The Role of the Circular Economy in the Coffee Value Chain and its Contribution Towards the Sustainability Development Goal 12 set out by the United Nations

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Declaration

I hereby certify that the material, which I now submit for assessment on the programme of study leading to the award of M.Sc., is entirely my own work and has not been taken from the work of others save to the extent that such work has been cited and acknowledged within the text of my own work. No portion of work contained in this thesis has been submitted in support of an application for another degree or qualification to this or any other institution.

Signed: Date:

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Abstract

The circular economy is a strategy that is gaining interest in resolving environmental and resource challenges that the food and beverage industry is facing. This study focused on how the circular economy can play a key role in the achievement of the sustainable development goal 12 of sustainable production and consumption that has been set out by the United Nations, with an objective to accomplishing the performance indicators identified. The worlds increasing population will result in increasing demands for food and beverages globally, placing increasing pressure on the already suffering environment and natural resources.

An overview of the current issues faced by the food and beverage industry and the coffee industry was given during this study. Spent coffee grounds normally end their lifecycle as waste in landfill resulting in greenhouse gases such as methane and carbon dioxide being emitted into the environment.

An evaluation was conducted on the various components that can be extracted from spent coffee grounds, and how value can be added to the spent coffee grounds either by the components of the spent coffee grounds that can be extracted, or the value added using spent coffee beans to produce energy.

In conclusion, the management of waste spent coffee grounds into energy and using the energy produced to roast coffee beans or use biofuel in various transportation steps along the coffee value chain is a promising outlook on how the circular economy can be used to achieve the Sustainability Development Goal 12 set out by the United Nations. Energy can be produced through various methods such as lipid extraction to create a biooil or through mixing spent coffee grounds with saw dust to create a pellet to burn in boilers. Future focus is required in the area to ensure all stakeholders of the coffee value chain are engaged and encourage strategic business models, with the uptake of the circular economy to achieve Goal 12 of the Sustainability Development Goals set out by the United Nations.

List of Abbreviations

Circular Economy	CE
European Commission	EC
European Union	EU
Food Business Operators	FBO
Food and Agriculture Organisation	FAO
Food Loss Index	FLI
Food Loss Waste	FLW
Food Waste Index	FWI
Green House Gas	GHGs
Sustainability Development Goals	SDGs
The Food and Agriculture Organization of the United Nations	FAO
United Nations Environmental Programme	UN Environment
Waste to Energy	WTE

Table of Contents

Chapter 1 Introduction

The focus of this thesis is to review the role of a circular economy (CE) business model in the coffee value chain and the contribution of the CE in the achievement of the Sustainable Development Goals (SDGs) in particular, goal 12 that has been set out by the United Nations (UN). Goal 12 focuses on sustainable production and consumption not only in the food and beverage industry but across all industries globally. The introductory chapter will provide an overview of the current waste situation in the food and beverage industry and its impact on the earth's resources. An overview will be provided of the linear economy versus CE and the SDGs. An insight will be provided into the challenges faced by the food and beverage industry to adapt a CE to reduce waste and do more with less to achieve the SDGs.

1.1 Overview of the Current Waste Situation in the Food and Beverage Industry

It is estimated that more than one third of food produced for human consumption globally is either lost or wasted during the food supply chain from production to consumption. This corresponds to almost $1 Trillion US Dollars (Alexander, et al., 2017). Food loss and food waste is one of the key obstacles and causes great challenges in creating a sustainable food, drinks and agriculture sector for many generations to come (Kozek and Wasilewska-Wojtan, 2020), however with the worlds increasing affluent population global food systems are subjected to increased pressure to deliver food and drinks while achieving environmental sustainability (Alexander, et al., 2017).The effects of food loss and food waste leads to wasted social, economic, and environmental opportunities. Food loss and waste can be defined as a decrease in the quantity or quality of edible food that is intended for human consumption, examples of a decrease in quantity include the redirecting of edible food to be used as animal feed, and sending food to landfill (Rezaei, 2017). Food loss can be defined as losses that occur within the food production system along the food supply chain from harvesting on the farm and right through to the food reaching the retail store. Food waste can be described as any waste that occurs at both the retailer and/or consumer level (Kozek and Wasilewska-Wojtan, 2020).

This report aims to focus on the coffee value chain. The coffee beverage many consumers are familiar with is the end product from roasted and ground Coffea plant seeds (Tylewicz et al., 2018).It is one of the worlds most consumed beverages, ranking second after tea and is cultivated in more than 80 countries across the world (Schmidt Rivera et al., 2020). Coffee is an important commodity, especially to the 25 million small producers who produce coffee to earn a living. Brazil is the largest producer and exporter of coffee in the world. It is estimated that each day over 2.25 billion cups of coffee are consumed across the globe, however while over 90% of the coffee produced in the world is produced in developing countries while consumption mainly occurs in the industrialised economies (Murthy & Madhava Naidu, 2012). With this variation of location of where coffee is produced and consumed, many greenhouse gases are associated with the transport from the exporting country to the importing country. Coffee as a beverage is usually consumed either hot or cold, however there are also many coffee flavored products on the market from syrups, chocolate, cake to yogurt, ice cream and cocktails. There are two coffee processing techniques to process from the coffee fruit to coffee beans, both which differ in complexity. These methods can be split into wet processing and dry processing (Murthy and Madhava Naidu, 2012). Each step has consequent waste associated with it.

The world's population is expected to reach 9.1 billion by 2050 (Rezaei, 2017), and as a result the worldwide demand for food will increase by 70% for food availability (Rezaei, 2017). The food loss and waste (FLW) already occurring in the food supply chain is expected to increase by 42% if no action is taken by the 27 European Union (EU) member states alone (Lemaire & Limbourg, 2019). FLW results in wastage of energy and resources invested in producing nutritional goods that end up being either lost or wasted along the food supply chain and ultimately not consumed (Kozek and Wasilewska-Wojtan, 2020) . This does not contribute to the sustainable production and consumption of food and beverages, as the biophysical boundaries of the earth are not respected. The global coffee market is also likely to experience growth, it was worth $102.15 Billion in 2019 and is expected to grow to a value of $155.64 Billion by 2026, with a compound annual rate (CAR) of 9%. The growth is expected due to increasing disposable income, white collar demographic, urbanisation and food service outlets, along with work cultures in corporate industries and enhanced living standards (Zion Market Research, 2020). The growth in the coffee industry will also put increase pressure on the earth's resources while contributing to increased levels of waste being sent to landfill and emitting harmful greenhouse gases (GHGs) such as methane and carbon dioxide into the environment. Current global consumption rates must be reduced to avoid global natural resources being completely depleted for future generations to come. A reduction in global consumption will improve the ever-worsening situation globally.

1.1.1 The Impact of Waste on the Environment

Appropriate waste management is a prerequisite for the sustainable production and consumption of food and beverage products. Waste can often be a non-value-added material across the supply chain from farmer to consumer, however waste can be a useful resource when managed correctly. By reducing FLW in the supply chain it can have a significant impact on the environment (Papargyropoulou et al., 2014). FLW results in energy and resources being invested in producing nutritional food and beverages that are not consumed. Farmers, producer's and manufactures across the supply chain need to make the most of the food that they are already producing to reduce the effect FLW has on water, land, energy, and other natural resources (Kozek and Wasilewska-Wojtan, 2020). Resource efficiency is a key call out when reducing FLW to minimise the natural resources being used but also the other emissions such as GHGs that are released into the environment and contribute towards global climate change (Papargyropoulou et al., 2014). A staggering 70% of global freshwater used is due to global food production (Lemaire and Limbourg, 2019). As seen in Table 1.1., if FLW was its own country it would be the 3rd largest greenhouse gas emitter globally (Lipinski et al., 2013). Global FLW accounts for about 8% of total anthropogenic GHG emissions. FLW contributes to global warming almost as much as global road transport emissions. In addition to the GHG emissions that are released to the planet because of FLW, almost 30% of the world's agriculture land is currently occupied to produce food that is ultimately never consumed (FAO, 2015). A reduction in FLW will contribute to a decrease in water, land, energy, and other natural resources being consumed. By preventing FLW from occurring it can reduce GHG by 456 million tonnes by 2050. Within the EU the food sector contributes to 22% of global warming, the food sector is also one of three sectors that is responsible for over 70% of the overall impact of human consumption and production (Papargyropoulou et al., 2014).

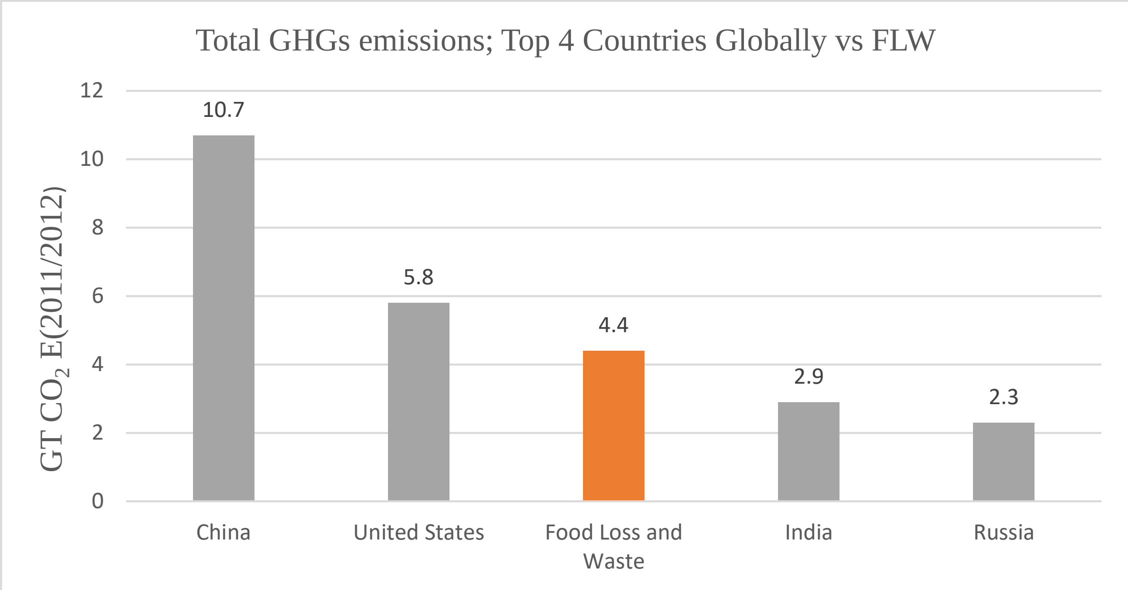

Table 1.1 Graphical representation of the GHGs emissions recorded globally in 2011/2012 versus the contribution of FLW to GHGs (FAO, 2015).

FLW also negatively effects the biodiversity across different commodities and regions. Cereal crops are likely to contribute to deforestation and species threats in the tropics. In comparison to meat which has a higher environmental impact than cereal crops however FLW only threatens species by a third (Vilariño et al., 2017). Coffee is a sensitive crop that requires a specific set of climatic characteristics including temperature, humidity, season length, and precipitations. Climate change can affect these conditions required to grow coffee. The final disposal of FLW has negative impacts on the environment especially when the final disposal is in landfills. Methane and Carbon Dioxide are produced during the natural decomposition process of FLW in landfills, which both contribute to climate change as they are GHGs. Methane is more potent than carbon dioxide as it traps 21 times more heat in the atmosphere than carbon dioxide. FLW that ends up in landfill contributes to 3% of global GHGs (Papargyropoulou et al., 2014).

1.1.1 The Impact of Waste on Socio Economic Factors

Everyone deserves a right to food and food security (Kozek and Wasilewska-Wojtan, 2020). As a society we need to make the most of the food that we already produce. Global food production is a topical subject as there are 820 million undernourished individuals across the globe while, there are 650 million individuals suffering from obesity (FAO, 2015). By decreasing FLW it will reduce world hunger and improve food security along with ensuring the safe delivery of food, especially for those in developing countries (Vilariño et al., 2017). FLW is thought to value at almost $1 Trillion US Dollars each year (Alexander et al., 2017). North America and Europe discard 30-50% of food supplies, that is enough to feed the undernourished population three times over. Global food security is an increasing global issue and raises questions about the amount of FLW in the global food supply chain, that otherwise could be used to feed people (Papargyropoulou et al., 2014).

Agriculture costs are associated with FLW due to the time invested in the production. Food that is not consumed in the food supply chain is also a significant economic loss. Not only does the increasing population, increase demand for food production, it also increases pressure on the environment. Moreover, it threatens the level and quality of life from food producers to consumers who are disadvantaged (Kozek and Wasilewska-Wojtan, 2020). A combination of an increasing global population, and one third of food being lost or wasted, there is a drive for the responsible production and consumption of food. In addition, FLW also results in less food being produced which results in a decrease in the quantity available to sell to consumers and in turn will result in a rise in food prices. Increasing food prices can accelerate poverty in developing countries. FLW can also result in a decrease in income for small farmers. With food prices rising and reduced income for farmers it will ultimately result in limited access to affordable food for lower income individuals (Vilariño et al., 2017). Avoidable FLW can have direct and negative impact on both farmers and consumers. By reducing FLW it can reduce food insecurity in the food supply chain. It can have an immediate and significant impact on the livelihoods of small farmers. It can reduce food poverty amongst consumers with a priority to supply nutritious, safe, and affordable food. Food insecurity is a question of access rather than supply. A decrease in FLW can decrease the cost of food and increase the access to food across the globe (Papargyropoulou et al., 2014).

1.2 United Nations Sustainable Development Goals

In 2015 the UN established 17 SDGs. The SDGs is a policy framework with an aim to regulate global development by 2030.The main aim of the SDGS is to end poverty and hunger, protect the plant and ensure prosperity for all populations and generations to come. The SDGs came into effect on January 1, 2016 (Lipinski et al., 2013).

The UN has recognised sustainable consumption and production as a distinct goal, SDG 12. The goal is to ensure sustainable consumption and production patterns across all industries and not just the food and beverage industry. Over the last century economic and social progression in many countries has led to the environmental degradation that is endangering the systems that which our future development and survival on earth for generations to come depend on. Not only industries but the entire population need to develop recovery plans that will reverse the current trajectory of trends and shift consumption and production patterns to a more sustainable production. This will lead to improvements in recourse efficiency and the consideration of the entire lifecycle of all economic activities (United Nations, n.d.) . The aim of Goal 12 Sustainable Consumption and Production is to do more and better with less. The 3rd target under SDG 12, target 12.3 calls for 'halving per capita food waste at the retail and consumer levels and reducing food losses along production and supply chains (including post-harvest losses) by 2030 (Lipinski et al., 2013). To meet the expectation of the world's population and to continue to supply food and beverages, it is critical that we do so in a sustainable manner. The demand for increasing food and beverages must be met by minimising the use of natural resources and reduce the waste and pollutants generated through the entire production and consumption supply chain.

SDG 12.3 is the biggest challenge embedded in goal 12. The progress towards SDG 12.3 can be measured by indicator 12.3.1, split into the Food Loss Index (FLI) 12.3.1a and Food Waste Index (FWI)12.3.1b (English and Food and Agriculture Organization of the United Nations, n.d.). The Food and Agriculture Organisation of the United Nations (FAO) and the UN Environmental Programme take ownership for the indicators FLI 12.1.1a and FWI 12.2.1b with the aim of providing the data for the estimates of FLW in the supply chain and the providing information of the causes of FLW in the supply chain (English and Food and Agriculture Organization of the United Nations, n.d.). Under the SGDs 12.3, the 50% reduction only applies to food waste, while no quantified reduction has been given for food loss. SDG 12.3 is an ambitious target that is achievable with the commitment of public and private sectors (Lipinski et al., 2013). Governments across North America, Europe and Australia have implemented policies and targets aligned with SDG 12.3 including both food loss and waste, while African and Asian Governments have only aligned with target 12.3 in addressing food loss only. There is greater implementation of national and regional governments measuring FLW as opposed to implementing polices, these include Canada, North America, South America, Europe, and Australia (Lipinski, 2013). The United Kingdom has reduced its food loss and waste levels by 25% from 2007 to 2018, the first country to get more than halfway towards meeting the target. Many of the world leading food manufacturing companies have also committed to aligning their targets with the SDGs. With less than 10 years to go, globally both government and food company targets have a long way to go if the target is to be met by 2030. Both countries and food and beverage companies must act to reduce their FLW (Lipinski et al., 2013).

Other targets in Goal 12 include the achievement of sustainable management and efficient use of natural resources covered under Goal 12.2. Goal 12.5 calls for reducing waste through prevention, reduction, recycling and reusing. Goal 12.6 calls for companies to adopt sustainable practices and to integrate sustainability information into their performance indicators. Goal 12.A calls for support in developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production. An overall achievement of Goal 12 sustainable consumption and production will contribute to the transition towards low carbon and green economies (United Nations, 2020).

Figure 1.1 highlights how reducing food loss and waste can impact the 17 other SDGs set out by the UN. SDG 12 sets the expectation of what is expected for the sustainable consumption and production patterns across all industries and can be applied to the food industry. By achieving SDG 12.3 it can have a positive impact on the other SDGs set by the UN. SDG 2 is linked to the food system as the expectation of this goal is to end hunger and achieve food security and improved nutrition across the globe and reduce the imbalance between the over nourished and undernourished population. The goal of SDG 6 is to achieve sustainable water management, the goal of SDG 11 is to achieve sustainable cities and communities, SDG 13 is related to climate change, and the SDG 15 goal is to improve terrestrial ecosystems, forest, land, and biodiversity. Reducing food loss and waste can have knock effects on SDG 1 as the goal is to end poverty, SDG 8 is based around sustainable economic growth and decent employment, along with SDG 10 and its goal to reduce inequalities. Progress on other SDGS can also impact and help achieve SDG 12. SDG 5, 7,9 and 17 can all have beneficial impacts on achieving SDG12 as their goals include gender equality, affordable and clean energy, infrastructure, industry and innovation, and partnerships respectively (English and Food and Agriculture Organization of the United Nations, n.d.).

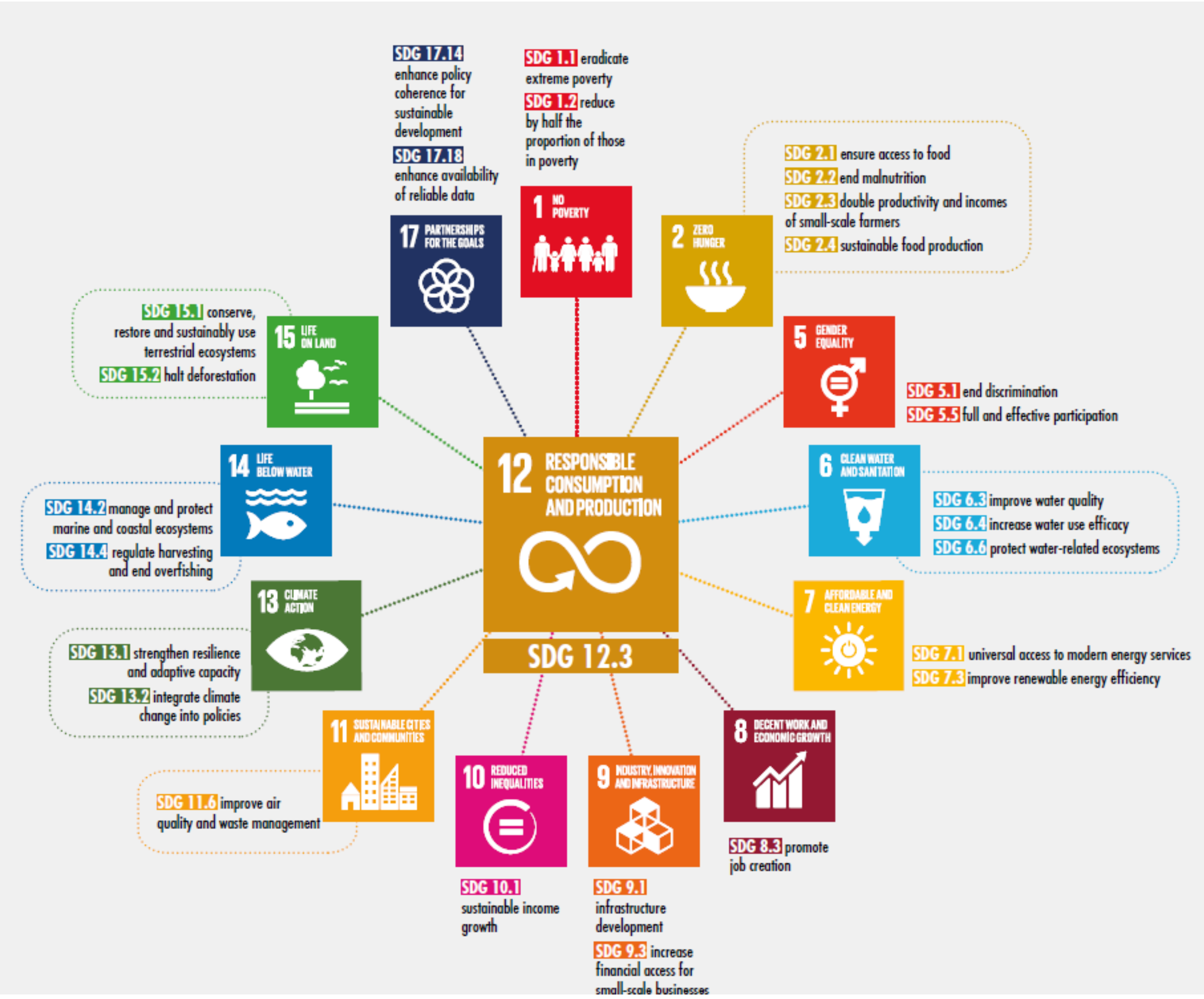

Figure 1.1 The 17 Sustainable Development Goals and their links to Goal 12 Responsible Consumption and Production. The round boxes refer to the impacts on food security, nutrition, natural resources, and the environment (English and Food and Agriculture Organization of the United Nations, n.d.)

1.3 The Challenge in Achieving SDGs

FLW refers to food intended to be eaten by people that leaves the food supply chain somewhere between being ready for harvest and being consumed. This journey from harvest to consumption is often referred to as from ‘farm to fork’. Food can be referred to as any substance (processed, semi processed or raw) that is intended for human consumption or more specifically, ingestions. Food loss and food waste are identified separately. Food loss is considered as unintended and caused by poor functioning of the food production and supply system or by poor institutional and legal frameworks. Examples of food loss include food that rots in storage because of poor refrigeration. Food wastes in comparison can be considered foods that are lost due to intended behaviors, i.e. by choice and examples include food that been spoiled. Food loss is often used to describe what is lost from farm to retail stores, and food waste is used to describe food that leaves the supply chain from retail to consumption however both food loss and food waste can apply anywhere along the food supply chain. To achieve the SDGS 12 and the sustainable production and consumption of food, there are various challenges that the food and beverage industries are faced with which will be discussed in further detail in this study (Hanson and Mitchell, 2017).

1.3.1 Quantifying Food Lost and Waste

For companies to implement more sustainable practices and embed sustainability into their strategies they must be able to quantify their FLW. SDG 12.3 sets the objective to halve per capita food waste at retail and consumer levels by 2030 and reduce food loss including post-harvest loss in the food supply chain. There is little known about how much food loss and waste occurs through the supply chain however the SDG monitoring framework of the FLI 12.3.1a and FWI 12.3.1b is expected to bridge this gap. Both FLI & FLW are under the custodianship of two UN agencies, FAO, and the United Nations Environmental Programme (UN Environment). Both agencies are working together to mandate these indicators and publish details on how FLI and FLW should be calculated throughout the supply chain.

1.3.2 The Food Loss Index & Food Waste Index

The FLI 12.3.1a focuses on the percentage of food removed from the food supply chain and its aim is to monitor the development and improvements of the FLI overtime with a reference point starting in 2015. By focusing on the FLI it will allow progress to be tracked against SDG 12.3. The FLI is calculated on loss percentages for the most accurate calculation, if it was based on total food production the FLI could increase overtime with an increase in production (English and Food and Agriculture Organization of the United Nations, n.d.) . Food loss can be classified as 'all the crop, livestock, fish and human-edible commodity quantities that, directly or indirectly, completely exit the supply chain post-harvest, post -slaughtering or post catch. The food leaves the supply chain and is discarded, incinerated, or otherwise disposed of, and does not re-enter the supply chain in any other utilisation (such as animal feed, industrial use, etc.) up to and excluding, the retail level. Losses that occur during the storage, transportation, and processing, as well as imported products, are therefore all included. Loss includes the commodity with its inedible parts (English and Food and Agriculture Organization of the United Nations, n.d.).Inedible parts however can strongly depend on cultural context (Hanson and Mitchell, 2017).

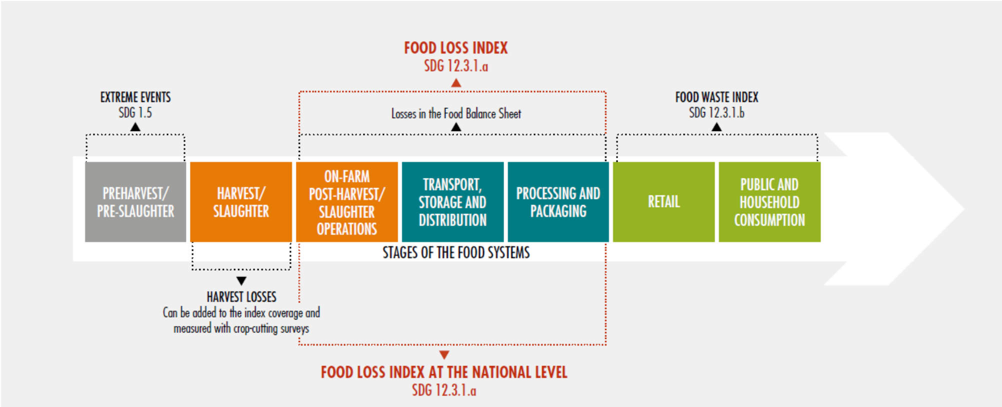

Figure 1.2 The scope of the FLI and FLW along the food supply chain (English and Food and Agriculture Organization of the United Nations, n.d.)

The first global estimate of the FLI released in 2019 contained details of food that was produced in 2016. Total FLI was 13.8% from the farm up to but excluding the retail stage. Table 1.2 focuses on the percentage of food loss globally and regionally. The greatest food loss is in Central and Eastern Asia of between 20-21%, in comparison to Australia and New Zealand with a food loss estimate of 5-

6%. The gap between Asia, a continent with many developing countries and Australia a developed country of almost 15% is a call for action. SDGS 12.A calls for support in those developing countries, to increase their scientific knowledge and technological capabilities to help reduce FLW and work towards a more sustainable consumption and production pattern across the supply chain (English and Food and Agriculture Organization of the United Nations, n.d.).

When comparing food loss across different commodities and seen in Table 1.3, root , tubers and oil bearing crops had the biggest percentage of food loss at an estimate of 25% with cereals and pulses having the smallest percentage of food loss at 15-16%.

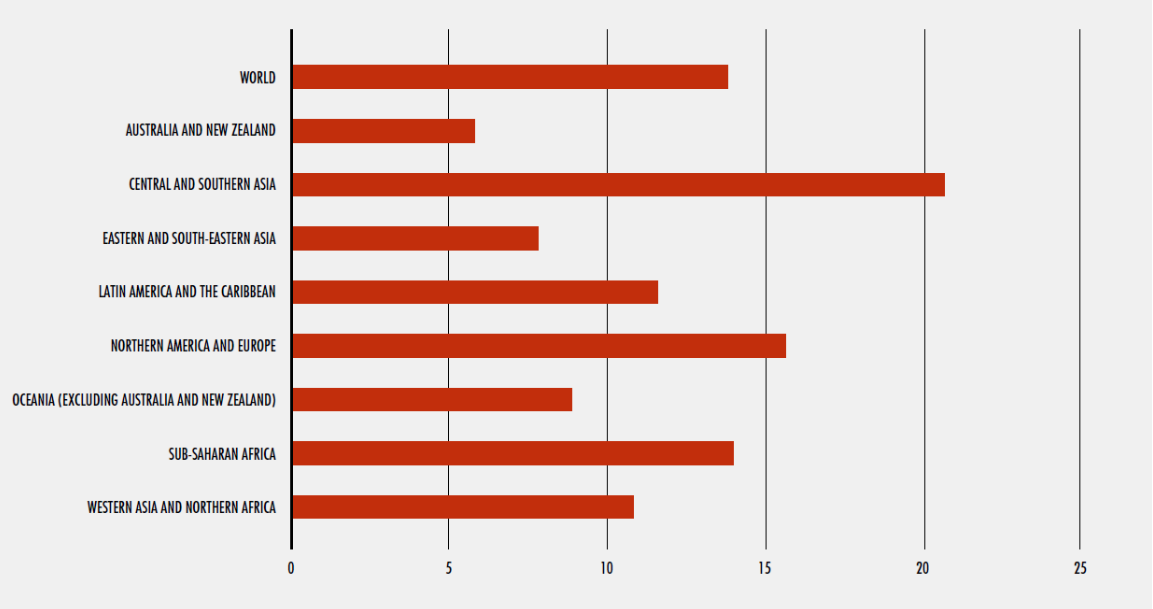

Table 1.2 Global and regional food loss from post-harvest to distribution in 2019 (English and Food and Agriculture Organization of the United Nations, n.d.).

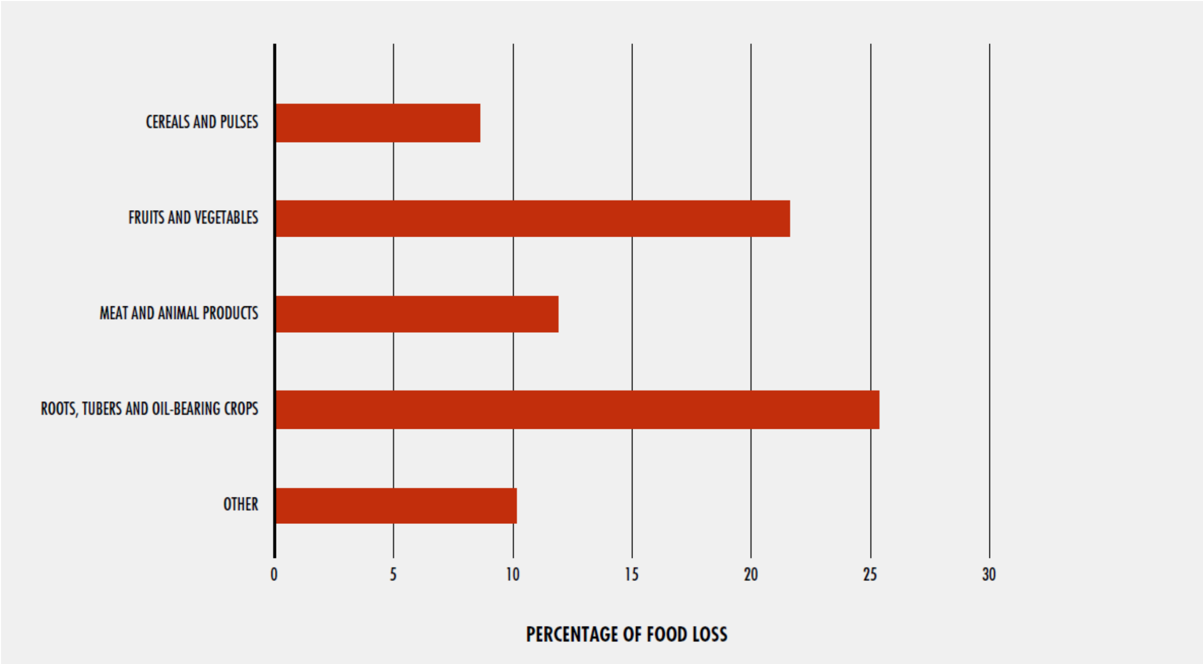

Table 1.3 Percentage of food loss across various commodities (English and Food and Agriculture Organization of the United Nations, n.d.)

In relation to FWI, significant work has gone into developing the methodological framework for it however the first estimates of food waste are still in preparation. Though the measuring of FLI is more advanced there are still numerous challenges associated with it. Definitions across industries are not consistent resulting in the comparability of data over time to be poor. The FLI also only focuses on 10 key commodities from five commodity groups ranked by production value and includes inedible parts which vary with cultural context (English and Food and Agriculture Organization of the United Nations, n.d.).Reducing food loss and waste can generate a triple win as it can save money for farmers, companies, and households. It can feed more people, while alleviating pressure on water, land, and climate (Hanson and Mitchell, 2017) and as a result contributes to a world of sustainable nutrition.

However, the data on FLW does not cover the whole supply chain, including the economic value of the amount of loss or the nutritional value of the FLW, it just focuses on the quantity lost. Lack of measurement of FLW makes it difficult to prove that there is a reduction occurring at each stage of the supply chain in the food industry.

1.3.3 Food Lost in the Food Supply Chain

For food producers to improve their sustainability commitment and achieve the SDG target called out in 12.3 it is essential that they understand why and where food is lost and wasted along the food supply chain. There are various reasons why food is lost in the food supply chain and they can be described as unintentional losses and intentional losses. Unintentional losses can be described as losses that are beyond the food producers' control in comparison to intentional losses that can be described as losses that are known and planned for (Raak et al., 2017). Understanding why food is lost and wasted is key to addressing issues however this often presents a challenge.

1.3.3.1 Intentional Losses

Intentional losses are tolerated in the food supply chain as they can be considered optimal from the perspective of producers to maximise their profits. A food producer may suffer from some physical loss of food due to product changes on the manufacturing line (Dora et al., 2020) (Principato et al., 2019), the taking of samples to meet external requirements or research and development requirements (Raak et al., 2017), or to inedible parts not fit for human consumption. Often the physical loss of food due to product changes on the manufacturing line decreases further food loss e.g., allergen contamination. The physical loss of food is often due to food residues on the line, it is important that raw materials and finished product from previous productions are fully removed, if not it may result in quality and food safety defects which in turn would result in further food loss (Dora et al., 2020). The stringent controls around food safety also lead to requirements for both microbiological and analytical analysis sample taking. These samples are classed as intentional losses. It is the responsibility of all Food Business Operators (FBO) to produce safe food as stated in the European Commission (EC) regulation 178/2002 and all member states must obey this law (European Commission, 2002). Losses expected in each production run that are not intended to be consumed by humans e.g., peels, seeds and inert waste are all classified as intentional food loss (Secondi et al., 2019). Intentional losses therefore contribute to the FLW in the supply chain.

1.3.3.2 Unintentional Losses

Unintentional losses along the food supply chain occur from harvest, to storage and transportation right through to packaging (English and Food and Agriculture Organization of the United Nations, n.d.). During harvesting, harvested crops may be left in fields due to quality standards not being met e.g., irregular fruit and vegetables or poor harvest scheduling. However, this could be reduced if the consumer changed their perception on irregular shaped fruit and vegetables. During storage and transportation food is lost due to lack of proper storage or transportation facilities (English and Food and Agriculture Organization of the United Nations, n.d.). The type of food is factor to food loss during storage and transport. Foods that have soft tissue are more likely to be damaged due to greater impacts during transport and storage due to compressions and abrasions. If serious damage occurs the food may not be processable and therefore, becomes unmarketable and inconsumable (Raak et al., 2017).

During processing and packaging technical malfunctions, and lack of proper process management can be causes of food loss (English and Food and Agriculture Organization of the United Nations, n.d.).The overproduction of food is a common reason for food loss in the food supply chain. Approximately 30% of overproduction of food during processing is required to balance unexpected losses however it can be estimated that overproduction currently exceeds 50%. There can be various reasons for the overproduction of food, including the risk of non-conforming product and poor forecasting (Raak et al., 2017). On short shelf-life products, the challenge for food producers is to get the right balance between shelf-life availability and minimum unsold food surplus. Production efficiency including establishing production sequences while ensuring the production of safe food is key to reducing overproduction and therefore reducing food loss in the food supply chain (Raak et al., 2017). Adding further to what food manufactures cannot control is power blackouts. Power blackouts can lead to food loss depending on the length of the power blackout and the type of food affected. While most food products can be reworked or reprocessed there are also many foods that cannot as further processing can change the profile of the food and therefore would not be consumable due to its sensory attributes (Raak et al., 2017). Equipment defects can also lead to food loss in the food supply chain (Raak et al., 2017) (English and Food and Agriculture Organization of the United Nations, n.d.). Equipment defects could be reduced by food manufactures investing in more sophisticated machinery however the cost of investing in the machinery could exceed the value of the savings in food loss (English and Food and Agriculture Organization of the United Nations, n.d.). Human errors are also classified as unintentional losses. Examples of human error occurring in manufacturing includes, the breakage of jars, incorrect labelling, errors in recipes, bad handling, lack of knowledge and a low level of training leading to policies not being followed resulting in expired shelf-life material not fit for use and therefore results in food loss (Dora et al., 2020)(Secondi et al., 2019).

1.3.4 Complexity of the Food Supply Chain

It can be estimated that food is handled approximately 33 times before it reaches the consumer through the first stages of the food supply chain (Dora, et al., 2020). The food supply chain as detailed in Figure 1.3, is a process that includes many stakeholders from the early stages of agriculture right through to the final consumer. To achieve SDG 12.3 as set out by the UN it is critically important that each stakeholder in the food supply chain plays a role in working towards halving per capita food waste at the retail and consumer levels and reducing food losses along production and supply chains (including pos harvest losses) by 2030 (Lipinski et al., 2013)but by also ensuring that at each step along the supply chain considers the sustainable management and efficient management of natural resources, by adopting sustainable practices and strengthening developing countries scientific and technology capacity. It can be achieved by adopting sustainable practices by reducing waste through prevention, reduction, recycling, reusing or in simple terms adopt a circular economy approach. The complexity of the food supply chain and the many stakeholders that are involved through each stage adds increased stress to decision making processes as all stakeholders must have the same goal and vison to reduce FLW along the chain.

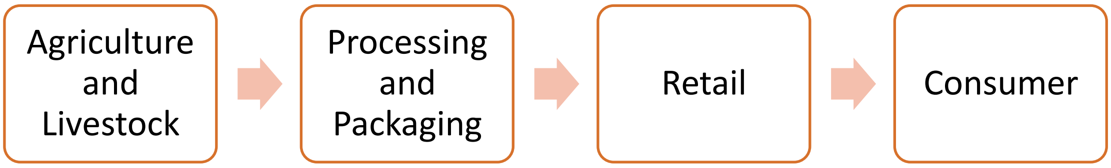

Figure 1.3. The food supply chain, between each step storage and transportation occurs (Raak, et al., 2017).

1.4 What Happens when Food is Lost?

The Waste Hierarchy outlined in Figure 1.4 was first introduced in the 1970's and became a legal binding in the EU back in 2008 through revision to the Waste Framework Directive. The Waste Hierarchy framework uses the basic concept of reduce, re-use, recycle with the aim of identifying options that will most likely drive the best overall environmental outcome with the most favorable option of discarding FLW to prevent it from occurring in the first place with the least favorable option to discard FLW is to dispose of the FLW in landfill (Papargyropoulou et al., 2014). For the most part reduction and elimination are at the forefront in the waste hierarchy however in most situations due to practical constraints the generation of waste is inevitable (Mata et al., 2018). Following reduction and elimination, valorisation of residues, in particular recycling or energy recovery are popular choices. The first approach is trying to recover as much waste as possible by using materials that have commercial value and can serve as raw materials to obtain new products. Raw materials used for energy recovery is used primarily for combustible waste in particular waste of organic composition. Waste that is used in energy recovery is often waste that ends up in landfill and contributes to GHGs (Mata et al., 2018).

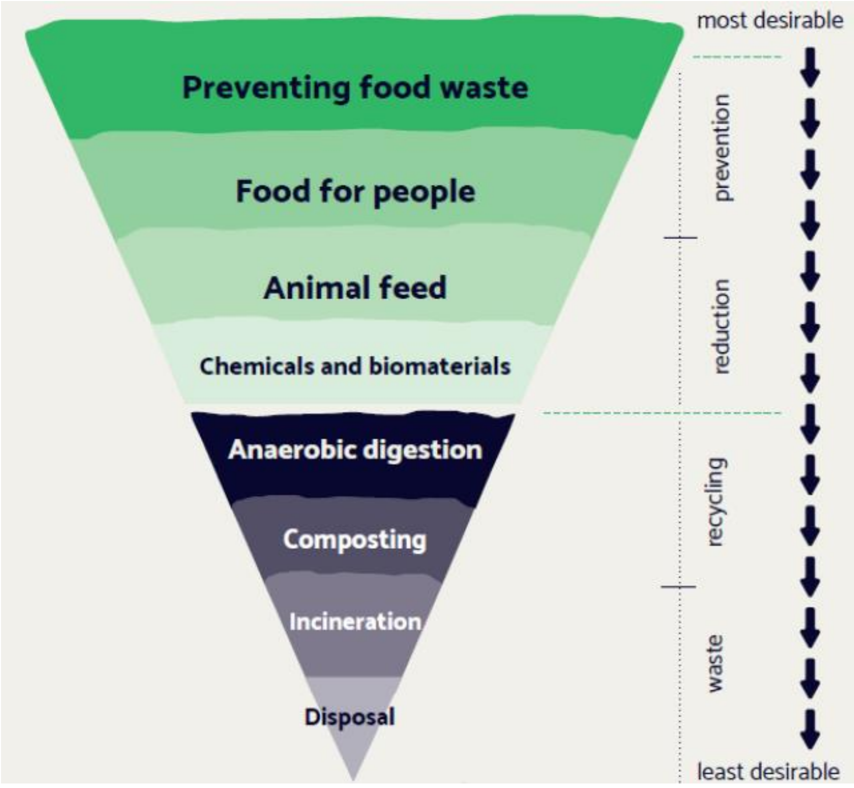

Figure 1.4 The Waste Hierarchy (Papargyropoulou et al., 2014)

For the UN SGD 12 to be achieved by 2030 collaborative and concentrated efforts to reduce FLW needs to occur. The best waste management system should be chosen however it is essential that the amount of waste is known, the composition of the waste and the frequency the waste produced. If recycling waste, it should be separated as soon as possible from other waste to avoid contamination. Education of all stakeholders involved in the food supply chain from the farmer to the consumer regarding the disposal of materials is necessary. To fully implement a waste management system, it is important that a systematic review of the whole process is completed, starting from collection, including storage and transportation, extraction/recovery of valuable components under the most adequate route, followed by removing contaminants with the least waste as possible going to landfill.

1.4 Waste Valorisation

By redirecting waste from its destination to the landfill and rejuvenating its life creates value from something that once would have cost to dispose of. By creating new value from waste, it benefits both the planet and people, creating a world of sustainable production and consumption. To create waste valorisation the shift from a liner economy to a circular economy is required.

1.5.1.1 Linear Economy

The linear economy can be described as a 'take – make – dispose' economic model. The linear economy is associated with high energy consumption and waste production (van Keulen and Kirchherr, 2021). Ever since the Industrial Revolution began in in late 1700's the world has been following a linear economy strategy. Figure 1.5 shows the unidirectional model of production, where natural resources provided to our factory's are inputs that are then used to create mass produced goods to be purchased and typically disposed of after a single use. The linear economy puts emphasis on mass production and mass consumption. The linear economy is testing the limits of the globe and as a result is unsustainable. If we continue at the same rate with no change we will need more than two planets worth of natural resources if demands are to be met by 2030, and three planets worth by 2050 (Esposito et al., 2018).

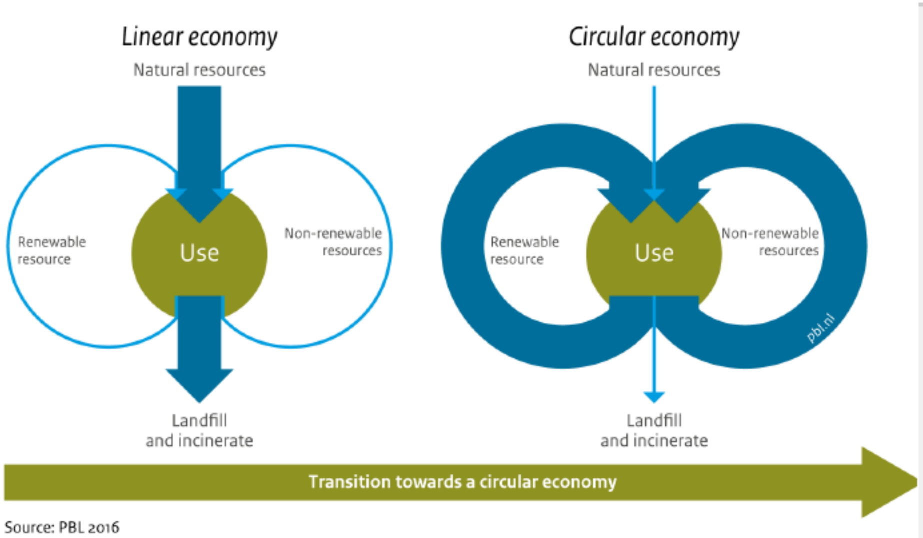

Figure 1.5 An overview of the transition towards a circular economy, with a shift from the traditional linear economy to a more circular economy (Potting et al., 2017).

1.5.1.2 Circular Economy

The Circular Economy (CE) provides an alternative to the current 'take-make-dispose' linear economy. Producers across the world need to act now to because there is no plant B, quoted by the Former UN Secretary General Ban Ki-Moon ahead of Paris Climate summit in 2015. The current models of production and consumption have placed increasing pressure on finite natural resources, while creating escalating carbon emissions, pollution, and waste. The circular economy focuses on the reduce, reuse, recycle methodology however the potential needs to be unlocked. The circular economy chooses to use the produced assets during production and/or consumption of a product. A company can see economic growth from the original resource consumption, it maximises what is already in use along all points of a products lifecyle from source to consumption (Esposito et al., 2018). It gives new life to a material previously considered waste contributing to the CE. The CE is a practical tool and can be used as a starting point of sustainability concepts or corporate social responsibility as it focuses on the closure of loops and minimises the environmental impact. As seen in Figure 1.5, in a circular economy chain, the materials from a discarded product ideally maintain their original quality so they can be applied again in the same type of product. As a result, no natural resources are needed to produce the new materials and discarded products no longer become waste or at lease delay the time it takes for them to reach landfill or incineration. The more circularity a product like coffee has, it leads to the reduced consumption of natural resources and production of new materials and directly impacts environmental effects by lowering them.

Chapter 2

Coffee

2.1 Coffee Value Chain

There is a strong 'take – make – dispose' attitude during the processing of coffee from production right through to consumption. With much of the waste associated with coffee ending up in landfill emitting harmful GHGs such as methane and carbon dioxide. Waste associated with coffee is being disposed of in the least desirable way according to the waste hierarchy outlined in Figure 1.4., with much waste going to landfill or incineration. When drinking your morning cup of coffee or one of the 2.25 billion cups that are consumed each day, it is important to think of the ethical, social, and environmental factors. Our coffee addiction not only has major consequences for the climate and biodiversity but also the financial wellbeing of the farmers across the world who grow the beans (Nespresso, 2020). Coffee has been grown on this earth for many centuries and can be traced back to the ancient coffee forests on the Ethiopian plateau. The best regions for growing coffee across the world include Colombia, Brazil, Guatemala, Ethiopia, Costa Rice, Kenya, India, and Mexico (Nespresso, 2020). It is a plantation crop belonging to the Rubiaceous family, subfamily Cinchonidea and tribe Coffeae. The sub genus Coffea is said to have over 80 species. It is a perennial plant and evergreen in nature, it has a vertical stem with a shallow root system (Murthy and Madhava Naidu, 2012).

It is said that if you know the origin of your coffee including the country and region, the specific characteristics of the coffee can be easily identified. This is due to the natural environment in which it is produced, the processing methods and general coffee growing culture in these geographic locations. There is a distinct journey of coffee from farm to cup as seen in Figure 2.1 below. As an agricultural product coffee is grown, selected, harvested, and processed on a farm, however a more sustainable approach to coffee production is required both socially and environmentally. This will allow farmers to consistently produce good quality coffee for many generations to come (Nespresso, 2020).

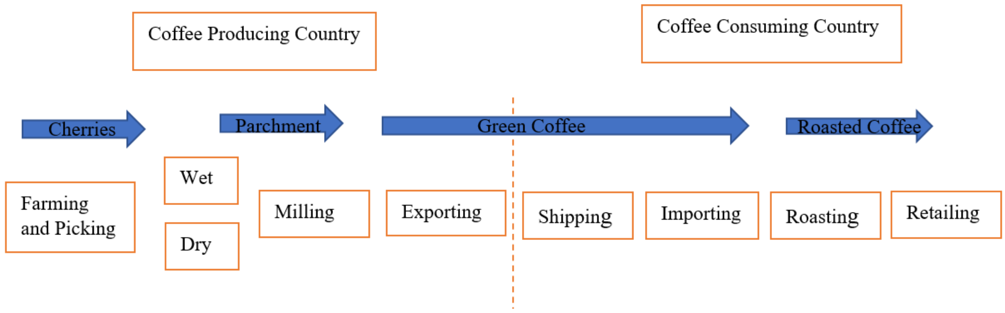

Figure 2.1 The Coffee Value Chain; an overview of the journey from the growth of the cherries right through to roasting coffee to send to the retailer for consumption (van Keulen and Kirchherr, 2021).

The coffee value chain seen above in Figure2.1 shows the various processes that coffee production can follow from farm to cup. Coffee grows as a fruit on a tree, in red cherries as big as a marble. The processing of the fruit results in two beans, with a characteristic curved lined formed in the middle. Depending on weather the coffee is wet or dry processed the beans are then known as parchment coffee, this refers to the parchment like layer that remains after the dry or wet process but still covers the bean, once the parchment is milled off the coffee is then known as green coffee and is ready for export. Once exported and shipped to the consuming country, the coffee is then roasted resulting in brown coffee beans that most consumers would relate to and associate to be coffee. Along this journey from farm to cup there are many residue and side products created which many are seldom used and are discarded as waste (Murthy and Madhava Naidu, 2012).

2.2 Types of Coffee Processing

The cherry fruit grown can be processed by either wet or dry processing.

2.2.1 Wet Coffee Processing

Wet processing is one of two ways that coffee can be processed when harvested from the fields. Wet processed coffee is called washed or parchment coffee. During wet processing the fruit pulp that is covering the coffee beans is removed by the pulper before they are dried. Various types of pulpers can be used such as a drum pulper, disk pulper, vertical and spiral drum pulper however all with the same primary objective to ensure the complete removal of mucilage (a thick gluey substance produced by plants) from the parchment cover for the production of high-quality coffee. The mucilage is digested through natural fermentation at an optimal temperature of 30-35 °C to avoid over or under fermentation which can lead to loss of bean color or moisture absorption respectively. Depending on the species of coffee this process can take up to 72 hours. In addition to removing the mucilage by fermentation there is a mechanical way of completing the process. The use of the machine is advocated to completely/partially fermented beans basically to achieve a total washing of the coffee beans to reduce the quantum of water usage and to achieve a desirable coffee flavor. Following the washing of the beans the parchment is soaked in clean water for 12 hours improving the beans visual appearance. Once washed the beans are dried on drying barbecues (Murthy and Madhava Naidu, 2012).

2.2.2 Dry Coffee Processing

Dry coffee processing can be performed as opposed to wet coffee processing. During the dry processing of coffee, the freshly harvested fruits are spread evenly across, approximately 8cm on a clean drying yard. They are stirred and rigid once every hour. The cherries on the coffee fruit are considered dry when a fistful of coffee produces a rattling sound when shaken. The drying of the cherries takes between 12-15 days under right weather conditions. The correct drying contributes to the quality of the coffee with respect to colour, shape and aromatic constituents. The drying rate is dependent on initial moisture of the parchment, ambient air temperature, humidity, thickness of the spread and how often it is stirred (Murthy and Madhava Naidu, 2012).

2.3 The Roasting and Brewing of Coffee

Following wet and dry processing the by products which are green coffee beans are classified into washed and unwashed depending on if they were wet or dry processed. Green coffee beans contain both volatile and nonvolatile compounds, with their major components being carbohydrates, protein, lipids, minerals, ash, caffeine, chologenic acid and trigonelline. Moreover, the green coffee beans become consumable once the coffee bean has become roasted. The quality of the green coffee bean is characterised by its odor and flavour, with size, shape, colour, hardness and presence of defects also contributing to the overall quality of the coffee. The well-known flavor and aroma of coffee are due to the hundreds of chemical compounds that are produced by reactions that occur during the roasting of coffee. There are three stages during coffee roasting, 1. drying, 2. roasting and

3. cooling. During the drying stage the bean change from green to yellow due to the slow release of water, volatile substances are released. During roasting, pyrolysis reactions occur resulting in major physical and chemical changes in the coffee beans properties, the major reaction that occurs during this stage is the Maillard Reaction. The cooling/brewing stage of coffee will be dependent on the type of coffee desired e.g., filter coffee, nordic boiled coffee, Turkish style, espresso, or cappuccino. Coffee processing is often viewed as an art as well as a science and involves a series of stages each with a distinct purpose. The production of high-quality coffee requires precise following of the procedures at each stage (Murthy and Madhava Naidu, 2012).

2.4 Waste Generated During Coffee Production

A large amount of waste is produced during processing from the initial fruit stages to consuming coffee from a cup.

2.4.1 Waste Generated During Wet/Dry Processing

The coffee pulp the is the first by product obtained during processing, for every 2 tons of coffee produced 1 ton of coffee pulp is obtained during wet processing. Coffee husks are produced when coffee berries are processed using the dry processing method. It is estimated that 0.18 ton of husk is produced from 1 ton of coffee fruits (Murthy and Madhava Naidu, 2012).

2.4.2 Waste Generated During Roasting Coffee

The coffee silver skin is obtained during the roasting process. The silvers skin is essentially what covers the coffee seed. During roasting the coffee beans expand and the silver skin is detached, and therefore becomes a waste product (Murthy and Madhava Naidu, 2012).

2.4.3 Waste Generated During Coffee Brewing

Spent coffee grounds is the waste obtained during the brewing process of coffee production. One ton of green coffee generates about 650kg of spent coffee and about 2kg of wet spent coffee is obtained for each soluble coffee produced (Murthy and Madhava Naidu, 2012). With the world population consuming over 2.25 million cups of coffee every day, the UK contributes to on average to 95 million of those cups. To make a cup of coffee using fresh ground coffee you will need approximately 11 grams of ground coffee, this results in 381,000 tonnes of ground coffee being used to brew cups of coffee every year. Moreover, contributing to quarter of a million tonnes of wet, waste coffee grounds each year in the UK. Typically spent coffee grounds are dumped into general waste and sent to the landfill emitting harmful greenhouse gases, including methane. Methane is a greenhouse gas that is 25 times more potent than Carbon Dioxide when measured over a 100-year period (Bio-Bean, 2021).

2.5 Issues in the Coffee Supply Chain

As SDG 12 relates to the sustainable production and consumption patterns, the regions where we source our coffee are particularly vulnerable to the impacts of climate change, including extreme temperature fluctuations, heavy rainfall, and droughts. This poses serious risks to coffee crops. To secure a consistent supply of high quality, sustainably grown coffee, coffee roasters and producers should directly work with coffee farmers and educate the farmers in developing countries as per SDG 12.A. Direct work with coffee farmers and training helps improve the coffee yield and quality of their harvest, while protecting the environment and improving their livelihoods. The education and training given to farmers ranges from simple techniques to more complex techniques. This includes showing farmers how to hand harvest only the cherries that have reached perfect ripeness, stumping the coffee tree to improve its yield, implementing fertilisation programmes based on soil and leaf analysis or integrated crop management practices. Farm management improves the overall sustainability of the coffee including the environment and its water use, soil conservation and deforestation prevention but also the safety, fair treatment of workers and prohibition of child labour (Nespresso, 2019).

2.6 Linear Vs Circular Economy in the Coffee Value Chain

In 2019 Bord Bia reported how consumers enjoy the consumption of coffee allowing them to relax, work and socialise. However, sustainability initiatives are front, and center as single use fall out of flavor for the consumer (Bord Bia, 2019). Although, coffee production and consumption follow a very linear economy of ‘single use’. Every stage in the supply chain from the fruit, to the spent coffee ground to even the cup it is consumed in is single use. The food and drinks industry are known for their ‘take, make, dispose’ attitude. It consists of an unidirectional model of production, where natural resources are used to provide raw materials for our factories, resulting in the mass production of 2.25 million cups of coffee per day in the UK and purchasing of the coffee by consumers with all waste associated with production of the cup of coffee typically disposed of after a single use. This linear approach to the production and consumption of coffee and other food and beverages across the food industry are testing the physical limits of the globe and threatening the stability of the earths future. At present, habitants of the earth are consuming resources at a 50% faster rate than what can be replaced. By 2030 the demand that will be seen by our inhabitants will require more than two planets worth of natural resources (Esposito et al., 2018). A higher level of circulatory in the coffee value chain will result in the waste products from coffee production and consumption remaining in the coffee value chain for longer, essentially creating value from waste. This report aims to understand the environmental impacts of waste produced during the production and consumption of coffee, and how the impacts can be reduced by implementing a CE strategy to achieve Goal 12 of the SDGs.

2.6.1 Barriers and Enablers in the Coffee Value Chain to a CE Model

2.6.1.1 Values

In order for a company to review their strategies in creating a CE business model to reduce waste, increase their sustainability profile and achieve the sustainability development goal 12 set out by the UN, a company must have a culture in favor of change. This includes constant training on culture however it is difficult to achieve this change when company strategies are linear in thinking. It is also critically important that a company shares its vison on the circular economy with both internal and external stakeholders, if companies’ external stakeholders such as suppliers do not engage in its strategies it can create setbacks in its implementation. A think outside the box culture, where the company looks across industry barriers and looks for solutions beyond its own borders is critical in embedding the circular economy culture and values within an organisation (van Keulen and Kirchherr, 2021).

2.6.1.2 Technology

The switch from a waste creating linear economy to a waste free CE requires a change in the design and services in a potential different way to the current technology and skill level currently in the business. At times there is often a lack of skills of how to achieve the activities required to a CE. There is also lack of sharing of knowledge or sharing of best CE practices due to intellectual property and competitiveness between companies, which impedes the pace of development of the circular economy strategies, as most companies will require starting from the beginning when implementing (van Keulen and Kirchherr, 2021).

2.6.1.3 Business Cases

For a business to implement CE it needs to be financially attractive and be willing to overcome the upfront investment costs to achieve a sustainable future. The value proposition of CE should be attractive enough for companies to get involved. Consumer demand is difficult to predict and control. With many consumers being engaged with problems we are facing on the planet however are less willing to buy more expensive sustainable products (van Keulen and Kirchherr, 2021).

2.6.1.4 Governmental Polices

Many government policies for legislation and tax incentives are in relation to the linear economy and do no focus on resource efficiency. Taxes on pollution emissions are often very low and perhaps if these were raised that companies would be encouraged to reduce their emissions. There lacks a policy coherence within the concept of waste (van Keulen and Kirchherr, 2021).

2.7 Business Case for Introducing the Circular Economy into the Coffee Value Chain

The food supply chain is inefficient due to the estimation that one third of all food produced in the world that is intended for human consumption is either lost or wasted. This results in a negative impact on the economy, society, and the environment (Alexander et al., 2017).By reducing food lost along the food supply chain it can have a triple win effect on the economy,and the environment however with the target set out in SDG12 by the UN there are still many companies not implementing food loss or waste reduction strategies as they do not believe there is a solid business case for implementing sustainability strategies(Criag Hanson and Peter Mitchell, 2017). There is common perception that costs associated with food loss is budgeted for in operational budgets and is accepted as the cost of doing business. Little consideration is given, as many companies believe the investment needed to achieve reductions is not worth the savings. There is a financial and nonfinancial business case to work towards the SDG12 and implement a CE model into each stage of the supply chain from production to consumption of coffee.

2.7.1 The Financial Business Case

Financial resources are needed to produce food from farm to fork. With a third of food being produced and never getting consumed, the producer is not redeeming the return on investment made to produce the food (Alexander et al., 2017). It takes a financial resource to grow, harvest, process, transport, market, consume and dispose coffee. When food exits the food supply chain before reaching its intended use, it is not recoupling the return on investment made (Hanson and Mitchell, 2017). In addition to this waste that ends up in landfill as an expense that a company must pay, especially spent coffee beans as they are wet and heavy which increase disposal costs. When value is created from waste it generates revenue that would have been a cost. For example, if a harvested coffee crop becomes contaminated by pests during storage before further processing, the crop will be disposed and classified as 'food lost'. The food loss also results in a financial lost. The financial loss is seen in the investment prior to the crop becoming contaminated but also, no finance is generated post contamination as the crop cannot be sold for further processing and a cost is associated with its disposal. Likewise, raw material waste can be seen when a food manufacturer purchases milk from a farmer but the milk spoils during processing. The food manufacturer will not earn market return on the portion of milk that spoiled. There are direct financial costs associated with the loss of food such as the price paid for the raw material, the energy used to process the food, the payment of staff, the disposal of the food lost. Moreover, when food companies are targeting to reduce their food loss there is also a financial element associated with it including payment of staff, consultants, new equipment, and process design. Therefore, it it's crucial that the benefits of reducing food loss outweigh the financial costs associated with reducing it. Financial and cost benefit data from 700 companies across 1200 business sites, ranging from Australia, China, Vietnam, Ireland, United Kingdom and the United States representing various sectors of the food industry showed that more than 99% of the 1200 sites have a net positive financial return. The median benefit cost ratio analysis was 14:1, with every $1 invested in reducing food loss, the median return was $14. The high return represents a strong financial business case for companies to target food loss. The financial benefits were seen through avoiding the cost of buying raw materials that were previously lost or wasted, increasing the share of food that is processed that gets sold further down the supply chain, repurposing waste that otherwise would have been lost or wasted and reducing waste management costs (FAO, 2015).

2.7.2 The Non-Financial Business Case

There are also reasons for food companies to implement food loss strategies to align with SDG 12. Reasons for reducing food loss include food security, waste regulations, environmental sustainability, stakeholder relationships and a sense of ethical or social responsibility. However, it is often hard to quantify financial benefits on these reasons and are seen more as a strategic business decision (Hanson and Mitchell, 2017).

Food security is seen as a major objective to both government and companies for political and humanitarian reasons and reducing food loss in the food supply chain is a critical in achieving food security. By reducing food loss, it increases the amount of food available for human consumption. Reducing food loss during storage increases the amount of food that can later be sold increasing the amount of food that can be sold on the market, with direct results of food producers nearest the farm earning income that can be used to buy food. The donation of safe food to charity that would otherwise enter landfill and other waste management systems can help people who cannot afford to buy food.

Often food companies are obliged to follow regulations that are set out by governments in the region they are operating in. As food waste includes any uneaten food and/or associated inedible parts it can be difficult for food companies to achieve. Waste regulations are set out by governments without introducing a strategy to reduce food loss. In Massachusetts, in the United States of America, the government restrict food companies in sending one ton of organic material per week to a solid waste disposal facility. In Japan, a food recycling law which came into force in 2001, provides incentives for companies to recycle food loss and waste into animal feed, fertilizer, and energy. Not only does it provide incentives to redistribute food, but they also set legal targets for producers who produce over 100 tons each year. The French government introduced a law in 2016 making it illegal for retailers of a certain size to send food lost or wasted to landfill and must redistribute or treat surplus food. The legal regulations implemented provide incentives for food businesses as they would be subjected to a noncompliance fine, adding to the financial business case (Hanson and Mitchell, 2017).

2.8 Thesis Outline

This thesis will review the role of the circular economy in the coffee value chain. It will particularly focus on waste valorisation of spent coffee grounds and its contribution to the circular economy and achieving SDG 12 set out by the UN. This will be achieved by reviewing various methods of waste valorisation in the coffee value chain. The objective of this thesis is to establish if a circular economy can be applied to the coffee industry and contribute towards SDG 12.

An understanding on the composition and characteristic of spent coffee grounds along with a detailed review of the various research that has been completed on the use of spent coffee grounds. Focus will be based on how spent coffee grounds can be used introduce a circular economy approach in the coffee value chain.

Chapter 3

The Role of the Circular Economy in the Coffee Value Chain and its Contribution Towards the Sustainability Development Goal 12 set out by the United Nations

Methods

3.1 Methods – Study Design

This section outlines the methods used to demonstrate the role of the circular economy in the coffee value chain and its contribution towards the SDG 12 set out by the UN. This was completed by reviewing waste management strategies within the coffee value chain with specific reference to spent coffee grounds. In addition, a review was completed on potential to add value to spent coffee grounds which are normally viewed as waste. The research method used was a desk-based study of, peer reviewed, published research papers along with data from government and non-governmental organisation sources.

3.1.1 Thesis Outline of Research

Several research studies have outlined the correlation of the waste valorisation of spent coffee grounds and its use in a CE. The research question proposed in this thesis, is the role of the CE in the coffee value chain and its contribution towards the SDG 12 set out by the UN. To address the research question, Chapter 1 reviewed the current situation in the food and beverage industry and the impact on the environment. It also looks at the SDGS set out by the UN and the importance of implementing them. An explanation of the linear versus the CE is outlined. Chapter 2 gave an insight into the coffee value chain with specific emphasis on processing, and roasting and the waste associated with each step. An overview was given of the linear economy approach in the coffee value chain and the barriers and enablers to make the change to a more CE business model. The reason why a business might want to implement a CE is also highlighted. Chapter 3 will outline the materials and methods used to address the research question, while Chapter 4 will present the results and findings related to the role of waste valorisation in spent coffee beans where they are used as a valuable resource as opposed to an environmental risk. This was completed by first looking at the composition of spent coffee grounds and the various components that can be extracted from the spent coffee beans. The extraction of the components of spent coffee beans and their uses is also discussed. Finally, Chapter 5 will critically review and discuss the findings in relation to a CE in the coffee value chain, with a conclusion of the research and discussion point on if it can be achieved. Chapter 6 will summarise key findings and future work in this area.

3.1.2 Scope

The scope of the research question focuses on the role of CE in supporting the coffee value chain to contribute towards the SDG 12 set out by the UN. Focus will be on applying a circular economy to valorise spent coffee grounds, resulting in a decrease in waste spent coffee sent to landfill. The scope will explore the requirements for valorising waste spent coffee grounds and its potential uses.

3.1.3 Date Inclusions

Data included in the study was drawn from experimental studies. Data included, for the most part, has been drawn from recent publication typically within the last 10 years. Older data that was used, when compared to recent data was current and relevant. With increasing concern in recent years in the environment and what action is needed to reverse the damage already done, much of the research available is recent.

3.1.4 Exclusions

Non peer reviewed data has been excluded for the review data and unsubstantiated data was also excluded.

3.1.5 Statistic Size Cohort

Data was obtained by a range of domestic and industrial size waste management coffee systems. This ranged from smaller coffee shops to larger roasting facilities. Statistical analysis has not been carried out as part of this study. This is due to the lack of available raw data.

Chapter 4

Results

As consumption in coffee increases, the sustainability concern, and challenges associated with substantiable production and consumption of coffee increase also. The coffee industry faces challenges around energy demand, waste management and GHG emissions increasing (Mayson and Williams, 2021). Increased emphasis has been put on sustainable consumption and production by the UN in Goal 12 outlined in the SDGs. The coffee industry has been criticised for disregarding the principles of sustainable, equitable and accountable trade (Mayson and Williams, 2021). A waste to energy (WTE) approach can address three key issues to achieve a CE system of production and consumption to meet the UN's SDG12. The three issues are waste management, energy demand and GHGs. The coffee value chain is energy and waste intensive. Spent coffee ground waste is increasing with the increase in population globally and therefore increasing demand for coffee, with most of the waste being sent to landfill. In 2014 it was estimated at 9 million tonnes of spent coffee grounds were being sent to landfill (Mayson and Williams, 2021). In this chapter the use of spent coffee beans will be reviewed to valorise the waste to a consumable product and how spent coffee beans can be used as energy.

4.1 Top Global Coffee Growth Markets

The growth in the global coffee market shows a range of diversity. Figure 4.1 and Figure 4.2 highlight this, with mature markets such as Italy and the US showing slower growth than Brazil, whose large population, enthusiasm for coffee and recovering economic prospects make its growth prospects over four times those of any country in the world. Local conditions play a major role in shaping demand and growth patterns in the future of the coffee supply chain (Coffee Growth Dynamics: The Four Market Types Shaping Global Coffee Demand, 2019).

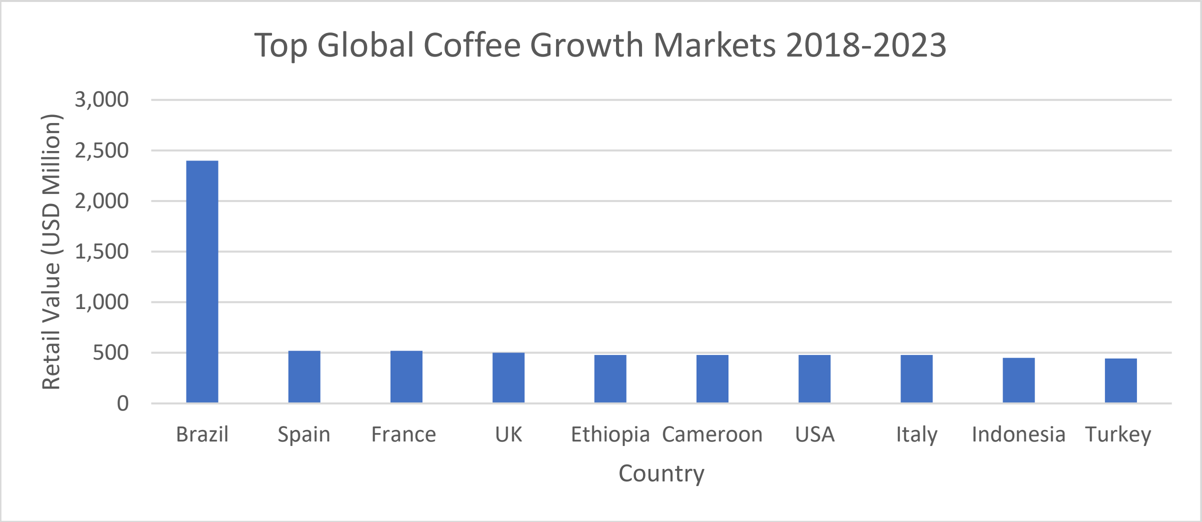

Figure 4.1 An overview of the retail value of the coffee growth markets by country (Coffee Growth Dynamics: The Four Market Types Shaping Global Coffee Demand, 2019).

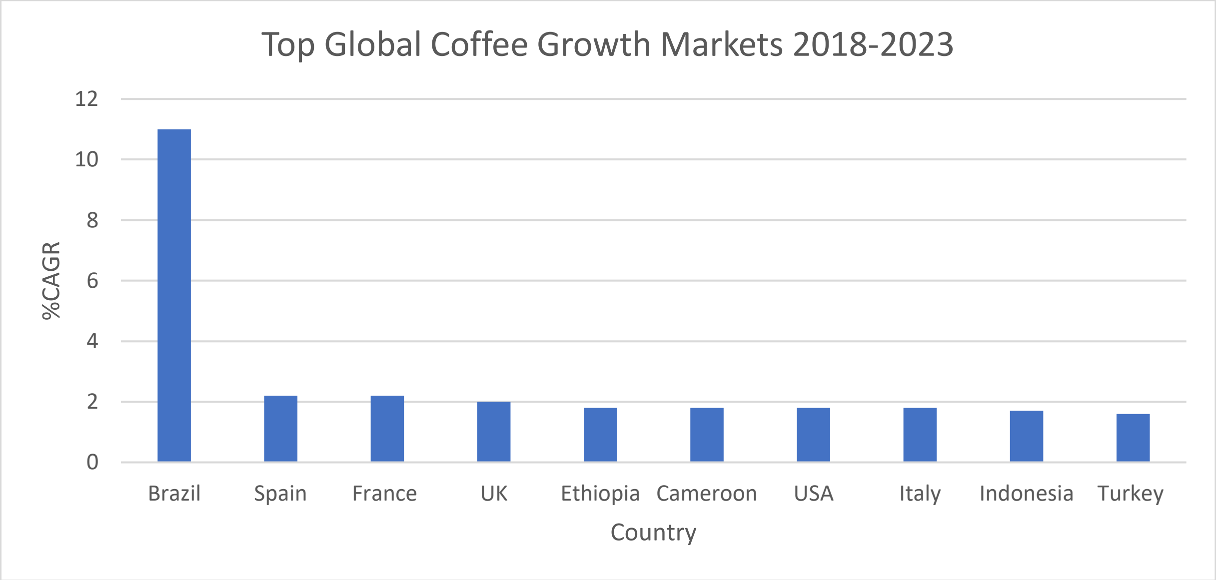

Figure 4.1 An overview of the top coffee growth markets by country in relation to & compound annual rate (Coffee Growth Dynamics: The Four Market Types Shaping Global Coffee Demand, 2019).

4.2 The Characteristics of Spent Coffee Ground

Several studies have published data on the characteristics of spent coffee grounds. The biochemical composition of spent coffee grounds is highlighted in Table 4.1. Lipids present in spent coffee grounds ranges from 9 to 16 wt%, its composition of carbohydrate ranges from 45-65.9 wt% and its protein content ranges from 4.9 to 17 wt% (Burniol-Figols et al., 2016; Passos and Coimbra, 2013; Wang et al., 2016). The moisture content of spent coffee ground before drying and when collected from coffee shops ranges from 33-56 wt.% as highlighted in Table 4.2 (Allesina et al., 2017; Kim et al., 2017; Ktori et al., 2018). The ultimate analysis of spent coffee grounds reported by various studies is highlighted in Table 4.2. Carbon, Nitrogen, Hydrogen, Sulphur and Oxygen results are similar across the various studies. Carbon content ranges from 48.67 – 54.9 wt.%, Hydrogen ranges from 6.54 to 7.9 wt.%, Nitrogen ranges from 1.5% - 3.51 wt.%, Oxygen ranges from 33.75% to 40.3%. and only one study reported the presence of Sulphur of 0.1 wt.%. Spent coffee composition consists of high organic compounds, that is attractive to be used as biomass to be converted towards biofuels and other valuable products.

Lipids wt%db	Carbohydrates wt%db	Protein wt%db	References
9 to 16	45-47	13-17	Burniol-Figlos et al., (2016)
13	65.9	4.9	Passos and Coimbra ., (2013)
13.7	54.1	13.8	Wang et al., (2016)

Table 4.1 Spent Coffee Grounds Biochemical Composition (wt%db)

C wt.%	H wt.%	N wt.%	S wt.%	O wt.%	Moisture Content wt.%	References
54.9	7.9	3.51	0	33.75	33	Ktori et al.,2017
48.67	6.54	2.27	0	40.3	45	Allesina et al., 2017
48.9	7.9	1.5	0.1	40.1	56	Kim et al., 2017

Table 4.2 Ultimate Analysis of Spent Coffee Grounds

4.3 What can be extracted from Spent Coffee Grounds?

Spent coffee grounds contain valuable resources that could be used to valorise the waste spent coffee grounds resulting in a range of commodities. Spent coffee grounds contain a wide range of organic compounds for instance fatty acids, amino acids, polyphenols, minerals, and polysaccharides (Zabaniotou and Kamaterou, 2019). Various extraction processes can be completed including oil extraction, polysaccharides extraction, phenolics extraction, caffeine extraction and tannins extraction. The extraction of caffeine, tannins and chlorogenic acid are of eco-toxicological concern and can limit their value adding applications (Zabaniotou and Kamaterou, 2019).

The extraction of lipids from spent coffee grounds is popular. Lipids extracted from spent coffee residues range from 9.3 to 16.2 wt% db (Cruz et al., 2012) and depending on the coffee variety there is promising research to produce biodiesel due to its high calorific value (Al-Hamamre et al., 2012). Hexane is the most popular solvent used for oil extraction, however supercritical fluid extraction is a modern environmentally friendly technology (Campos-Vega et al., 2015). There are reports of increasing use of this technology for oil extraction (Campos-Vega et al., 2015).

Spent coffee grounds also contain many phenolic compounds that are associated with human health. The phenolic compounds are shown to have antioxidant, antibacterial, antiviral, anti-inflammatory and anti-carcinogenic properties (Zabaniotou and Kamaterou, 2019). The techniques that can be used to extract valuable compounds from spent coffee grounds can be split into two categories, conventional extraction, and non-conventional extraction.

Conventional Extraction	Non-Conventional Extraction
Soxhlet	Ultrasound assisted extraction (UAE)
Maceration	Pulsed electric field extraction (PEF)
Hydro distillation	Enzyme – assisted extraction (EAE)
-	Microwave assisted extraction (MAE)
-	Pressurized liquid extraction (PLE)
-	Supercritical fluid extraction (SFE)

Table 4.3 Spent coffee grounds contain many phenolic compounds associated with human health. Conventional and non- conventional extraction can be used to extract the phenolic compounds (Zabaniotou and Kamaterou, 2019).

4.3.1 Oil Recovery

Spent coffee grounds have an oil content of 10 to 15% and is dependent on the coffee variety (Jenkins et al., 2014). A study completed by Somnuk et al., (2017) evaluated four different solvents (Hexane, ethanol, hydrous ethanol, and methanol) on coffee oil extraction yield using a circulation process. The study showed that under optimal conditions of 30.4 minute extraction time and a ratio of 22.5g of spent coffee grounds to hexane, oil yield was 11.8 wt% (Somnuk et al., 2017). In a similar study where Phimsen et al., (2016) extracted oil, the study used n-hexane and was used as a solvent to extract oil from spent coffee grounds. The yield of the extracted oil ranged from 10-13 wt% db of spent coffee grounds. This study proved that bio-hydrogenated fuel productions and its potential to be used as a renewable energy. The diesel fuel produced had a diesel fuel fraction cetane of 80. The physiochemical properties of the diesel fraction comply with other commercial standards. The bio hydrogenated fuel produced is both ecofriendly and nonpolluting (Phimsen et al., 2016).

4.3.2 Polysaccharides Recovery

Polysaccharides have endless potential in healthcare, food, and cosmetic industries. Polysaccharides contain bioactive compounds that have therapeutic effects and relatively low toxicity. To isolate and purify polysaccharides there is a distinct process that is different to the isolation and purification of other macronutrients such as proteins and fats. The extraction of polysaccharides from spent coffee grounds has been studied, mainly using chemicals as extraction agents (Allesina et al., 2017). Polysaccharides by autohydrolysis of spent coffee grounds was investigated by Ballesteros et al., (2017). The 29.29 wt% of polysaccharides extracted were characterised by high antioxidant activity. The extraction was completed under the following conditions, 15ml water/g spent coffee grounds, for 10 minutes, at 160 °C. The polysaccharides extracted were thermostable in a large range of temperatures. The suggested use by Ballesteros et al was in the food industry (2017).

4.3.2 Phenolic Compounds Recovery

Polyphenols are classified as micronutrients with many health benefits associated with them and their effects in food systems as an antioxidant compound. The recovery of relevant natural antioxidants for use as nutritional supplements, foods, or cosmetic additives can be achieved by spent coffee grounds extraction with environmentally friendly procedures. A study completed by Shang et al (2017), optimised spent coffee ground extraction conditions for total phenolics by using a pressurised liquid extraction method with water and ethanol. The optimal conditions were 195 degrees °C extraction temperature which extracted total phenolics content of 19 to 26 mf/GAE/gDw.

The extraction of phenolic compounds from spent coffee beans was also achieved by Al- Dhabi et al (2017) by ultrasound-assisted solid-liquid extraction of phenolic compounds. Ultrasonic power, temperature, time, and solid liquid ratio were parameters studied. The optimum conditions of the extraction process were 244 W of ultrasonic power, 40 °C temperature, 34 minutes of time and 1:17g/ml of solid-liquid extraction. These conditions obtained yields of 33.84 GAE/g of total phenolic content.

4.3.3 Tannis Recovery

Tannis can be extracted from spent coffee grounds and be used for a wide variety of processes. Low et al (2015) studied what influenced the extraction of tannis from spent coffee grounds. It was shown that sodium hydroxide concentration, extraction temperature and liquid to solid ratio considerably effected the spent coffee ground extraction yield and its reactivity. The optimal conditions were seen when 5 wt% of sodium hydroxide concentration was used at a 100 °C extraction temperature, 30 minutes extraction time and 8.2 liquid to solid ration was combined. An extraction yield of 21.02% was achieved with high reactivity. Tannis are low-cost natural biopolymers that can produce bio-sorbents, low cost, ecofriendly products such as plastic. Tannis based products also have a natural affinity to absorb heavy metals dyes, and pharmaceutical compounds from contaminated waters (Allesina et al., 2017).

4.3.4 Caffeine Recovery

Caffeine can be extracted from spent coffee grounds by using membrane technology, with no organic solvents or adsorbents required as shown by a study completed by Brazinha et al (2015). Caffeine was also extracted from spent coffee grounds using a pressurised liquid extraction method with water and ethanol. The optimal conditions required to achieve a yield of 9mg/g db of caffeine is 195 °C extraction temperature, this was seen in a study completed by Shang et al (2017). Extracted caffeine from spent coffee grounds has specific health benefits (Allesina et al., 2017).

4.4 The Valorisation of Spent Coffee Grounds for Bioenergy and Carbon Materials Production

Using spent coffee grounds for energy recovery is a way to reduce waste, produce fuels, and protect the environment by mitigating greenhouse gas emissions. Energy recovery from spent coffee grounds has been documented across varying literature in relation to biochemical (transesterification) and thermochemical (pyrolysis, gasification, hydrothermal liquefaction, combustion. The products of energy recovery and their uses from spent coffee grounds include, biodiesel, biooil, CHP, heat, biochar and activated carbons (Zabaniotou and Kamaterou, 2019).

4.4.1 Biodiesel Production

Spent coffee grounds contain approximately 16% lipids w/w% as highlighted in Table 4.1. There is potential to use spent coffee grounds as oil feedstock. Feedstock can be classified as any renewable biological material that can be directly used as fuel or converted to another form of energy. Transesterification is a common method used to extract oil from spent coffee grounds (Zabaniotou at al., 2019).

A study completed by Al-Hamamre et al. (2012) extracted oil from dried spent coffee grounds to be used for biodiesel production. Similarly, Kondamudi et al (2008) extracted oil from spent coffee grounds, this was achieved by using solvents such as hexane, ether, and dichloromethane under reflux conditions. The oil extracted was then used to produce biodiesel and achieved a 100% conversion rate. The oil extracted was stable for one month under ambient conditions. Go and Yeom (2017) also studied how lipids can be extracted from spent coffee grounds via the transesterification process. The biodiesel production was dependent on time and temperature with optimum conditions of 0.5% catalyst and 1.5mL methanol per gram of lipid at 45 degrees C for 9 hours. Similarly, Varden et al (2013) also studied a method of oil extraction with the addition of an acid neutralisation and alkaline transesterification step. The study showed that the biodiesel produced fulfils the quality standards to be used in normal engines. There are standards that must be met for biodiesel production set out by NP EN 14214:2009. A study completed by Mata et al., (2013) did not meet the standard requirements when they extracted oil from spent coffee grounds using a two-step acid process of acid esterification followed by alkaline transesterification. The economic and environmental analysis of biodiesel production from spent coffee grounds was also reviewed. The conclusion that oil extraction from spent coffee grounds was only attractive in a large-scale production plants and not economically sound for small scale units (Kookos, 2018).

4.4.2 Biooil Production

'Pyrolysis is the thermochemical decomposition of organic matter into non condensable gases, condensable liquids, and a solid residual co product, biochar, or charcoal in an inert environment (Mandal et al., 2016). Research has shown that spent coffee waste can have value added to the final product by using it as a heat source. During coffee production and consumption fossil fuels such as natural gas are used as an energy resource. Fast pyrolysis can convert spent coffee grounds into biooil and biochar.

A study completed by Ktroi et al., on the valorisation of Nespresso spent coffee grounds through pyrolysis for energy and materials production in the concept of a circular economy demonstrated the successful recovery of energy from waste spent coffee grounds. Pyrolysis was completed over a range of 380 °C to 700 °C into char, liquid, and non-condensable gas. As show in Table 4.4 a maximum yield was achieved at 540°C for biooil. The Low Heating Value MJ/m3 of biogas produced at 540°C is 13.3 MJ/m^3. At this value it belongs to the medium level gas fuels, because of this it can be used in engines, turbines, and boilers for powder production. Biooil and biochar characteristics need further characterisation to be assessed as biofuel and biochar respectively (Ktori et al., 2018)

Pyrolysis Temperature °C	Yield wt%	Low Heating Value in MJ/m^3	Product
540	36	-	Biooil
540	29	-	Biochar
540	9	13.3	Biogas

Table 4.4 An overview of the use of spent coffee grounds through pyrolysis for energy and materials production. This table illustrates the temperatures required and products produced (Ktori et al., 2018)

A similar study completed by Kelkar et al (2015) focusing on biooil production in a screw convey reactor. Yields of 61.8% ww% at 500 °C were observed. Biochar was also observed during pyrolysis at 429 °C. The biooil contained fatty acids, fatty acid esters, medium chain paraffins, olefins, and caffeine (Kelkar et al., 2015). Bok et al (2012) experimented with spent coffee grounds and produced biooil with a maximum yield of 55 ww% at 550 °C pyrolysis temperature in a fluidised bed reactor (Bok et al., 2012).

4.4.3 Biochar Production

The slow pyrolysis of spent coffee grounds can produce biochar. Biochar from spent coffee grounds is a much better fertiliser compared to directly applying spent coffee grounds to fields (Zabaniotou at al., 2019). A study completed by Kim et al ., 2014 compared the application of spent coffee grounds versus biochar from spent coffee grounds to soil. The soil phytotoxicity increased due to the amount of carbon released from spent coffee grounds, slowing the growth of the plant or completed inhibiting growth however, when biochar from spent coffee grounds was applied it did not exhibit the same soil phytotoxicity due to organic matter already being removed in the pyrolysis step (Kim et al., 2014).

Biochar from spent coffee grounds can also be used as solid fuel in the industrial sector due to its high calorific value. The potential of spent coffee grounds as feedstock to produce biochar via pyrolysis was evaluated by Tsai et al., (2012). The temperature of the pyrolysis ranged from 400-700 °C with a heating rate of 10 °C per minute. The study reported that the produced biochars showed a high carbon content of greater than 8 ww%, with a fixed carbon content of >60 ww% and a calorific value of greater than 30.1 MG/kg.

4.4.4 Energy Production

Like the study completed by Ktori et al., (2018) research was completed on a roasting coffee company in Caffee Cagliari in Italy. During this research Zabaniotou et al., (2019), mixed dried spent coffee grounds with pine sawdust to increase the mechanical resistance. Pellets were produced with varying content of spent coffee grounds. Table 4.5 highlights the pellets with varying content of spent coffee grounds. The range of pellets produced included P100, P70-30 and P50-50. The pellets contained 100% spent coffee grounds, 90% spent coffee grounds and 30% saw dust and 50% spent coffee grounds and 50% saw dust respectively. The pellets were used in direct combustion tests on a pellet stove. The pellet stove used was a conifer wood pellet, certified EN plus A, to make an accurate comparison between optimal fuel for the pellet stove and the coffee derived fuel. Table 4.5 shows that P50-50 a combination of coffee and saw dust preforms better overall in the average higher heating value, the average thermal power, and the average overall efficiency. When the coffee content of the pellets increases, problems with combustion rise. It was reported that P70-30 and P100 caused an unstable combustion, most likely due to the significant generation of ash by coffee. This suggests that P50-50 is the best biofuel (Zabaniotou at al., 2019).

Parameter tested	Pwood	P 50-50	P 70-30	P100
Average HHV dry of the fuel (kWh/kg)	4.83	5.26	5.43	5.69
Avergae thermal power (kW)	8.02	8.86	5.39	3.61
Average overall efficiency (%)	37.7	41.2	29.7	19.2

Table 4.5 Comparison of the various saw dust and spent coffee blends **(**Zabaniotou et al.,2019)

The same method of a blend of pine dust and spent coffee grounds was also researched by Limousy et al.,(2013). Agro pellets produced from pure spent coffee grounds, or a combination of spent coffee grounds were used in the study. Evaluation was completed in a commercial residential pellet boiler. An evaluation of high potential combustion values was completed. Spent coffee grounds had a good combustion efficiency however the energy recovery was much lower than the pine dust or blend at only 64.1% in comparison to 84.3% and 83.5% respectively, as seen in Table 4.6. However, like the research completed by Allesina et al., (2017) a blend of spent coffee grounds of 50/50 wt%, combustion and boiler efficiencies as well as exhaust gas emission characteristics were extremely close to wood only characteristics. A blend of pine dust and spent coffee grounds may be an attractive alternative fuel for boilers (Limousy et al., 2013).

Sample	Combustion efficiency (%)	Boiler Efficiency
Spent Coffee Grounds	86.3	64.1
Pine	90.3	84.3
Blend	91.9	83.5

Table 4.6 A comparison of various blends and their combustion efficiency and boiler efficiency (Limousy et al.,2013)

4.4.5 Cogeneration of Heat and Power (CHP)

Combined heat and power can be produced by spent coffee grounds gasification. Waste spent coffee grounds can be turned into energy producing enough heat and power for their own needs with surplus energy feeding back into the grid. (Allesina et al., 2017). Steam gasification of spent coffee grounds was investigated over a temperature range of 650 °C to 850°C, with a steam partial pressure range of 0.05 to 0.3 bar. Gas chromatography was used for gaseous product analysis. When analysed it showed that products contained higher carbon and lower volatile matter compared to the original spent coffee grounds. It also had a high calorific value. However not much studies have been completed in this area of spent coffee grounds gasification for CHP and more investigations are required (Pacioni et al., 2016).

4.4.6 Bio- refinery approach for spent coffee grounds valorszation

Bio refining is the sustainable processing of biomass into a spectrum of marketable products and energy (Mata et al., 2018). Coffee can be used as a bio refinery raw material due to its chemical composition and organic biological origin. The final product of bio refinery depends on the characteristics of the raw materials and process involved and may have various applications. The utilisation of organic waste i.e., spent coffee grounds makes sense from a sustainability point of view (Mata et al., 2018). Biomass disintegration through combustion, gasification or fermentation only do not lead to optimal utilisation of biomass feedstock. Keeping biorefinery in mind its multifunctional processes are integrated in an optimised sequence to utilise waste. The objective of biorefinery is maximising the productivity of marketable products such as bioenergy/biofuels to enhance the process economics.

A study completed by Obruca et al., (2015) shows how PHAs and/or carotenoids can be produced from spent coffee grounds. Oil is extracted as part of the first step followed by a second’s step of hydrolysis to convert to PHAs. The fuel can then be used in industrial boilers to generate heat as it has a heating value of 24 912.80 KJ/kg. Kondamudi et al., (2008) used an extraction step with hexane to produce triglycerides used to produce biodiesel by transesterification. The residual glycerin is processed further to obtain hydrogen in particular steam reforming. The solid matter resulting from the extraction step is then fermented to obtain ethanol that can be used as transportation fuel and the remaining solids can then be made in to pellets and used as an energy source as they have a large energy content.

4.5 Caffee Cagliari Case Study – Using Spent Coffee Grounds for Roasting

Caffee Cagliari produces more than 5 tons of roasted coffee beans per day through 25 roasting cycles. Once exported the green coffee beans must go through a roasting stage to turn into brown coffee beans that are consumed. The green coffee beans go through the roasting machine from 95 °C to 220 °C. Each year Caffee Cagliari spends more than €63,000 for the gas supply to run the machine. By introducing a new concept by transforming spent coffee grounds into pellets, the company can satisfy its heat demand. It results in savings, potential to obtain environmental certificates that provide a financial benefit, social and environmental improvements.

Table 4.7 highlights the natural gas consumption and costs the company encounters. However, if Caffee Cagliari were to collect the spent coffee grounds from their customers when they are delivering the roasted coffee beans each week to bring back to their factory to use as a fuel source, a dryer would be required to be purchased along with a pellet mill and a hot air generator. As previously mentioned, a blend of 50/50 wt% of pine dust and spent coffee grounds is the best application of spent coffee grounds to produce energy. Financial feasibility and sustainability can be achieved, while the initial investment is €38,846, to include the purchase of a dryer, pellet mill, hot air generator, automatic system for the biomass loading and silos for spent coffee grounds, with an additional €52,787 for installation, ordinary maintenance, electrical consumption, purchase of sawdust and the hiring of a new laborer for pellet transformation and combustion. Savings of €10,398 resulted per year from environmental certificates achieved and the saving of the cost of the gas, this saving includes expenditure deducted (Zabaniotou et al., 2019).

In addition to financial savings up to 90% of carbon dioxide emissions can be saved by introducing a circular economy model by the thermal valorisation of coffee waste. The reduction in carbon dioxide emissions is difficult to get an exact measure as emissions released are only due to the electrical consumption of the pellet mill due to carbon neutrality of biomass combustion. In addition, it should also be noted that the trucks delivering the roasted coffee to the coffee shop is picking up the spent coffee grounds and therefore emitting no additional carbon dioxide into the environment

Parameter	Value
Higher Heating Value Natural gas	47.70 MJ/kg
Natural Gas Density	0.72kg/m3
Natural gas cost	0.62€/m3
Gas consumption per day	400m3/day
Gas consumption per year	101600 m3/year
Gas cost per day	248 €/day
Gas cost per year	63185 €/year
Thermal power	159 kW

Table 4.7 A breakdown of the gas consumption and gas costs per year at the Caffee Cagliari roasting facility (Zabaniotou et al., 2019)

Chapter 5

Discussion

5.1 Discussion

The purpose and objective of this study, was to review the role of the circular economy in the coffee value chain, focusing on waste valorisation of spent coffee grounds. The focus was also to review how the circular economy can contribute to achieving SGD 12 set out by the UN with a particular focus on SGD 12.3, to ensure the sustainable consumption and production of coffee for many generations to come. Not only does food waste create environmental problems it also causes huge economic and social problems. Food waste is a great resource of added- value materials (Zabaniotou and Kamaterou, 2019).

The study gave an overview of the coffee value chain. It gave insight into the processing of coffee and the waste associated with each different step of processing. It was identified that spent coffee grounds are a big contributor of the waste that is associated with the coffee value chain. A review was conducted on the composition of spent coffee grounds and what can be extracted from the spent coffee grounds that are normally viewed as being waste material. Based on the review, it could be concluded that various components can be extracted by various extraction techniques, each with different end uses, resulting in waste valorisation of spent coffee grounds. The characteristics of spent coffee grounds are highlighted in Table 4.1, containing lipids, carbohydrates, and protein. Spent coffee grounds also contain Carbon, Hydrogen, Nitrogen, Sulphur and Oxygen, as seen in Table 4.2. Spent coffee beans contain a high number of organic compounds making it attractive to be used as biomass. Biomass is a renewable organic material that originates from plants. The plants stored chemical energy from the sun and biomass is produced through photosynthesis. Biomass can be then burned directly for heat of converted to renewable liquid or gas through different processes. However, the use of spent coffee grounds can also be harmful as due to its high organic compounds, it can be toxic when used as fertiliser in soils.

Lipids extracted from spent coffee beans as seen by (Al-Hamamre et al., 2012; Cruz et al., 2012) shows potential for oil recovery. Oil extracted from spent coffee grounds with a high FFA’s can be hydrogenated to liquid biofuel. The physiochemical properties of diesel fractions comply with commercial standards (Phimsen et al., 2016). The extraction of polysaccharides, phenolic compounds and caffeine have specific health benefits that can be used as functional ingredients in many food productions processes. The extraction of tannis from spent coffee beans contributes to certain plastic production. Tannis can also absorb metal dyes and pharmaceutical compounds from contaminated water. However, it was seen that the biorefinery approach was the best long-term strategy to develop a competitive and resource efficient model. Spent coffee grounds can be used as a bio refinery raw material due to its chemical composition and organic biological origin(Mata et al., 2018). The oil extracted from spent coffee beans in the biorefinery can be used to fuel industrial boilers as studied by Obruca et al.,(2015). Kondamudi et al., (2008) also produced biodiesel by transesterification of spent coffee beans and was used as transportation fuel. Biorefinery is about using multifunctional processes to optimise the waste, albeit the fuel is extracted as oil using a solvent or extracted using transesterification, and there is a left over solid. The left-over solids in biorefinery can be used as pellets as an energy source as they have a large energy content.

Spent coffee beans can be used as feedstock to directly fuel or can be converted to another form of energy. Oil extracted from spent coffee grounds as seen by Al-Hammamre et al., (2012) & Kondamudi et al., (2008) can be used for biodiesel. The oil extracted and converted to biodiesel can be used in normal engines, as seen in a study completed by Varden et al., (2013) however it also must be noted that a study completed by Mata et al., (2013) successfully extracted oil and converted to biooil however did not meet the standards of biooil production to be used. The extraction of oil from spent coffee grounds is a promising way to reduce waste. Oil extraction from spent coffee grounds is also only successful in large scale production plants and not economically sound for small scale units. However, there is potential for large scale operations to roll this strategy out and to collect spent coffee grounds from coffee shops, and in turn extract oil to sell the biooil/biodiesel produced back to the coffee shops to use in their transportation and embrace the circular economy strategy. The above methods are in relation to the transesterification process. Pyrolysis can also be completed for biooil production and was defined as the thermochemical decomposition of organic matter into non condensable gasses, condensable liquids, and solid residual product, biochar, or charcoal (Mandal et al., 2016). It was reported by (Zabaniotou and Kamaterou, 2019) that during fast pyrolysis spent coffee grounds can be converted into biooil and biochar. The spent coffee grounds undergo a pyrolysis process where the optimum temperature is 540℃. Similarly, biochar can be produced during slow pyrolysis. Biochar from spent coffee beans can be applied directly to the fields. Spent coffee grounds can be toxic and when disposed of in landfill emit methane a GHG that is contributing towards climate change. Spent coffee grounds can also be toxic when applied directly to the ground as fertiliser. When spent coffee grounds are applied directly to the soil the phytotoxicity increases due to the amount of carbon released from spent coffee grounds however when biochar is applied as fertiliser the soil doesn't exhibit the same phytotoxicity due to the organic matter being removed in the pyrolysis step (Kim et al., 2014) . Biochar has also shown potential in the solid fuel industry due to its high calorific value (Tsai et al., 2012).

The potential of spent coffee grounds to be used in energy recovery to reduce waste shows real potential. The use of the energy recovery in the coffee value chain in a CE strategy also shows potential with the energy recovery through, biochar, biogas and biooil. While there are little studies completed, the use of the biochar, biogas and biooil could be used to fuel transport at various stages of the coffee value chain. Cogeneration of heat and power could also be a method to reduce spent coffee grounds waste while contributing to the circular economy by using the energy from spent coffee grounds to sell energy back to the grid. Combined heat and power can be produced by gasification of spent coffee grounds. Spent coffee grounds can produce heat and power for their own needs, allowing the energy to be used to either roast coffee beans or it could be used in another industry contributing to the overall sustainable production and consumption of all industries, however, not many studies have been completed in this area.

The most promising use of spent coffee beans and a direct study completed on the CE of the spent coffee beans is the use of spent coffee beans for energy production to power pellet stoves to roast the coffee beans to turn the bean from green to brown. In the study completed by Ktori et al., (2018) spent coffee grounds were mixed with saw dust to make a pellet like material. The highest thermal power and overall efficiency was a combination of 50% spent coffee grounds and 50% saw dust, as seen in Table 4.5 (Ktori et al., 2018). This was further validated by a study completed by Limousy et al., 9(2013) where agro pellets were produced from pure spent coffee grounds and mixed with pine dust, the blend showing an overall combustion efficiency and boiler efficacy as seen in Table 4.6.

The roasting of coffee from green beans to a brown bean using gas to complete the process is energy intensive. The case study completed on Caffee Cagliari showed by transforming the new concept of transforming spent coffee grounds into pellets, the company can satisfy the heat demands usually provided by gas by using mixed pellets containing spent coffee grounds and sawdust. This results in savings on gas spend, obtaining environmental certificates that provide financial benefit and improve their social and environmental improvements. This aligns with the UN SGS goal 12, of sustainable production and consumption of coffee. Caffee Cagliari were utilising a full CE by collecting the spent coffee grounds from their customers when they are delivering their coffee beans and therefore not increasing their fuel usage. Acknowledging there is a spend to invest in the dryer and purchasing the pellet mill and hot air generator and to install. However, Caffee Cagliari saw a saving of over €10,000 per year. In addition to the financial savings, up to 90% carbon dioxide emission was saved by introducing a CE model by the thermal valorisation of spent coffee grounds that otherwise would be sent to the landfill as waste material.

Food waste prevention is an integral part of the implementing a CE (Zabaniotou and Kamaterou, 2019). Food waste and loss are a key challenge in making the food and beverage supply chain more sustainable. With the CE creating value from waste and reducing the energy and resources that are being invested into the processing along the supply chain. Waste doesn’t only have an impact on the environment but also has impacts on socio economic factors with many costs associated with agriculture and invested in the production and supply chain of food that is not consumed. With most of the coffee grown in developing countries, by reducing loss and waste in the coffee supply chain the quality of the life of the farmers can be increased. By converting spent coffee grounds to energy, it reduces the amount of GHGs that are emitted into the environment. Due to spent coffee grounds high organic matter content, it takes a huge amount of oxygen for their degradation in landfills. Methane and carbon dioxide are also emitted into the environment. To align with SDG Goal 12 with the aim of creating a more sustainable consumption and production supply chains and to do more and better with less, valorisation of waste towards material and energy recovery than disposal is gaining interest. By redirecting spent coffee grounds from landfill to energy recovery it reduces waste and contributes towards goal 12.3 for halving per capita food waste at the retail and consumer levels and reducing food losses along the production chain. To meet the increasing expectations of coffee consumption minimising the use of natural resources and reduce the waste and pollutants generated during the supply chain. It is essential in the achievement in SGS Goal 12.2, the sustainable management and efficient use of natural resources. By redirecting spent coffee grounds from waste landfill to energy production it is contributing towards SDG 12.5 by reducing waste through reusing. By reducing the amount of spent coffee grounds that are sent to landfill and reducing the overall GHGs that are emitted into the environment as a result it also contributes towards SDG Goal 13 that is related to climate change. To add further, by using spent coffee grounds as a source of energy production to reduce the use of fossil fuels it also contributes towards SDG goal 7, in particular goal 7.3 to improve renewable energy efficiency. Figure 1.1 highlights how the various goals interact with SGG Goal 12. However, there is a challenge in quantifying the food waste that is prevented by collecting spent coffee grounds from coffee shops to use as a methods of energy recovery to roast the green coffee beans to consumable brown coffee beans as Caffee Cagliari was the only roaster that was completing this tasks, with 5 tons of coffee beans being roasted per day. However, there is a lot of potential in this due to the 2.25 million cups of coffee drank each day and with over 381,000 tonness of ground coffee used to brew cups of coffee each year.

By using spent coffee grounds for energy recovery, waste can be reduced, fossil fuels can be reduced, and the environment can be protected. Energy recovery from spent coffee beans can be described as waste valorisation and therefore can be applied in the CE approach. The disposal of spent coffee beans is most likely to landfill. The waste hierarchy discussed in section 1.4 describes the basic concept of reduce, reuse, and recycle with the aim of identifying options that will drive the overall best environmental performance. Sending waste to landfill is the least desirable method of waste disposal. There is no specific call out for the circular economy and using raw materials such as spent coffee beans and converting it to energy to use as fuel in the transportation or the roasting of coffee beans. It could be argued that it falls under chemicals and biomaterials that sits halfway in the waste hierarchy as seen in Figure 1.4. It is recommended when fully implementing a waste management system that a systematic review of the whole process should be reviewed. This has been completed in this study as waste was identified through each process in Chapter 2, a review of the extraction/recovery of valuable components was completed but also the use of the spent coffee beans to completely remove the requirement to send the spent coffee grounds to landfill. By reducing the amount of spent coffee grounds sent to landfill it add values to something that would have cost to dispose of. This benefit both the plant and people. However, at an industrial scale there has been very few biofinery literature papers published. Biodiesel production, energy production and CHP can contribute to more sustainable and circular economies with a clear path towards achieving SDG Goal 12 of sustainable production and consumption.

By using the spent coffee grounds and adding value to the spent coffee grounds it contributes towards reducing waste and towards the journey of achieving Goal 12 set out by the UN. The sustainable consumption and production of coffee can be achieved by reducing waste and mitigating greenhouse gas emissions associated with the processing of coffee. GHGs are reduced as the spent coffee beans are not emitting methane when sent to landfill but also a reduction in costs as ultimately waste that ends up in landfill is an expense that the company must pay. In turn when value is created from waste it generates revenue that in other terms would have been a cost.

There has been good research on the various methods where value can be added to waste spent coffee beans however at industrial level there is little on how the CE can be implemented. It is clear there are challenges remaining in the coffee industry and quantifying food waste is a major challenge, the amount of coffee drank, and the growth predications globally are widely available however there are no definite volumes of spent coffee grounds defined as going to landfill or even having the value added to them. There is a journey to be taken to achieve SDG 12 of sustainable consumption and production, more specifically SGD 12.3 where the FLI & FWI which focuses on measuring FLW along the food supply chain however the FLI is the only index that has published figures, and the FLW is still to be defined. However, these methods are not accurate in the sense that they only measure tonnage and not the value of the waste. For example, if spent coffee grounds was to be measured according to the FLW indexes there wouldn't be a requirement to define the valuable components in spent coffee grounds that can be extracted as seen in this study. The complexity of the food supply chain also hinders the development of the CE in the how spent coffee grounds can be used as a raw material for energy recovery. As detailed in Figure 2.1, the coffee value chain has many different processing steps. Spent coffee grounds can be used as raw material for energy production to fuel boilers or to roast the coffee beans from green to brown or to extract lipids that can be biohydroganted into biodiesel to use in the transportation from the various processing steps in the coffee value chain. However, to make a change by using spent coffee grounds as a raw material, it is critically important that all stakeholders in the coffee value chains recognises the importance of contributing to the CE and work towards achieving SGD 12 set out by the UN. While the use of spent coffee beans as biooils, biofuels or mixed pellets are the most obvious approach for use in CE to fuel boilers, the roasting stages of the coffee. Spent coffee grounds can also be used as fertiliser by the farmers growing the coffee fruits if the spent coffee grounds undergo a pyrolysis step to create biochar which has been seen to reduce the toxicity of spent coffee grounds but also improve soil performance. This further adds to the CE.

Chapter 6 Conclusion & Further Study

6.1 Conclusion

In conclusion, the role of the CE in the coffee value chain and its contribution towards the SDGs Goal 12 set out by the UN is promising. The aim of this thesis was to review the role of the CE in the coffee value chain with an objective of evaluating if a CE business model can be applied to the coffee industry to contribute towards SDG 12. The review attained the proposed goal. At the end of this thesis, the following can be concluded.

- The current complex coffee supply chain is unstainable and produces a vast amount of waste at each step in the supply chain. The roasting and brewing stages produce the largest amount of waste and is contributing to the elimination of the earth's natural resources as they are energy intensive processes. The impact of waste produced during the production of coffee is having a negative impact on the environment for generations to come.
- The important issues of the prospects of the use of spent coffee grounds after their primary use was discussed. Waste valorisation is an important concept that can contribute towards the sustainable consumption and production of food and therefore contributing towards SDG 12. Waste valorisation creates value to something that was once classified as waste.
- As highlighted in the introduction the reporting of FLW is poor. This results in limited visibility of any progress made to date in the Food & Beverage industry but also the Coffee industry on improving FLW in the supply chain.
- This report confirms that the current linear economy business model of 'take-make-dispose' in the coffee industry can be changed to CE business model by using spent coffee grounds as energy. Spent coffee grounds can be converted to energy through various methods such a pyrolysis or mixing the spent coffee grounds with wood dust to produce pellets that can be burned in boilers. This energy can then be used to roast coffee beans or used for oil or diesel in transportation through the various stages of the coffee value chain. This reduces the negative impact on the earth's environment.
- Value can be added to spent coffee grounds through extraction of valuable components and the use of spent coffee grounds as fertiliser once treated. This adds further to the CE model that is proposed to be used in the coffee supply chain. Fertiliser can be spread on coffee farms while valuable components can be used in other products in the food and beverage industry.

- Savings both financially on fossil and environmentally can be achieved when CE is implemented in the coffee supply chain. This was seen in the study by in terms the Caffee Cagliari company.

6.2 Future Work

The potential for the CE in the coffee value chain was proven to be successful once applied, despite the number of studies related to the production of energy from spent coffee grounds and using that energy to roast coffee beans are limited. There are also limited studies in the use of the components that can be extracted from spent coffee beans and how they can be used in a circular economy approach. The use of the biochar that can be created from spent coffee grounds as fertiliser also lacks studies with a huge potential in this area.

From the findings of this study, benefit could be derived from various stakeholders in the coffee value chain working together to use spent coffee grounds as energy and use it to produce energy to roast coffee beans, the use of spent coffee grounds biochar as fertilizer or the use of the other components that can be extracted from spent coffee beans.

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