it. A study conducted by Tavares and Mourad (2020) aimed to understand which method would be the best to prepare the most environmental-friendly coffee beverage. They concluded that the preparation of a single-serve soft pod using an automatic machine is the type that emits less CO_2. Its environmental impact is one of the minors because of its small volume of waste in landfills. On the other hand, the single-plastic capsules with aluminum top seal are the ones that represent the greatest environmental impact by the volume and waste generated that led to higher consumption of water and energy. In conclusion, the single-serve pods using paper sachets is the greenest method of preparing a coffee beverage [232].

Disposable cups are usually delivered in coffee shops or automatic vending machines for their practicality, however, many of them are not recycled, ending up in landfills. Indeed, large amounts of CO2 are generated with the use of these types of cups that can be made of plastic or paper. The latter, however, are not composed exclusively by paper, also having 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 to recycle coffee cups due to the difficulty on separating the paper from the polyethylene layer: it would require equipment that does not exist in many countries and specialized labor, in addition to entailed high logistics costs. Therefore, this process is not feasible. And often, when it is possible to return disposable coffee cups, their subsequent use is not possible due to contamination with organic compounds and other materials [234]. To address this problem, Kosior and Mitchell in their recent study highlight the possibility of creating a new compound containing resins, the paper cup, and agents that interconnect all materials, thus forming a molding resin that can be used for various applications [235, 236]. Although biodegradable cups seem like a good alternative, it turns out not to be very viable for two reasons: first, in most 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 [234]. 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 has 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 life cycle of three different types of cups: one that has a single-use biological basis (polylactic acid), another with single-use plastics (polypropylene and terephthalate of polyethylene), and a third multi-use stainless steel alternative. The results suggested that 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 lead to a decrease in the environmental impact, encourages 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. In addition, multi-use cups must be used effectively a considerable number of times to justify their environmental impact. [237]. So, the use of reusable coffee cups is undoubtedly the best solution, but it is necessary to raise consumers' awareness about this problem, take effective and feasible measures, and provide alternatives to consumers. The study carried out by Poorting and Whitaker (2018) did show that if these measures are effectively implemented, it can help consumers to select reusable coffee cups [234].

9. Conclusions

To achieve sustainability (i.e., when no gap is observed between social, environmental, and economical areas and these are perfectly harmonized with reflection on the well-being of future generations), it is necessary to focus on education. This was the main goal of the present master's dissertation: to share knowledge and sensitize coffee producers, consumers, and the population in general. Indeed, only with the sharing of knowledge is it possible to exchange ideas and make effective changes in the future.

With this review, it was possible to clarify concepts and perceive different opinions about this very complex and relatively current theme. It will not be easy to make the entire coffee production chain sustainable as it involves many points where it can be difficult to apply the concepts and control the situation. But small sustainable actions in some parts of the chain can make a big difference. Indeed, a great effort on this field is still necessary not only from the part of governments and certifying entities but also from supply companies, producers and researchers, so that the ideas go all in the same direction and actions are expanded. Only with the union of all the parts, it will be possible to guarantee social, economic, and environmental benefits for all.

Along with this work, it was possible to clearly distinguish the three areas of sustainability (without forgetting that a change in one can influence the others) and apply them to the coffee production chain. Attention to endogenous species in the regions where coffee is cultivated, soil health, forest integrity, good agricultural practices, use of by-products, efficient water management, among other concerns, are part of the environmental field. In the social field, we can insert people who produce and harvest coffee, as well as their families, and a special attention should be given to their living and working conditions, which must be fair and dignified, to their health conditions, education, if human rights are being guaranteed, and if there is no child labor or any other form of forced labor. About the economic field, work should be paid, ensuring that payments that pass through the entire value chain actually reach producers and are distributed fairly and equally.

It was possible to understand that although certifications are not a guarantee for a complete practice of sustainability along the entire chain, they are at least a proof that something is being done. By this way, consumers should buy certified items instead of non-certified ones. There is also a paradigm shift on the subject. It should be pointed out, for example, the LIDL supermarket chain, which is doing a very positive job in raising consumer awareness, because they include the certificate symbol on the price presented to the consumer (this price is often competitive compared to uncertified products). They also refer when the product is certified in television advertisements. In fact, such marketing

strategies can encourage a paradigm shift, as well as sustainable practices. If they are well applied, they can be very positive.

With regard to the application of the circular economy concepts to the coffee production chain, there is already an effort on the part of companies and the scientific community, because more and more articles are emerging that demonstrate innovative ideas for the use of coffee by-products. However, there is still a long way to go until all wastes are used in a profitable way.

There are still many points that should be considered in future studies. There are also other topics that were not address in this review because this is a very complex theme with many key points that could be explored. One is the environmentally friendly food packaging and the response that the coffee consumer has in relation to its existence. A recent systematic review about consumers' opinions about different containers for storing food can be consulted [238]. Other points of future studies should cover economic issues related to certifications, carbon footprints due to the coffee production chain until it reaches the final consumer, environmental pollution issues associated with transport from producers to consumers, among others.

In sum, the creation and adoption of more sustainable business models could bring benefits to consumers, economic growth, and shareholder value. In addition, it allows the creation of more social, environmental, and economic value that will allow to achieve the objectives of the economic activity more efficiently [239]. Thus, and extrapolating to the coffee-producing chain, if all stakeholders work on a common direction and oriented towards a more sustainable practice, personal and business objectives will be achieved more easily.

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