Circular Economy System to Transform Coffee Waste into Biodiesel

Estefania Moreno Piña

Thesis to obtain the Master of Science Degree in

Energy Engineering and Management

Supervisors: Prof. Ana Isabel Cerqueira de Sousa Gouveia Carvalho

Dr. Ana Sofia Ramos Brasio

Examination Committee

Chairperson: Prof. Susana Isabel Carvalho Relvas

Supervisor: Prof. Ana Isabel Cerqueira de Sousa Gouveia Carvalho

Member of the Committee: Prof. Tânia Rute Xavier de Matos Pinto Varela

September 2022

Declaration

I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Declaração

Declaro que o presente documento é um trabalho original da minha autoria e que cumpre todos os requisitos do Código de Conduta e Boas Práticas da Universidade de Lisboa.

ACKNOWLEDGMENTS

I would like to thank my supervisor, Prof. Ana Carvalho, for reading my work multiple times and assisting me in making sense of the chaos.

I would also want to acknowledge Ana Brasio and PRIO for the opportunity to join in this project, as well as for all their help and encouragement with my work.

I would like to express my special appreciation and thanks to Innoenergy for their support.

I would like to thank all my friends. My college friends, who accompanied me on my journey, and the ones who were far away yet made me feel as if they were right there with me.

I would like to express my deepest gratitude to Prashant Jha, who never let me give up, was my biggest supporter, and never stopped believing in me.

Finally, I would like to show all my thankfulness to my parents Maria del Carmen Piña and Aquiles Moreno, and my sister Maria Moreno for their unconditional support throughout the entire process. I cherish your care and support.

ABSTRACT

Biofuels, such as biodiesel, stand out among renewable choices for lowering fossil fuel consumption in difficult-to-electrify industries such as transportation, aviation, manufacturing, and construction (IRENA, 2020a). The coffee industry, on the other hand, is one of the most traded commodities, and Spent Coffee Ground (SCG) is a by-product generated after a coffee brew that can be utilized to produce biofuels and value-added products such as biodiesel, biogas, bioethanol, fuel pellets, and bio-oil (Atabani et al., 2019).

The circular economy has recently been recognized as having the potential to replace fossil fuels in the energy sector with sustainable bioresources, products, and processes (Brandão et al., 2021) It also provides a possibility for various industries, including energy, chemicals, and materials (Philp & Winickoff, 2018); however, the success of sustainable energy is dependent on supply chain management, from biomass feedstock production through shipping and biorefining conversions to product or service delivery (Tan & Lamers, 2021). Moreover, circular economy evaluations are using Value Stream Mapping (VSM) more frequently to understand the scale and complexity of the issue provided by the circular economy in supply chains (Howard et al., 2022).

In this context, the company PRIO decided to examine the reverse logistics required to use SCG as a feedstock for biodiesel production in collaboration with the companies Delta Cafes and Ecobean. To gain a better understanding of what is needed for a Reverse Logistics (RL) system, the elements of collection, selection, recovery, and redistribution were investigated. To evaluate the processes the benefits and limitations of implementing a circular economy framework, it was proposed to conduct a VSM study of the forward supply chain and the RL system.

After evaluating the pilot project to test the RL system to collect SCG as feedstock for biodiesel production, it was possible to identify the major aspects of the forward supply chain in this case study, propose and compare an RL system to collect SCG, and evaluate it. According to this study, the aspects associated with RL within the framework of a circular economy were successfully analyzed and evaluated. Additionally, the theoretical production of biodiesel from SCG has a positive environmental impact, as it reduces greenhouse gas emissions. Furthermore, it emphasizes the benefits of enterprise collaboration and the success of that collaboration in facilitating the circular economy. In addition, the VSM has proven to be an effective tool for evaluating processes and highlighting the advantages and challenges of implementing a circular economy framework.

Keywords: Circular Economy; Spent Coffee Ground; Biodiesel; VSM; Reverse Logistics.

RESUMO

Os biocombustíveis, como o biodiesel, destacam-se entre as escolhas renováveis para reduzir o consumo de combustíveis fósseis em indústrias de difícil eletrificação como transportes, aviação, fabrico e construção (IRENA, 2020a). A indústria do café, por outro lado, é uma das mercadorias mais comercializadas, e o Spent Coffee Ground (SCG) é um subproduto gerado após uma cafeteira que pode ser utilizada para produzir biocombustíveis e produtos de valor acrescentado como biodiesel, biogás, bioetanol, pellets de combustível e bioólio (Atabani et al., 2019).

A economia circular foi recentemente reconhecida como tendo o potencial de substituir os combustíveis fósseis no setor energético por biorecursos, produtos e processos sustentáveis (Brandão et al., 2021) Também oferece uma possibilidade para várias indústrias, incluindo energia, produtos químicos e materiais (Philp & Winickoff, 2018); no entanto, o sucesso da energia sustentável depende da gestão da cadeia de abastecimento, desde a produção de matérias-primas de biomassa através da navegação e das conversões biorescídeas para fornecimento de produtos ou serviços (Tan & Lamers, 2021). Além disso, as avaliações da economia circular estão a utilizar mais frequentemente os VSMs para compreender a dimensão e complexidade da questão fornecida pela economia circular nas cadeias de abastecimento (Howard et al., 2022).

Neste contexto, a empresa PRIO decidiu examinar a logística inversa necessária para utilizar o SCG como matéria-prima para a produção de biodiesel em colaboração com as empresas Delta Cafés e Ecobean. Para se conhecer melhor o que é necessário para um sistema de Logística Inversa (RL), foram investigados os elementos de recolha, seleção, recuperação e redistribuição. Para avaliar os processos os benefícios e limitações da implementação de um quadro de economia circular, propôs-se a realização de um estudo vsM da cadeia de fornecimento a prazo e do sistema RL.

Após a avaliação do projeto-piloto para testar o sistema RL para recolher o SCG como matéria-prima para a produção de biodiesel, foi possível identificar os principais aspetos da cadeia de fornecimento para a frente neste estudo de caso, propor e comparar um sistema RL para recolher SCG, e avaliá-lo. De acordo com este estudo, os aspetos associados ao RL no âmbito de uma economia circular foram analisados e avaliados com sucesso. Além disso, a produção teórica de biodiesel da SCG tem um impacto ambiental positivo, uma vez que reduz as emissões de gases com efeito de estufa. Além disso, sublinha os benefícios da colaboração empresarial e o sucesso dessa colaboração na facilitação da economia circular. Além disso, o VSM provou ser uma ferramenta eficaz para avaliar processos e destacar as vantagens e desafios da implementação de um quadro de economia circular.

Palavras-chave: economia circular; borra de café; biodiesel; VSM; logística inversa

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

CLSCM - Closed-loop Supply Chain Management

CSCM - Circular Supply Chain Management

DSCG - Defatted Spent Coffee Ground

EU - European Union

GHG - Green House Gases

GSCM - Green Supply Chain Management

NECP - National Energy and Climate Plan

RL - Reverse Logistics

SCG - Spent Coffee Ground

SCGO - Spent Coffee Ground Oil

SCM - Supply Chain Management

SSCM - Sustainable Supply Chain Management

VSM - Value Stream Mapping

WCO – Wasted Cooking Oil

1 INTRODUCTION

1.1 BACKGROUND AND CONTEXT

Since the last century, the over-exploitation of fossil fuels due to the industrial and technological revolutions' energy demands, combined with human activities, has pushed climate and environmental boundaries(Steffen et al., 2015). The energy industry must, among other things, reduce greenhouse gas emissions and reliance on fossil fuels to become sustainable and decarbonized (Papadis & Tsatsaronis, 2020).

Bioenergy stands out among renewable solutions to reduce fossil fuels in hard-to-electrify sectors including transport, aviation, industry, and buildings (IRENA, 2020a). It is often derived from agricultural, forestry, and waste biomass, and it has the potential to reduce fossil fuel dependence and decarbonize a portion of the energy system (IEA, 2017). Agricultural and forestry byproducts and food wastes can be transformed into a byproduct, a new product, or a new resource. This comprises a form of liquid biomass produced for fuels, heating, and industrial using standard or accelerated conversion procedures (Brandão et al., 2021; Nizami et al., 2017).

Biodiesel is a biofuel with a production of approximately 36 billion liters in 2016, primarily derived from food oils. Currently, 60% to 80% of the total cost of biodiesel production is attributable to the cost of feedstock, which is derived from edible oils. Moreover, biodiesel is anticipated to account for 70% of transportation fuel by 2040. Thus, biodiesel's biggest challenge is to find low-cost and sustainable sources for its production (Athar & Zaidi, 2020; Zullaikah et al., 2019).

On the other hand, the coffee industry is one of the greatest traded commodities, valued at 30 billion USD in 2019. Global coffee consumption was 164 million bags (10 million tons) in 2018-2019 and is predicted to grow (WBG, 2021). The by-product obtained after a coffee brew is Spent Coffee Ground (SCG). It is the most abundant type of coffee by-product, representing almost 55% of the total remanent from coffee production (Mussatto et al., 2011). Consequently, millions of tons of SCG have been generated annually, calling for exploration of the opportunities for its utilization on an industrial scale (Kamil et al., 2019). Using SCG as a feedstock enables the production of biofuels and value-added products such as biodiesel, biogas, bioethanol, fuel pellets, and bio-oil (Atabani et al., 2019).

Recently circular economy has been seen as an opportunity to replace fossil fuels with sustainable bioresources, products, and processes in the energy sector (Brando et al., 2021) since it tries to establish a balance between economic, social, and environmental progress by closing material loops (Tan & Lamers, 2021). It also represents a potential for several industries, such as energy, chemicals, and materials (Philp & Winickoff, 2018); nevertheless, sustainable energy success needs innovative business models and changes in supply chain management, from biomass feedstock production, shipping, and biorefining conversions through product or service delivery (Tan & Lamers, 2021). Implementing a Circular Supply Chain Management (CSCM) is especially challenging due to the requirement for extensive changes in production planning and management, logistics, and supply chain decisions (Frishammar & Parida, 2019).

In this context, PRIO, in cooperation with Delta Cafés and as part of the PRIO Jump Start innovation challenge, selected Ecobean's creative concept to develop a project that aims to satisfy customer demand and increase biodiesel's market share. As a result, a pilot test was proposed to evaluate the collection of SCG and its availability for biodiesel production. The purpose of this dissertation is to develop and evaluate a reverse logistic system for the aforementioned pilot project.

1.2 Purpose and goals

This research was conducted as part of PRIO's innovation challenge, which aims to promote and enhance PRIO's value chain. To meet consumer demand and enhance the market share of biodiesel, PRIO chose to develop a pilot study to test the Reverse Logistics (RL) system to collect spent coffee ground as feedstock to produce biodiesel. This model was developed in partnership with Delta Cafés, PRIO's coffee supplier, and Ecobean, the technology provider.

This dissertation aims to propose a reverse logistic system, which allows to collect spent coffee ground as feedstock to produce biodiesel. To perform this goal, other intermediate objectives were addressed, and the master dissertation has three major contributions:

- A literature review on the circular economy and circular supply chain management to establish a solid foundation for the development of the reverse logistic system.
- An assessment of the current state of the process and the pilot system's evaluation.
- Diagnosis and assessment of a pilot system, where coffee will be collected in some local points and distributed in a biodiesel plant. This requires field work to diagnose the drives and bottlenecks among stakeholders for the logistics implementation of the system.

1.3 Methodology structure

To propose and evaluate the reverse logistic system, the following steps were followed:

First, data was collected, followed by a description of the motivations and objectives for building this project. This section is also intended to establish the information essential for identifying the most important information of the forward supply chain in the case study and planning the RL process.

Second, a VSM was created to evaluate the linear supply chain. When applied to a circular system, the VSM methodology shows how waste is generated in a comprehensive way. It is possible to assess several aspects of sustainability and identify potential areas for improvement by combining these indicators.

Third, based on the data gathered and the VSM results, a reverse logistic plan was proposed for the pilot project. This information was initially presented in the form of a conceptual flow, which made a general comprehension of the system possible.

Lastly, the VSM for the reverse logistic system was created to illustrate how the process would change because of the implementation of the reverse logistic system. RL inputs and outputs included waste management, transportation, and the recovery process. This was followed by a

KPI computation based on a VSM map. In addition, a comparison between the current and future state maps was created to highlight the challenges and opportunities involved with integrating this technique into a network and to assess the actual value obtained.

1.4 Master dissertation structure

The presented dissertation is composed of the following six major chapters (Figure 1.1):

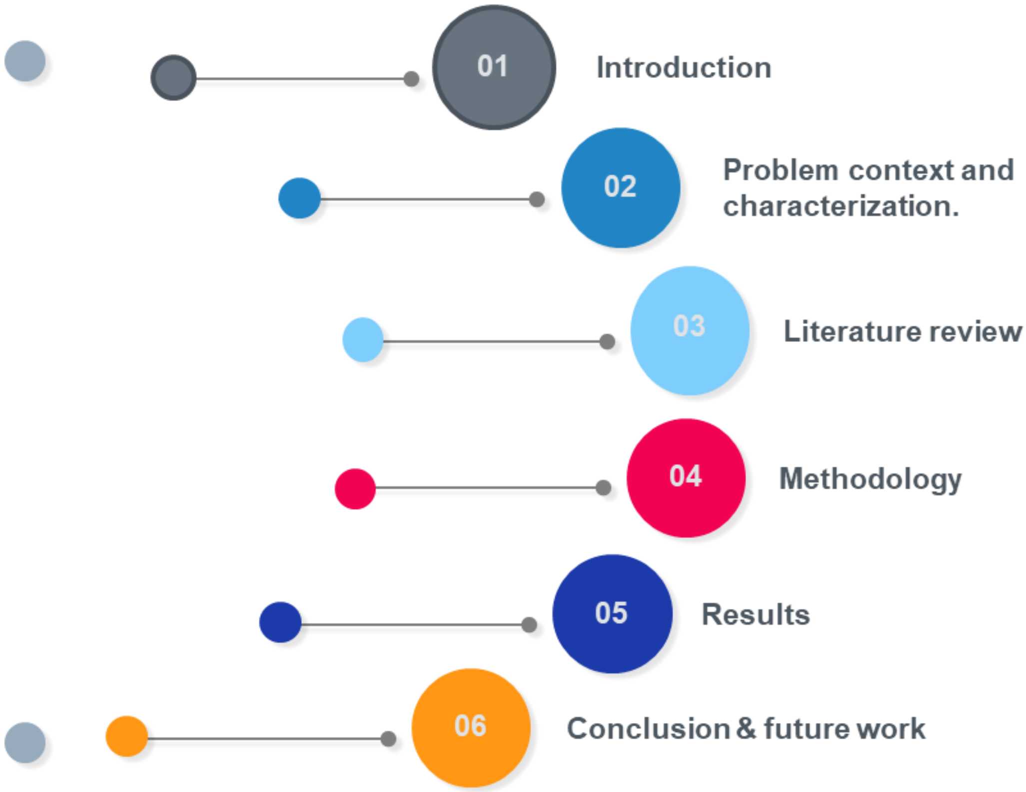


Figure 1.1 Master dissertation structure.

Chapter 1 – Introduction – This chapter presents a brief contextualization of the problem is presented, as well as the dissertation's objectives and structure.

Chapter 2 – Context – This chapter is divided into two. The first section of the chapter provides an overview of the global and Portuguese energy sectors and the issues of the energy transition, with a focus on bioenergy and biodiesel production. The second section of the chapter examines the worldwide coffee market, its production chain, and an overview of biofuels derived from SCG.

Chapter 3 – State of the art – A literature review on circular economy for sustainable energy and supply chain management is presented. Then, the importance of reverse logistics in the circular economy and its key aspects are described. Finally, a discussion of value stream mapping as an effective tool for describing value creation as a strategic activity in a circular supply chain is presented.

Chapter 4 – Methodology – The approach established and utilized for this dissertation involved supply chain analysis-based research. The first section addresses the data collection required to examine the forward supply chain in the case study. Followed by the analysis technique approach for the diagnosis. The reverse logistic proposal's methodology is next described. Finally, the assessment technique for the reverse supply chain is addressed.

Chapter 5 – Results – The outcomes of the methodology proposed in Chapter 4 are presented. These include the deployment and analysis of the data collection, the analysis of the forward supply chain, and the proposed reverse logistics system, culminating in the assessment of the RL system.

Chapter 6 – Conclusion and future work – This chapter presents the main conclusions of the master thesis as well as further thoughts and considerations for developing future works.

2 CONTEXT

This chapter consists of a current introduction situation of the energy sector and the coffee sector both in the world and Portugal. First, section 2.1.1 presents a summary of the current situation of the energy sector in the world and Portugal and the requirements to transit into a sustainable energy sector. Then, Section 2.1.3 shows a brief resume of the different technologies that comprise bioenergy and biodiesel production, and its main components, with the main emphasis on the biomass used as feedstock. Later, section 2.2 focuses on the global coffee market, its supply chain, and by-products, along with a summary of the opportunity to produce biofuels.

2.1 ENERGY SECTOR

2.1.1 ENERGY IN THE WORLD

Since the last century, the energy demand required by the industrial and technological revolutions joined by numerous practices from humankind has pushed the climate and environmental boundaries, generating immeasurable negative impacts worldwide (Steffen et al., 2015). Currently, the energy demand is covered by energy carriers such as electricity, heat, and fuels generated from the combustion of fossil fuels. In 2010, fossil fuels contributed to 65% of the Green House Gases (GHG), causing adverse environmental impacts such as global warming (IPCC, 2014). Moreover, the global human population is expected to grow from 7.4 billion in 2016 to 10 billion people by 2060, foreseeing increased energy demand. Therefore, the world requires the energy sector to satisfy the energy demand while reducing GHG emissions, controlling climate change effects, reducing fossil fuels dependency, and limiting biodiversity depletion to transit into a sustainable and decarbonized energy industry. (Papadis & Tsatsaronis, 2020; Vlachokostas, 2020). The aforementioned is a complex problem that requires innovative solutions, and no single technology can supply the total energy demand in a sustainable way (IRENA, 2020c).

Several institutions have modeled energy systems to plan and estimate the possible decarbonization pathways of the sector. For example, the International Renewable Energy Agency published the *Global Renewable Outlook* (2020), which outlines the investments and technologies needed to decarbonize the energy system. It highlights the importance of developing renewable technologies, intensifying energy efficiency, and using Carbon Capture and Storage or Usage technologies. Within the mix of renewable energy are mentioned technologies such as wind, solar, geothermal, hydro, and bioenergy, the bulk of these will help electrify the energy system. These will require raising the share of the renewable energy mix from 25% of the power generation in 2017 to 86% in 2050 (Figure 2.1). Scaling up the potential of renewable energy and energy efficiency could offer over 90% of the mitigation measures needed to reduce energy-related emissions in the Transforming Energy Scenario[1] (IRENA, 2020a).

[1] The *Global Renewable Outlook* (IRENA, 2020a) report outlines the Transforming Energy Scenario that describes the pathway required to decline the GHG emissions by 70% below today's level by 2050.

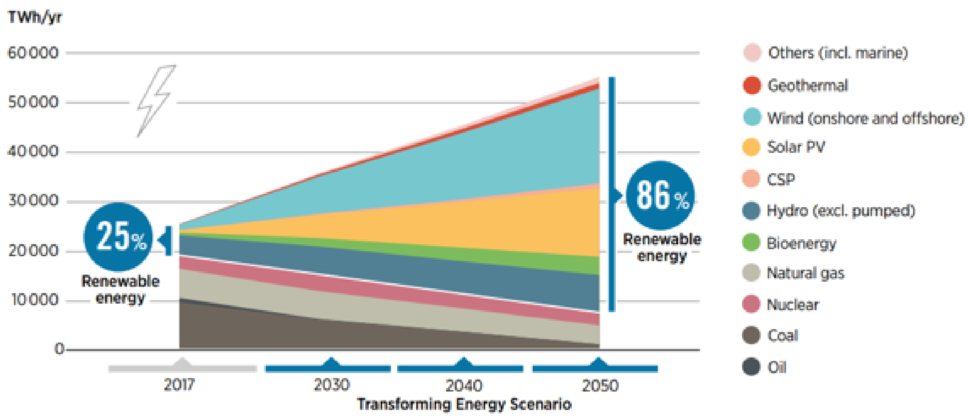


Figure 2.1. Renewable power generation until 2050 under the Transforming Energy Scenario[1] (IRENA, 2020).

Within the global mix of renewable technologies, bioenergy stands out for its role in decarbonizing the energy sector by replacing fossil fuels. Particularly to balance the electric grid from solar, wind, or hydro energy and reduce fossil fuels in industries challenging to electrify, such as shipping and aviation, industry and buildings (IRENA, 2020a).

The following section will summarize the current state of the energy sector in Portugal, highlighting the importance of developing bioenergy technology in the country.

2.1.2 Energy in Portugal

Portugal (officially the Portuguese Republic) is a country on the Iberian Peninsula that borders Spain with a 10.3 million population. Portugal's main economic activities are based on services (63% of the gross domestic product, 2019), followed by industry (19%), tourism (14%), and agriculture (2%). Moreover, the primary CO_2 emissions in 2019 were related to the use of fossil fuels, especially in the transport sector (40.5%), followed by electricity and heat generation (31.9%), industry (18%), services (5.4%), and residential (4.2%) (IEA, 2020).

Although Portugal has no fossil fuel sources and relies entirely on imports, it is still the primary energy source in the country. In 2019, imported fossil fuels accounted for 60% of the total final consumption, of which around 49% was oil, 10% was natural gas, and 1% coal. However, renewable energy and electricity covered around 40% of the total final consumption, of which electricity covered 24.5%, and bioenergy and waste covered 13%. Thus, renewable energy meant the final energy consumption of 54% of electricity generation, 42% of heating and cooling demand, and 9% of transport demand. Moreover, bioenergy was distributed as follows: 52% was used in the industrial sector, 36% in buildings in solid biomass, and 12% in biofuels in the transport sector (IEA, 2020).

Regarding the transport sector, it still relies heavily on fossil fuels. In 2019, the primary fuel used was diesel (71%), followed by gasoline (19%) and biofuels (5%), with smaller shares from a variety of fossil fuels. Electricity accounted for just 0.7% of transport energy demand and came primarily from rails, along with a small but growing fleet of electric vehicles. Portugal has a biofuel blending duty, which mandates fuel suppliers to blend a set percentage of biofuels into vehicle diesel and gasoline. The rate gradually increased from 6% in 2009 to 10% in 2015 (IEA, 2020).

Portugal is among the leading countries to set 2050 carbon neutrality goals, pushing for carbon neutrality primarily, which targets reducing GHG emissions and are set under European Union (EU) directives and national laws. Like, Portugal's National Energy and Climate Plan (NECP) establishes the targets for 2030, which include the reduction of GHG emissions from 45% to 55 [2] (in relation to 2005), the reinforcement of renewable energies up to 47% for electricity generation, and 20% in the transport sector (use of biofuels and electrification of industry), as well as increasing the energy efficiency to 35% (EU, 2020b).

Moreover, in 2015, Portugal adopted the "Green Growth Commitment," which aims to promote a circular economy to reduce disposal in landfills of biodegradable urban waste from 63% to 35%[3] and increase reuse and waste recycling from 24% to 50%, among developing a green economy (Portugal et al., 2016).

Additionally, the Portuguese government is preparing a national bioeconomy strategy through the Ministry of Environment and Climate Action: The Sustainable Bioeconomy Action Plan. This plan aims to promote a paradigm shift, accelerating the production of high-added-value products from biological resources (as an alternative to fossil-based materials). This plan is being developed while considering existing bio-based sectoral maps and understanding the ecological limits of both the bioeconomy and the territories in question, providing considerable support for local, regional, and national bio-based operations (BIC, 2021).

As seen before, bioenergy is an excellent opportunity to decarbonize the energy sector worldwide and in Portugal to reduce its fossil fuel dependency. Therefore, it is essential to understand what bioenergy is and specifically biodiesel, in this dissertation.

2.1.3 Bioenergy

Bioenergy is defined by Lago, Herrera, et al. (2018) as *"a renewable energy produced from biomass capable of replacing fossil energy."* Likewise, biomass is defined "*as plants and animals' matter and their metabolic by-products."* The biomass can be processed to different end-up uses like power generation (electrical energy), heat (thermal energy), and transport (biofuels) (Sunggyu & Shah, 2012). In other words, bioenergy is the energy derived from the transformation of biomass, which includes agricultural, forestry, and wastes, into energy that can supply the demand, thus reducing fossil fuel dependency and helping the decarbonization of the energy system (IEA, 2017).

Currently, bioenergy is the largest renewable energy source, accounting for 10% of the Total Primary Energy Supply. In 2018, 67% of the renewable energy produced globally was biomass-based (Figure 2.2A), mainly used in traditional forms (IRENA, 2020b). As far as the type of the feedstock, 86% was a solid biomass source, including wood chips, wood pellets, or the traditional

[2] Not including land-use change and forestry.
[3] 1995 as reference year.

biomass sources (wood and charcoal); followed by 7% of liquid biofuels in the form of liquid biofuels mainly from food crops, 5% of incineration of the municipal and industrial waste sector, and 2% of biogas (Figure 2.2B) (WBA, 2020). In terms of the final application, the most common was used in the building sector, including cooking and space heating (26%), followed by the industrial sector (7%), the transport sector (3%), and the power sector (2%) (IRENA, 2020b).

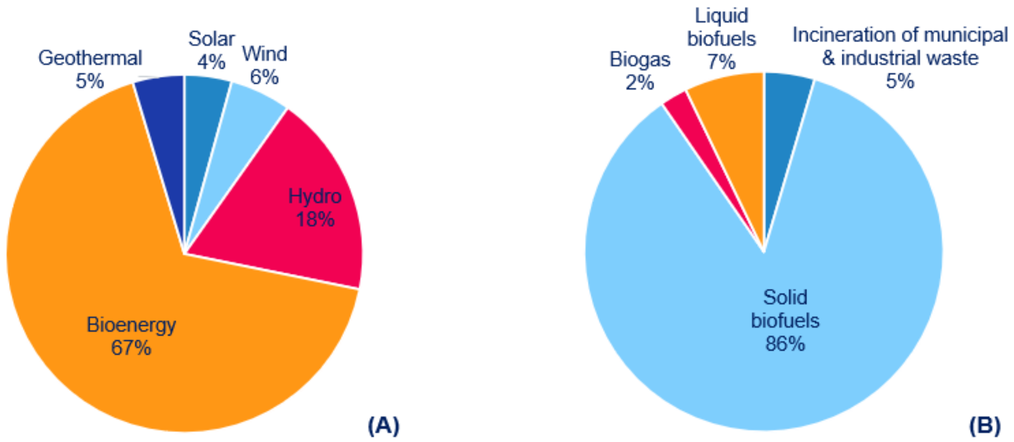


Figure 2.2. (A) Global total primary renewable energy supply in 2018; (B) Global bioenergy supply in 2018 (WBA, 2020)**.**

However, there are several points of consideration for bioenergy development. The traditional use of biomass can carry negative impacts such as loss of biodiversity, indirect land-use change, pollution, and water consumption associated with it, to mention a few (Lago et al., 2018). IRENA define the traditional use of bioenergy as "*the use of wood, charcoal, agricultural residues, and animal dung local collected or from unsustainably produced sources with basic techniques for cooking and heating at very low conversion efficiency (10% to 20%) in open stoves or fires with no chimney or hood. These uses often release flue gases indoors or cause high concentrations of air pollutants."*

It is estimated that by 2030, the traditional uses of bioenergy will be replaced with sustainable energy options, like the modern use of bioenergy and other renewables (IRENA, 2020a).

Moreover, the modern use of bioenergy refers to the "*direct combustion of commercially produced primary biomass and the indirect use of pretreated solid biomass with heightened energy density for electricity and heat generation. It includes liquid forms of biomass produced via conventional or advanced conversion routes for transport fuels, cooking, and industrial applications; biogas produced through anaerobic digestion of residues and waste; and syngas produced through biomass gasification. Biomass use in improved cookstoves can be categorized as modern if sustainably sourced"* IRENA, (2020b).

Modern bioenergy has several advantages compared to fossil fuels, like an abundant renewable local source of energy and GHG emissions neutrality. In the *Global Renewable Outlook* (IRENA, 2020a), the Planned Energy Scenario[4], the share of primary energy that is expected to meet with modern bioenergy increases from 5% to 10%. Moreover, to reduce the 70% of the GHG emissions proposed in the Transforming Energy Scenario, bioenergy plays a more important role, increasing the share of primary energy to 23% (Figure 2.3) (IRENA, 2020a).

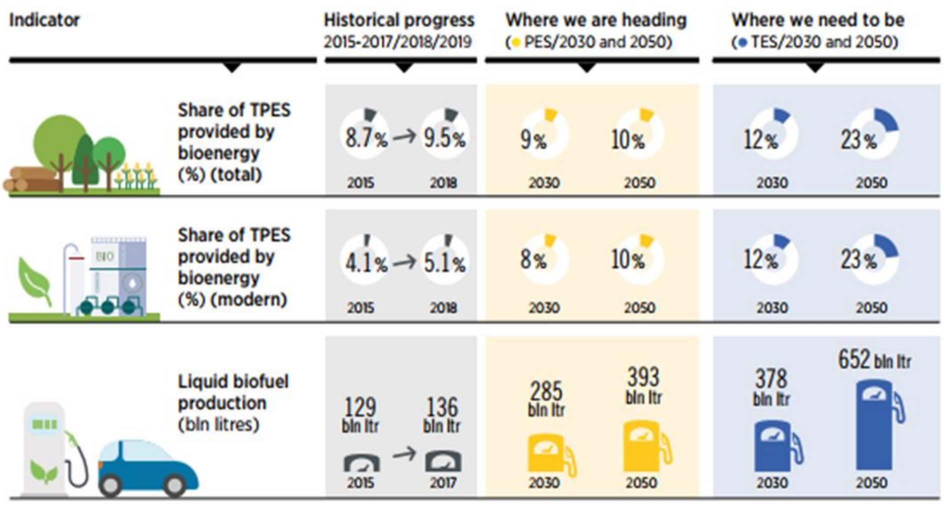


Figure 2.3. Scenarios of Bioenergy shares production (Adapted from IRENA, 2020).

Besides the traditional or modern use of bioenergy, literature reports several ways to classify biofuels based on the commercialization of the technology and the feedstock's nature. According to the review by Ruan et al. (2019), biofuels can be classified into five generations based on the technology and the feedstock nature, as shown in Figure 2.4.

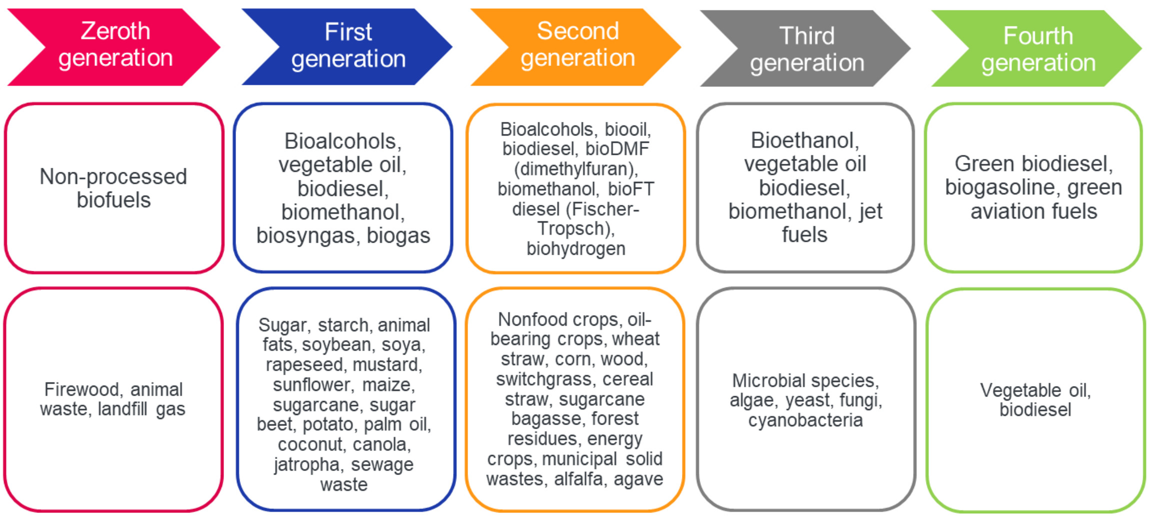


Figure 2.4. Biofuels are classified into five generations (Based on Ruan et al., 2019).

- Zeroth generation refers to the raw or natural biofuels used directly without pretreatment, processing, or modification, and are part of the traditional use of biomass.

[4] The *Global Renewable Outlook* (IRENA, 2020a) outlines the "Planned Energy Scenario", based on government plans and other international planned targets and policies, including the "Nationally Determined Contributions" settled under the Paris Agreement until 2019.

- The first-generation biofuels use edible oils as feedstock and are well-established conventional biofuels produced on a large scale and blended with conventional fuels. However, edible oils have several disadvantages, like direct competition in the global food supply and agricultural land use, i.e., a higher carbon footprint than other biofuel generations.
- Second-generation biofuels come from agricultural residues typically composed of lignocellulosic, hemicellulose, and lignin. Nevertheless, these can only supply a portion of the total diesel fuel demand, and until today, they are not economically competitive. Moreover, although these biofuels are close to meeting environmental sustainability, using agriculture and forest residues degrades the soil quality and induces soil erosion. The third generation primarily consists of macroalgae and microalgae, with the advantage that its cultivation can be done on-demand with low requirements on land. As a result, the feedstock from biofuels can produce more energy than those found in the first and second generations without competing for land or food with low energy and quality requirements. However, the process is costly, and the production technology is under development, requiring innovative technologies from the production of feedstock to process into the final biofuel product.
- The fourth generation of biofuels is the product of advances in plant biology and biotechnology (metabolic engineering) in the realm of carbon capture and storage. It includes green diesel, bio gasoline, and green aviation fuels.

Moreover, non-food and waste biomass materials (agricultural and forestry residues, and food wastes) are materials worth processing that can become a by-product, a new product, or a new resource. Targeted biofuel deployment of these feedstocks is necessary to mitigate land-use impacts and GHG emissions compared to traditional fuels. Additionally, non-food and waste biomass resources coincide with rising technology alternatives that provide new bio-based products in various industries (Brandão et al., 2021; Nizami et al., 2017).

Biomass is converted into biofuels, bioproducts, or biopower in a facility known as a biorefinery, which is equivalent to an oil refinery; crude petroleum is transformed into multiple fuels and products with specific differences (U.S. Department of Energy, 2006). Biomass might be used to create practically all petroleum products in biorefineries, thanks to the existing combination of feedstocks, platforms, and processes (IRENA, 2019). Conteratto et al. (2021) defined biorefinery as *"a physical, chemical, or biological process which purifies, separates, refines, or transforms elements constituting biological assets from the kingdoms Monera, Protista, Plantae, Animalia, or Fungi, originating from the terrestrial or oceanic environment, in bioproducts for final use or that serve as raw material for other bioproducts."*

The technology used in a biorefinery depends on various factors, such as the type of product to be obtained, the availability of raw materials, production costs, etc. Nonetheless, each biorefinery scheme must be assessed individually to achieve the highest level of sustainability in terms of both economic viability and environmental friendliness (Gutiérrez et al., 2017). Biodiesel has garnered much interest in several different biofuel technologies due to its role in decarbonizing the transport sector. Next, the main characteristics of the technology will be presented.

Biodiesel

Biodiesel is an oxygenated biofuel obtained from the transesterification of triglycerides with alcohol in the presence of a catalyst. The triglycerides required can be obtained from vegetable oil, animal fats, algae lipid, waste grease, and short-chain alcohols like methanol, ethanol, or mixtures (Gutiérrez et al., 2017; Ruan et al., 2019). Compared with petroleum diesel, biodiesel has advantages such as a higher flash point and cetane number, safe storage, transportation, and better ignition quality. It also contains low levels of aromatics and sulfur, which reduces air pollutant emissions, making it a better option in terms of environmental impact. On the other hand, its main disadvantages are a lower calorific value, requiring more biodiesel than diesel to obtain the same energy and acids that can harm the engines. Also, a higher pour point in colder temperatures and higher viscosity negatively affect the fuel spray atomization (Ruan et al., 2019).

Biodiesel is made using various technologies that vary in terms of the type of catalyst used and the conditions under which the transesterification process takes place that define the efficiency of the conversion (Gutiérrez et al., 2017; Ruan et al., 2019). The process consists of four steps. The first is oil feedstock pretreatment, where the pollutants are removed to avoid harmful substances for the subsequent processing steps. Second, the transesterification, where the pretreated triglycerides react in the presence of an alcohol component to form natural methyl esters and glycerol. Third, methyl ester purification separates the catalyst, alcohol, and glycerol from the transesterification process. Finally, glycerol purification to separate the catalysts and alcohol remains (Duncan, 2003). For the sake of comparison, Table 2.1 summarized various transesterification techniques found in the literature.

Table 2.1. Operating conditions for biodiesel production processes (Gutiérrez et al., 2017; Ma & Liu, 2019)**.**

Process Index	Homogeneous catalyst	Heterogeneous catalyst	Enzyme catalyst	Supercritical Alcoholysis process	Ultrasonic irradiation
Biodiesel yield (%)	>95	85-95	85-90	>95	>93
Temperature (°C)	50-90	55-150	10-40	200-250	10-60
Reaction time	Short	Long	Long	Short	Short
Catalyst reuse	Unable	Good reusability	Good reusability	No need catalyst	No need catalyst
Catalyst cost	Cheap	Costly	Costly	Nil	Nil
Development	Industrialization	In-depth study	In-depth study	Preliminary study	Preliminary study

In 2016, global biodiesel production was over thirty-six billion liters, whose primary feedstock came from edible oils. The leading producer countries are the United States, Brazil, and Germany (Azizan, 2020). Currently, biodiesel commercialization's main obstacle is the high production cost; in particular, feedstock from edible oils represents 60% to 80% of the total production cost.

Moreover, biodiesel and petro diesel blends are expected to grow (up to 30%/70%) by 2030. Additionally, biodiesel is expected to be 70% of the transport fuel by 2040. Due to this, the selection of low-cost and sustainable feedstock from the vast variety of available sources is the most challenging task to achieve (Athar & Zaidi, 2020; Zullaikah et al., 2019). Moreover, large volumes of by-product glycerin, utilized as a food sweetener or pharmaceutical humectant, have entered the market due to the global expansion in biodiesel production (IRENA, 2019).

In 2017, biodiesel dominated the market in the EU biofuel sector, accounting for 80% of the biofuel consumption, followed by bioethanol with 19% of the total EU biofuel, and biogas with a small fraction (1%), concentrated mainly in Sweden and Germany (IRENA & EU, 2018).

In Portugal, biodiesel production accounted for around 7 kboe[5] , and consumption of 5 kboe versus diesel consumption reached over 90 kboe in 2018 (EU, 2020a; IEA, 2020). Thus, biodiesel blended with biodiesel accounted for 87% of the renewables used in transport. Moreover, the NECP established targets by 2030, decreasing first-generation biofuels by approximately 35% and increasing the production of advanced biofuels by 50% in 2030 (EU, 2020b).

2.2 Coffee Sector

2.2.1 Coffee consumption

The coffee brew comes from the cherry fruit of the plant *Coffea L.,* of which there are seventy-various species. Two of these are commercially exploded worldwide: *Coffea arabica* (Arabica), which provides 60% of the world's production, and *Coffea canephora* (Robusta), which provides the other 40% of the world's output (ICO, 2021; Mussatto et al., 2011).

Coffee brew consumption started around one thousand years ago by the Arabs. However, consumption in Europe began in 1615 by the Germans, Frenchmen, and Italians, and soon spread all around the world, becoming one of the most popular drinks in the world (Figure 2.5) (Mussatto et al., 2011; Thurston et al., 2013). Currently, the coffee industry is one of the largest traded commodities, with a value of USD 30 billion in 2019(OEC, 2019). In 2018-2019, global coffee consumption was around 164 million bags[6] (10 million tons), and its consumption is expected to grow globally by approximately 1,3% by 2021 (WBG, 2021).

[5] Kboe = Kilobarrel of Oil Equivalent.
[6] Bags = 60 kilograms bags.

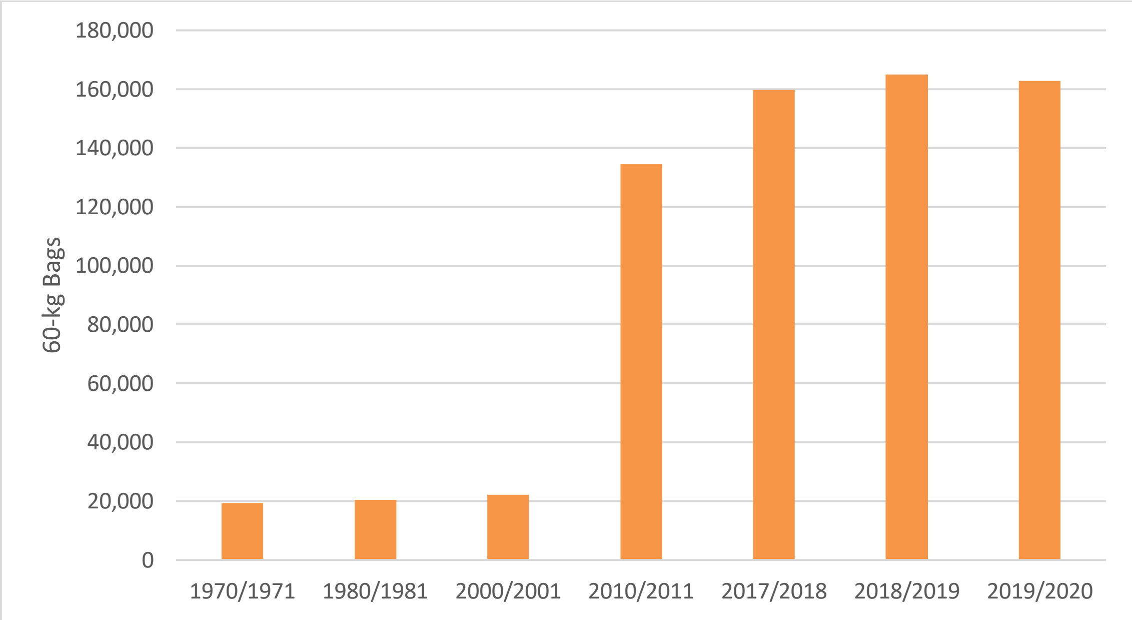


Figure 2.5. Global coffee consumption from 1970-2020 (WBG, 2021)**.**

The largest consumer of coffee worldwide is the EU, followed by the United States and Brazil, as depicted in Figure 2.6A. In 2018, the EU consumed around 23.403 thousand bags. Within the EU, Germany was the largest consumer with around 6.000 thousand bags, followed by France (2.760 thousand bags) and Italy (2.511 thousand bags). However, Finland is the largest coffee consumer per capita (12 kg/capita/year) and consumed only 788 thousand bags in 2018. In Portugal, on average, a person consumes 4,3 kg/capita/year, and 250 thousand bags were consumed in 2018. Therefore, placing Portugal as the world's 24th largest coffee consumer per capita (Bernard, 2020).

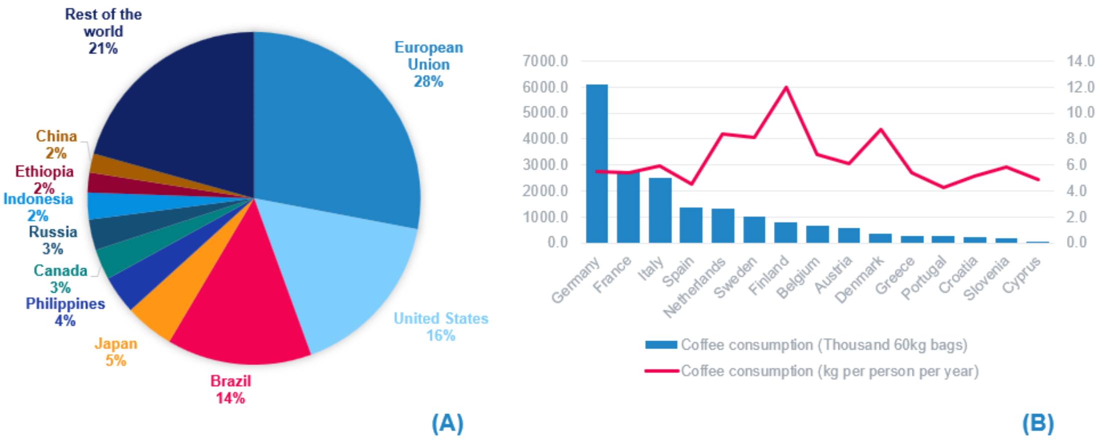


Figure 2.6. A) Coffee consumption 2018-2019 in the world (WBG, 2021)**; B) Coffee consumption in Thousand 60 kg bags vs. Consumption in kg per person per year in 2018** (Bernard, 2020; WBG, 2021)**.**

2.2.2 COFFEE CHAIN AND BY-PRODUCTS

Coffee cherries are two coffee beans covered by a thin parchment-like hull and further surrounded by pulp. The coffee cherries are then processed into green coffee beans, where the pulp and hull are removed (ICO, 2020). This process can be effectuated by wet or dry methods, obtaining two different residues depending on the extraction method, pulp, or husk, respectively. Later, the green coffee beans are roasted to give the specific organoleptic properties typical of the coffee brew (flavors, aromas, and color). This step is performed at elevated temperatures (260 °C) for a brief time (5 min. approx.), resulting in chemical changes in the composition of coffee beans (Teixeira & Mussatto, 2014). The by-product of this process is the tegument of coffee beans known as the coffee silverskin. After obtaining roasted coffee beans, they are packaged, shipped, and processed, ready to prepare a coffee brew (Figure 2.7) (Mussatto et al., 2011).

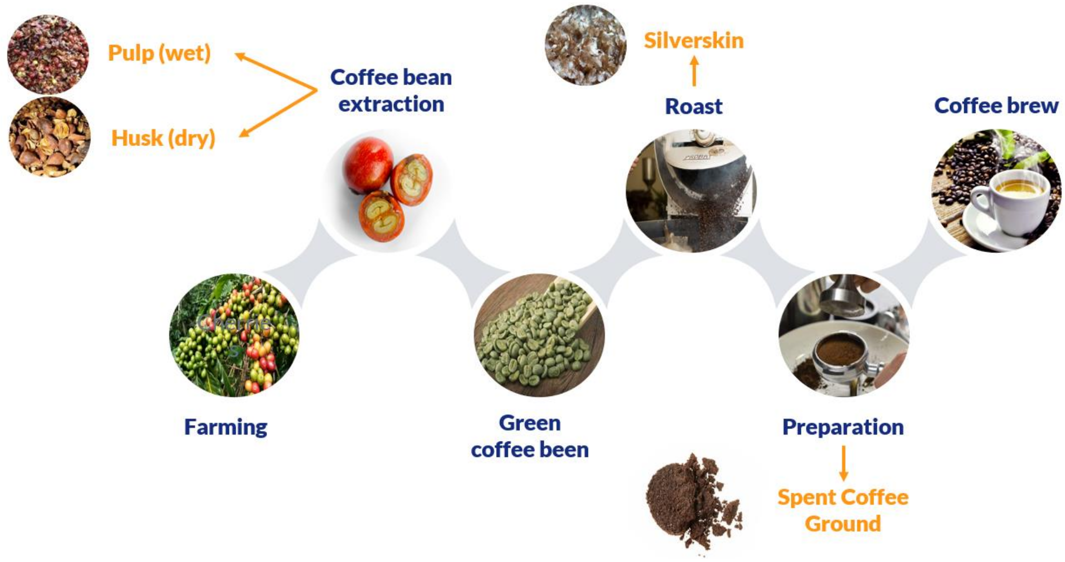


Figure 2.7. Coffee production chain and by-products (Mussatto et al., 2011)**.**

Depending on the method used, a coffee brew takes around 7 to 20 grams of roasted ground coffee to be prepared (Dellino et al., 2017). The by-product obtained after a coffee brew is called Spent Coffee Ground (SCG). It is the most abundant type of coffee by-product, representing almost 55% of the total remanent from coffee production (Bottani et al., 2019; Giller et al., 2017).

The SCG represents an environmental liability if discharged directly into the environment due to the high amount of oxygen required for degradation, and the presence of several organic constituents (more than 100 individual compounds) converts it into a toxic material (Atabani et al., 2019). According to Pflueger (1975, as cited by Kamil et al., 2019), 1 kg of green coffee beans generates 650 g of SCG, and the brewing of 1 g of soluble coffee grounds produces 2 g of SCG. Consequently, millions of tons of SCG have been generated annually, calling for exploration of the opportunities for its utilization on an industrial scale.

2.2.3 Biofuels from Spent Coffee Ground

The first evidence of the possible reuse of SCG dates back to 1976, and its potential use as a raw material for many non-energy products like compost/fertilizer, adsorptive filtering materials, plastics, composites, bricks, etc. (Bottani et al., 2019; McNutt & He, 2019). Moreover, SCG can produce energy, i.e., biodiesel, biogas, bioethanol, fuel pellets, and bio-oil, besides non-energy products such as bioactive compounds, adsorbents, compost, polymers, etc. (Atabani et al., 2019).

The extraction of oil from SCG presents numerous advantages. For example, assuming 15-16 wt.% of oil in SCG, the production of biodiesel from Spent Coffee Ground Oil (SCGO) could add around 1 million tons of biodiesel to the world's fuel supply (Bendall et al., 2015; Goh et al., 2020). Moreover, saving SCG one ton of landfilling could avoid 682 kg of CO_2e (Kamil, Ramadan, Awad, et al., 2019).

According to Atabani et al., (2019), SCG can produce more oil per unit of land (386 kg/ha) SCG area than other traditional crops (375 kg/ha soybean) with a high lipid remanent (90.2%). The fatty acids contained in SCGO go from 7 to 21.5%, dominated by linoleic acid (44-50%) and palmitic acid (35-40%), followed by oleic acid (7-8%), stearic acid (7-8%). Besides, it contains a considerable number of polymerized sugars (cellulose and hemicellulose). Therefore, compared to other oils extracted from wastes SCGO has higher stability and is more cost-effective. In addition, it does not contain caffeine, which may increase NOx emissions since the caffeine is extracted during the brew preparation. This structure yields biodiesel with high cetane number and oxidation stability, low iodine value, acceptable higher heating value and flash point besides higher cloud point, pour point, cold filter plugging point, and kinematic viscosity higher than 5mm2/s at 40 °C

Additionally, the potential of the solid remanent after oil extraction, called Defatted Spent Coffee Ground (DSCG) is to be utilized as fuel pellets is due to the significant amounts of cellulose and hemicellulose (around 50% of the dry mass of SCG), lignin, and protein components (20% of the dry group of SCG). Thereby, SCG pellets are an excellent fuel, with a higher calorific value in the range between of 19.3 to 24.9 MJ/kg in comparison with different biomass such as wood (22.7 MJ/kg), brown coal (8.5-16.6 MJ/kg) or lignite (16.38 MJ/kg) (Atabani et al., 2019).

According to Atabani et al., (2019), SCG recovery enables the production of seven distinct biofuels, including bioethanol, bio-oil, biodiesel, hydrocarbon fuel, biogas, biohydrogen, and fuel pellets, as well as five valuable added-value products, including bioactive compounds, adsorbents, compost, biochar, and glycerin, as illustrated in Figure 2.8.

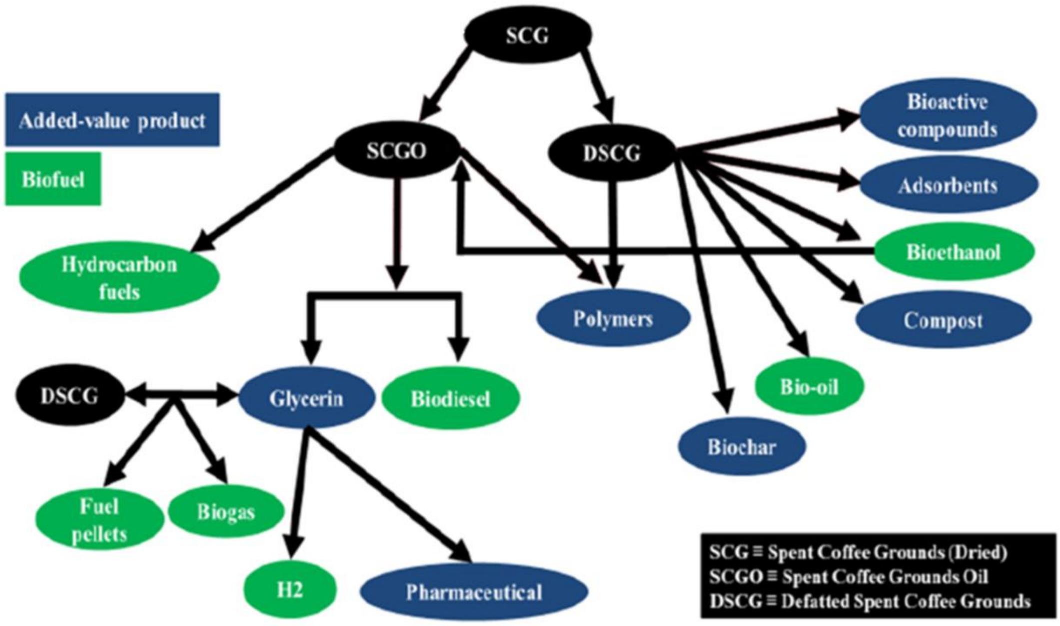


Figure 2.8. Scheme of the added-value products derived from SCG (Atabani et al., 2019)**.**

Feedstock availability and continuity are critical difficulties in industrial bioprocessing; one of the primary limits is the upstream supply chain, which involves collecting and transporting SCG. Insufficient research has been undertaken in this area, and parameters/variables such as the collection points, the quantities available for collection, and the type and cost of transportation need to be thoroughly evaluated (Massaya et al., 2019).

2.3 Chapter Conclusions

The transition to a more sustainable energy sector requires fomenting energy efficiency, using CCSU technologies, and developing several technologies such as solar, wind, hydro, and bioenergy. The last one is of particular interest due to its role in decarbonizing the industries such as transport. In Portugal, the interest is more significant because its development presents the chance to reduce fossil fuels dependency. Moreover, Portugal has promoted several plans to boost bioenergy development to reduce GHG emissions in compliance with its international commitments.

Bioenergy encompasses several technologies such as biogas, bio methanol, biodiesel, inter alia. Moreover, bioenergy is currently the largest share of renewable energy consumed worldwide. However, most of it comes from the traditional use of bioenergy associated with negative impacts, such as loss of biodiversity, indirect land-use change, pollution, and water consumption. Therefore, the next generation of biofuels needs to be developed to produce sustainable bioenergy, emphasizing sustainable feedstock, like non-food and waste biomass materials.

Biodiesel is a biofuel capable of reducing diesel petroleum dependency, especially within the transport sector. Compared to diesel, biodiesel possesses advantages like higher flash point and cetane numbers, safe storage, transportation, and better ignition quality. In addition, biodiesel can be produced from several biomass feedstocks and obtain value-added products, making the technology more flexible.

Furthermore, coffee is one of the most traded commodities around the world. Just in the 2018-2019 period, coffee consumption worldwide was approximately ten million tons. A coffee brew generates around 7 to 20 grams of SCG, producing more than thirteen million tons of SCG that, if disposed directly into the environment, can cause severe negative impacts. There is evidence of the use of SCG to produce biofuels like biodiesel and other by-products of interest.

Therefore, the purpose of this dissertation is to propose a logistics system and evaluate it from a circular economy perspective the use of SCG as a feedstock to produce biodiesel in a specific example.

3 STATE OF THE ART

This chapter presents the theoretical concepts of supply chains in the context of the circular economy as the focus. Section 3.1 provides an overview of the circular economy and the role it plays in attaining long-term energy security. Next, in Section 3.2, a brief introduction to Supply Chain Management (SCM) is provided, as well as a concise synopsis of the key subjects in supply chain operations and the circular economy are discussed. After that, RL is explained as a subset of SCM. Finally, Section 3.3, presents an overview of assessments within the framework of a circular economy and Value Stream Mapping (VSM) as a method to promote sustainability and a circular economy.

3.1 CIRCULAR ECONOMY FOR SUSTAINABLE ENERGY

Several approaches to achieving sustainable energy are mentioned in the literature, include circular economy, bioeconomy, and bio-based circular carbon economy (Dahiya et al., 2020). However, all these concepts are relatively novel and, at times, confusing, especially concerning their building blocks (Dahiya et al., 2020; Tan & Lamers, 2021). Furthermore, because of the changes in supply chain management, it is important to address and understand these concepts in this dissertation.

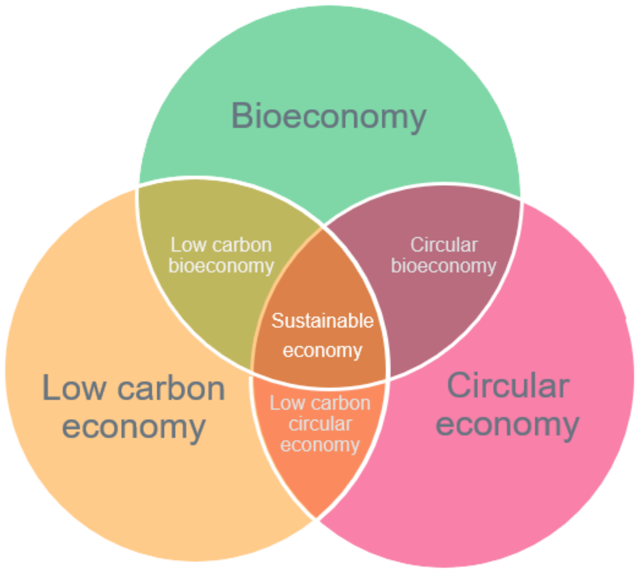


Figure 3.1. Venn diagrams various economies for sustainable energy (Dahiya et al., 2020)**.**

The circular economy concept aims the transition from the linear model of production and consumption (take-make-use-dispose); to a sustainable model where resources can be reused or reprocessed and reincorporated back into the economic system. Thus, reducing waste disposal, extending the useful life of resources, and minimizing (new) natural resource extraction (Hadley Kershaw et al., 2021). The circular economy concept is widely popular, but its definition differs based on the object of study, with over one hundred definitions existing. However, the ordinary agreement is that a circular economy aims to balance economic, social, and environmental development by closing material loops using renewable energy and non-toxic materials. Therefore, reducing or eliminating the extraction of unsustainable new materials and ensuring products can be reincorporated (Tan & Lamers, 2021).

At the same time, the bioeconomy relates to an economy that produces biofuels and bioproducts through the optimal conversion of biological resources for economic, environmental, and social benefits, using biotechnology and knowledge-based innovations (Brandão et al., 2021; Lago et al., 2018). Furthermore, Tan & Lamers (2021) argued that the bioeconomy is not sustainable by definition. However, it requires several factors such "*as the use of renewable biological resources, a sustainable supply chain, including sustainable biomass feedstock production and logistics, sustainable biomass conversion processes and sustainable products*."

The case of the circular bioeconomy concept then is a complement between circular economy and bioeconomy (Tan & Lamers, 2021). Circular bioeconomy is an emerging concept that complements both ideas mentioned above. It is seen as an excellent opportunity to transit away using biomass as a renewable source of feedstock (Venkata Mohan et al., 2020).

Circular bioeconomy refers to the production and use of sustainable bioresources, products, and processes to replace fossil or (new) natural resources to provide high added-value goods and services, as depicted in Figure 3.2 (Brandão et al., 2021). Reintroducing bio-based wastes or byproducts can prevent pollution and reduce natural resource demand being the intersection of circular economy and bioeconomy (Arruda et al., 2021; Hadley Kershaw et al., 2021; Salvador et al., 2021).

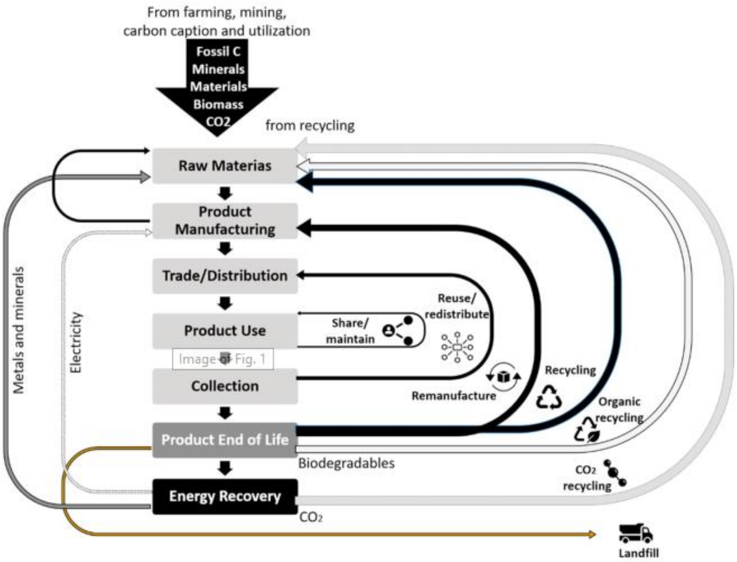


Figure 3.2. A comprehensive concept of Circular Bioeconomy (Brandão et al., 2021).[7]

The circular bioeconomy represents a valuable opportunity for a great number of industries and sectors worldwide, from energy, chemicals, and materials to developing novel eco-materials. However, it also presents challenges concerning biomass sustainability and unknown supply and

[7] Biomass includes all kinds of biological resources, from agriculture, forestry, and marine environments as well as organic recycling.

value chains (Philp & Winickoff, 2018). Furthermore, there are certain concerns about its sustainability regarding biomass because employing non-sustainable biomass could lead to a chain of negative environmental impacts. For example, increased demand for non-sustainable biomass, could lead to changes in land use, producing more GHG emissions (Tan & Lamers, 2021).

In terms of GHG reduction, the Low Carbon Economic focuses on leveraging and exploiting atmospheric carbon via photosynthetic sequestration in biomass feedstock, closing the circular carbon loop (Dahiya et al., 2020; Tan & Lamers, 2021).

As a result, the convergence of circular economy, bioeconomy, and low carbon economy complement and empowers a sustainable economy. In the purpose of this dissertation, the aforementioned concepts shall be referred to as circular economy. Adopting a circular economy and the corresponding concepts previously mentioned could provide benefits in the social, environmental, and economic dimensions, as depicted in Figure 3.3.

Figure 3.3. Benefits from the circular economy approach (Brandão et al., 2021).

Sustainable energy success with a focus on the circular economy requires new business models and changes in operations management. It also requires sustainable supply chain management, from the production of biomass feedstock, logistics, and biorefining conversions all the way to the delivery of a sustainable product or service. Today, circular economy implementation is in its early stages, and the transition to a circular economy requires the participation of all players in society, as well as their ability to link and build appropriate collaboration and exchange patterns. (Silveira, 2019; Tan & Lamers, 2021).

3.2 Supply chain management towards a circular economy

According to the Council of Supply Chain Management Professionals, *"Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies."* A supply chain is the network of companies involved, directly or indirectly, to deliver a product or service to a final consumer. It involves all the processes, from the extraction of raw materials to the supply, manufacturing, distribution, and retail to the customer (Gandhi & Fajardo, 2016). Moreover, SCM incorporates business innovation strategies by creating a network to ensure the efficient and cost-effective flow of goods, information, and capital, to the end consumers (Bowersox et al., 2002).

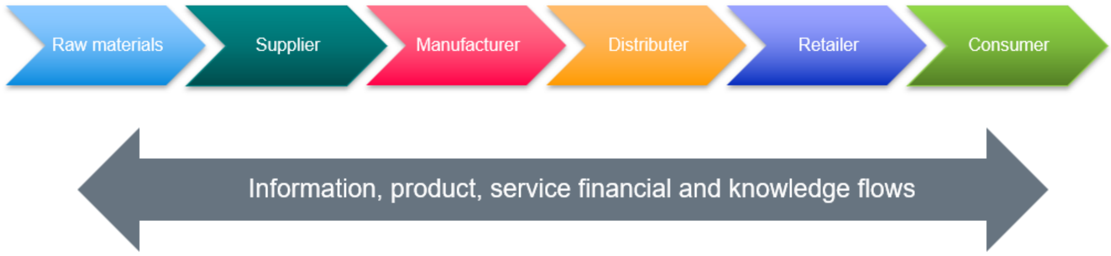


Figure 3.4. Generic supply chain model.

Traditionally, SCM focused on strategies in a linear model of production designed to get an efficient and effective flow of goods, services, or information, also known as an open-loop supply chain (Mann et al., 2010). However, open-loop supply chains do not enable the transition to a sustainable economic model due to the implicit linear lock-in. As a result of the increasing awareness of SCM's key role in achieving economic sustainability, new strategies and concepts have been developed to create the framework required for a sustainable economy (Genovese et al., 2015; Hazen et al., 2020).

Due to its novelty, SCM focusing on the circular economy has had several different approaches from concepts, research, and methodologies that contribute to a path to a circular economic model. However, all researchers emphasize the absence of knowledge in the SCM framework in a circular economy context (Aminoff & Kettunen, 2016; Farooque et al., 2019; Hazen et al., 2020). The following is a brief synopsis of the main topics proposed to link the supply chain operation with a circular economy:

- Green Supply Chain Management (GSCM)

  The idea of incorporating sustainable environmental processes within the traditional supply chain is referred to as a GSCM. It aims to reduce pollution in supplier selection and material procurement, product design, production and assembly, distribution, and end-of-life management (Khan, 2019). The American Production and Inventory Control Society defines the green supply chain as *"a supply chain that considers environmental impacts on its operations and takes action along the supply chain to comply with environmental safety regulations and communicates this to customers and partners"* (Mathu, 2019).

  GSCM examines the environmental impact of its activities, takes steps to comply with environmental safety standards along the supply chain, and communicates this to consumers and partners. Its main strategies aim to reduce the environmental and energy footprint throughout the supply chain. These are material handling, waste management, packaging, and logistics (Mathu, 2019).

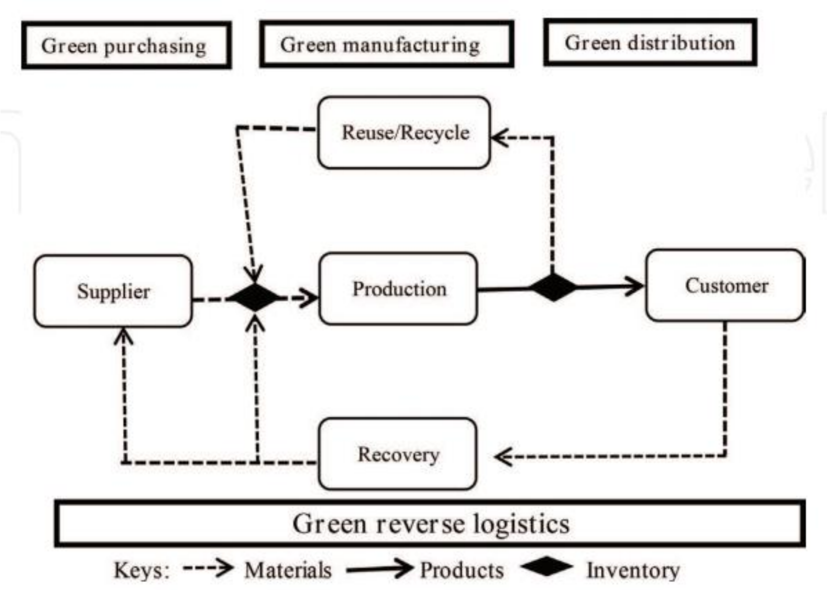


Figure 3.5. Green supply management (Khan, 2019)**.**

- Sustainable Supply Chain Management (SSCM)

  SSCM surged the increasing demand to cover the new environmental regulations and the rising recognition that an organization's sustainability impact must be evaluated throughout its supply chain (Asgari et al., 2016; Hussain & Malik, 2020; Mann et al., 2010). Therefore, SSCM theories have emerged, mainly in product lifecycle and the operational influence within the business model (Genovese et al., 2015). Narrowing down the resources is how the SSCM emphasizes cleaner production and resource efficiency in supply chains.

- Closed-loop Supply Chain Management (CLSCM)

  In CLSCM, the objective is to combine the forward and backward flow of commodities to capture value and ease costs (Mathu, 2019). There are two options for recovery: 1) a physical (closed-loop) to the original user, or 2) a functional (closed-loop) to the original functionality. When considering a supply chain from a closed-loop perspective, it is critical to coordinate the forward and reverse flows (Dekker et al., 2004). However, value recovery is generally limited since efforts are limited to the producer's original supply chain, which restricts the waste's availability to be reused/recycled, generating large amounts of rejected materials and ending up in landfills (Farooque et al., 2019).

According to Hazen et al. (2020), SSCM, GSCM, and CLSCM differ essentially but are valuable tools to achieve their goals from a circular economy perspective. For example, SSCM stands for repurposing economic activity for the benefit of society. Moreover, GSCM insights are crucial in the design and operation of resource efficiency. Likewise, CLSCM proffers dynamic recovery to maximize value throughout a product's useful life with dynamic recovery. Greer et al., (2021) addressed the possible risks of using waste to close-loops chains in the circular economy context, such as the high demand for waste streams, which might increase the open-loop model and energy consumption.

While these are not circular supply chains, it is vital to understand the primary characteristics of these various supply chains because they contribute to their formation. In reality, it includes both closed-loop and open-loop supply chains, in which items are recovered and reused by parties other than the original supplier (González-Sánchez et al., 2020).

Moreover, Geissdoerfer et al., (2018) defined the term Circular Supply Chain Management (CSCM), as *"configuration and coordination of the organizational functions marketing, sales, R&D, production, logistics, IT, finance, and customer service within and across business units and organizations to close, slow, intensify, narrow, and dematerialize material and energy loops to minimize resource input into and waste and emission leakage out of the system, improve its operative effectiveness and efficiency and generate competitive advantages."* CSCM includes the collaborative effort among consumers, suppliers, and other stakeholders to keep used products, components, and materials in circulation. Cooperation is required among all parties in the supply chain, including those from other industries (Aminoff & Kettunen, 2016).

In the literature, it is clear that there is a huge research gap in terms of how to realistically change a linear supply chain into a CSCM (Rosa et al., 2019). The research by Geissdoerfer et al., (2018) from case studies that integrated circularity components into supply chains and business models confirmed value creation from waste. Nevertheless, the cases analyzed still face difficulties in shifting from a linear to a circular paradigm, particularly regarding the changes required in the companies' supply chains.

Furthermore, there are various roadblocks on the way to deploying a CSCM, due to the significant adjustments in production planning and management, logistics, and supply chain decisions required to achieve the optimal business model (Frishammar & Parida, 2019; Lopes de Sousa Jabbour et al., 2019; Salvador et al., 2019).

As stated previously, the goal of the CSCM is not to save resources but to fully capitalize on them and identifying RL as a component of CSCM implies that it should be explored. It demands new logistical requirements because of production system changes, including those connected to resources and waste, as well as product distribution and recovery. As a result, the network of companies involved in the supply chain develops upper and lower linkages in the multiple processes and activities, demanding integration. (Dekker et al., 2004; González-Sánchez et al., 2020; Hazen et al., 2020).

3.2.1 Reverse logistics

In recent years, RL has risen to prominence as a critical function for all enterprises. While the focus has been on traditional logistics, which aims to coordinate forward distribution, i.e., transportation, warehousing, and inventory management from suppliers to customers, RL has been acknowledged to play an essential part in achieving long-term sustainability (Farooque et al., 2019). Moreover, achieving better value extraction from goods and reusing resources or products are two important goals of RL in the CSCM (Agrawal et al., 2015).

RL is defined by the Council of Logistics Management as "*The process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal"* (Rachih et al., 2019).

It is worth noting that waste management is distinct from RL in that the latter focuses primarily on efficiently and effectively collecting and processing trash (items for which there is no new purpose). RL focuses on those streams where there is a significant amount of value to be recovered and where the output is transferred into a new (or existing) supply chain (Dekker et al., 2004). Due to the difficult and complex procedures, RL can be challenging and uncertain, and it has become a new problem when recovered products are managed in phases with multiple actors and recovery options (Tseng et al., 2022).

Melo et al., (2022) examined and detailed the activities that comprise RL operations, as well as presented a conceptual framework for a better understanding and definition of RL processes. In Figure 3.6, a conceptual framework proposal shows the main stages of RL. This approach grouped RL into two macro processes: I-Reverse Logistic Process (I-RL Process), which relates to information management, and M-Reverse Logistic Process (M-RL Process), which refers to material flow management operations. These processes are discussed in more detail below.

The IR-L process is responsible for the general management and operation of the system. In order to collect, transport, process, recover and reintegrate waste back into forward supply chains, it is necessary to identify and integrate origin (suppliers), reverse channel and destination facilities for waste collection. It also unifies all RL process phases by sharing information among reverse supply chain actors. Methodologies and methods for reverse supply chain management must be used to integrate existing RL operations and connect essential reverse channel actors. It considers collecting information about the specifications, types, and likely amounts of recovered trash to efficiently match offers and requests. It helps with dimensioning, long-term capacity planning, and RL process stage performance (Melo et al., 2022).

The activities of waste acquisition and gatekeeping occur within this procedure. Waste acquisition refers to the identification of waste generation sources, the definition of waste categories, and waste volumes. Gatekeeping refers to the refined selection (filtration) of waste and the precise definition of quantities to be collected, transported, and processed. Information such as a list of available materials and recovery procedures must be used to identify, select, and collect residues with the highest recovery rate (Melo et al., 2022).

The M-RL process refers to the RL activities that comprise transport, warehousing, sorting, and recovery. These processes are then discussed in further depth.

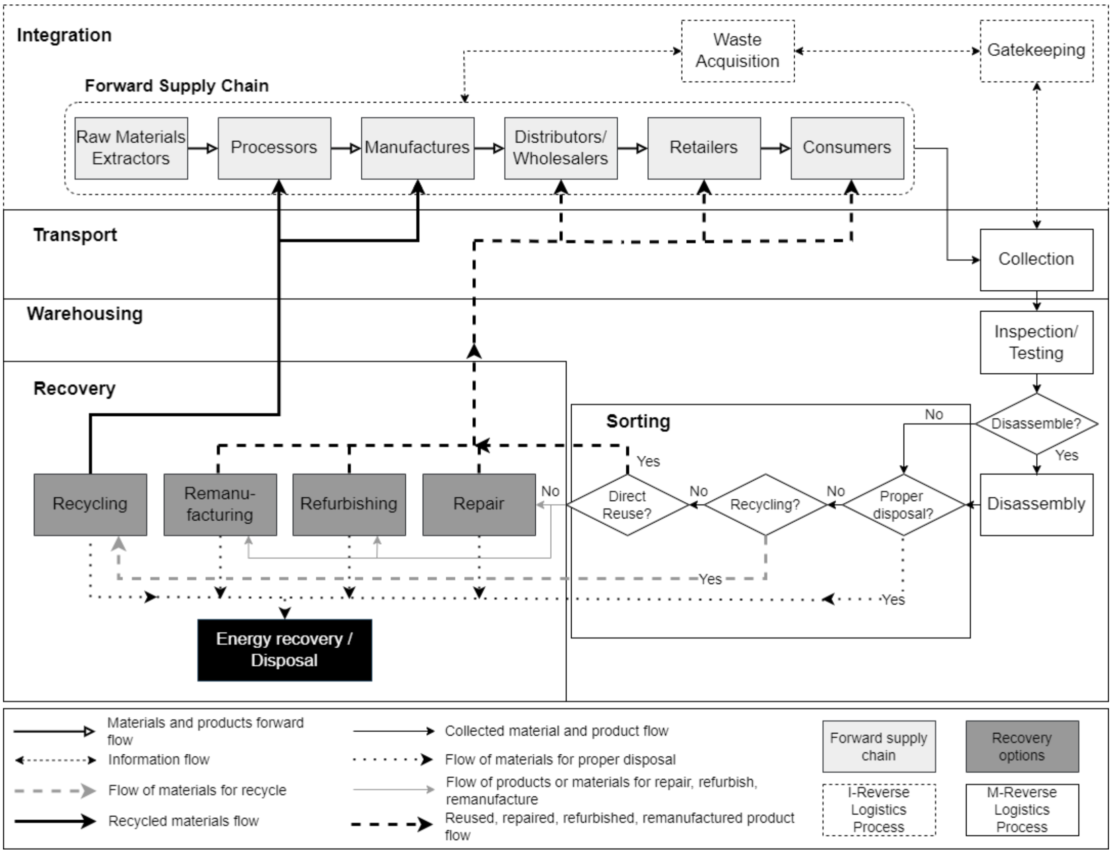


Figure 3.6. Structure of the RL process (Adapted from Melo et al., 2022).

COLLECTION

The collection is the consolidation of selected waste from source facilities to processing centers, where transporting, inspecting, and sorting operations occur (Agrawal et al., 2015). It begins when companies and consumers send their returns to processing centers. This transfer can occur passively when collection agents go to the source of generation or actively when those responsible for generating the material execute some type of movement. Active collection refers to the gathering of discarded products and transferring them to the collection point. In passive collection, the waste might be transferred by the industry itself, public urban cleaning firms, or independent companies that engage directly with the recovery market (Melo et al., 2022).

The volume collected per visit is a significant aspect of the collection as well. In terms of the volume collected per visit, it is usual practice to collect all goods. The vehicle's capacity is the constraint. In that situation, the leftovers are collected soon after or during the next scheduled appointment (Beullens et al., 2004).

Another important specification is the moment of collection, which refers to when the collection site is serviced. There are various kinds of collection moments, such as (Beullens et al., 2004):

- Periodic schedules. A periodic schedule is a sequence of consecutive periods that are repeated (days). The user selects visit times.
- By monitoring demand. Smart drop-off sites monitor generating rates to prevent overflow in a dynamic route-planning model.

- Call services. Visits can be prompted by calls from staffed drop-off locations. The collector may select a minimum product quantity before calling. In a periodic call service, the collector visits the collecting place at the next pre-arranged period. In call services with timely collection assurance, the collector assigns visits at will but guarantees collection before a defined time.
- Triggered by a distribution schedule. If collection and delivery can be connected, a customer's distribution schedule at the collection site or nearby could trigger collection.

The collection is a substantial cost in RL, thus the system design must be efficient and convenient (Beullens et al., 2004). The appropriate collection method is determined by the type of industry and the amount of the collection, as well as the parameters of initial investment, value-added recovery, return volume, operating cost, and degree of logistics management (Sangwan, 2017).

Transport

Transport refers to the movement of collected wastes (products, components, or materials) from source facilities to processing centers and recovery facilities. This acts as a material-movement action between facilities or operations (transport, upload/download, handling) and it occurs through all reverse routes where the RL process occurs (Melo et al., 2022).

In terms of transportation, transferring many low-volume flows raises collection costs while also influencing the environment. As a result, businesses have researched ways to reduce transportation costs (Fleischmann, 2003). There are numerous methods for combining transportation-related services, but one of the most interesting is integrating collection and delivery tasks. It includes both a collection of consumers to whom items must be supplied and a set of vendors whose goods must be carried back to the distribution center (Toro O. et al., 2015).

Combining delivery and pickup can save money by cutting down on the number of empty trips, the number of vehicles needed, the overall distance traveled, and the amount of fuel consumed, both of which minimize transportation's impact on the environment. It can reduce CO_2 emissions by 25% to 42% as compared to single-compartment transportation. Moreover, a collaborative network can generate cost reductions ranging from 13 to 28% when compared to more traditional transportation (Santos et al., 2020).

Borrello et al., (2016), found that combining delivery and pickup is presented as a feasible solution for increasing efficiency, cost-effectiveness, and environmental friendliness within CSCM. Regarding the type of vehicle, it is suggested that the characteristics of the collection vehicles correspond to the collecting method (Beullens et al., 2004).

Warehousing

Also known as storage, the process involves all material handling activities in the facilities that make up the reverse channels. This includes the following: unloading, compliance, control of quantities and kinds, picking, packaging, dispatching, shipping, and loading. The importance of warehousing derives from the fact that firms must ensure that sufficient storage and handling capacity is available for return processing, as well as that the facility's space is effectively handled.

For instance, whether a specialized facility for return processing is optimal, or whether returns should be processed in the same facility, but a distinct zone, return storage must be coordinated with forwarding activities such as order collection and transportation (de Brito & de Koster, 2004).

Consequently, warehousing involves several logistical operations that are carried out across all of the processing centers, including inspection/testing, disassembly, and sorting as needed (Melo et al., 2022).

Sorting consists of several activities that are dependent on the nature of the returned item. This is due to the complexity of the items under consideration; for example, in the case of batteries, a simple classification such as type and model may be sufficient to determine the optimal destination. In some circumstances, such as vehicles, a disassembly procedure is required after inspection/testing to gain more information from the product of the component in the sorting process, which might identify the optimum destination (Melo et al., 2022). Disassembly is the process of separating waste (a product, material, or pieces of these) into primary parts or components. Inspection/Selecting determines if and how a product can be reused depending on its value and recyclability. Used products are sorted for reuse, reprocessing, or disposal after examination and selection (Krikke et al., 2003).

Furthermore, location affects both interior handling methods and internal transit costs. In internal transportation, the selection of reusable containers is a crucial factor. This can be challenging because before being reused, product carriers must be collected, returned to the warehouse, checked, stored, and cleaned (de Brito & de Koster, 2004).

Recovery

Product recovery is the final element of RL, which is related to the flow of goods or parts destined for remanufacturing, repair, or disposal while maximizing resource usage. Typically, it is performed to recover hidden economic value, satisfy market demands, or comply with government regulations (Sangwan, 2017). Although recovery is not considered to be a genuine component of the RL process, it is, however, an important aspect. This is because RL serves as a link between returned items in the supply chain and potential value recovery activities (Melo et al., 2022).

Recovery may be direct or include some form of reprocessing. It is possible to reprocess a product by repairing, refurbishing, or remanufacturing it; retrieving a component from it; recycling the material, or incinerating it to recover energy (Krikke et al., 2003). Listed below is a brief explanation of the available recovery possibilities (Sangwan, 2017):

- Direct recovery occurs when a used product fulfills appropriate quality standards and may be sold without further processing.
- Repair entails the replacement of defective components. Repairs can be done on-site or at a manufacturer-controlled center.

- Refurbished products are returned to a specific quality level without losing their original characteristics. Sometimes refurbishing involves upgrading technology by replacing old modules and pieces.
- Remanufacturing raises used products to new-product quality and dependability criteria. In remanufacturing, the product enters the reverse channel at fabrication, where it is disassembled, remanufactured, and reassembled to flow back through retail to the consumer.
- Retrieval aims to recover product parts. Products that are repurposed in this way are likely to be used in the production of raw materials for new products after some initial processing in the reverse value channel.
- Recycling recovers resources from used items. Recycling destroys products' identities and functionality.
- Incineration is used to recover the energy contained in the product.
- If the product remains useless even after being reprocessed, the final alternative is to dispose of it as waste.

A relatively novel alternative for recovery is to incorporate a biorefinery, which is a facility designed to optimize biomass and the wastes of organic composition from various conversion pathways and transform them into valuable bio-based product streams. A biorefinery is an infrastructural facility that combines various conversion technologies, such as thermochemical, biochemical, combustion, and a microorganism growth platform, to produce biofuels, biochemicals, bioenergy, and other high-value bioproducts (Ubando et al., 2020).

Overall, the role of RL and supply chain in establishing circular economy business models focuses on building skills linked to improving the integration of RL operations; the ability to establish and improve industrial symbiotic relationships; the utilization of tools to enhance the traceability and transparency of the movement of materials; and improving take-back solutions by partnering with the informal sector/recycling cooperatives, and end consumers (Lopes de Sousa Jabbour et al., 2019).

A circular economy optimizes waste processes generated by linear or open supply chains by creating closed or semi-closed systems in which materials are collected, repurposed, or moved between enterprises. This demands a structural evaluation of the previously listed benefits (Walker et al., 2021).

3.3 Circular Supply Chain Management Assessment

Given potential trade-offs between circularity and sustainability, the positive sustainability implications of CE activities (i.e. circular business models, supply chains, and product solutions) have only recently been evaluated, although they have been largely assumed (Walker et al., 2021). In this sense, several researchers have reviewed research trends, gaps, and future studies (Calzolari et al., 2022; Lahane et al., 2020; Walker et al., 2021).

Lahane et al., (2020) noted that, from the standpoint of CSCM, the applicability of various management strategies, such as RL management, is yet to be determined. This has resulted in the creation of a wide range of performance metrics, but there is a need to define CSCM standards performance metrics for evaluation before, during, and after adoption.

Walker et al., (2021) concluded that the toolkit for assessing the sustainability of CE practices in circular networks does not need to be reinvented; rather, appropriate assessment methodologies should be found from the existing literature. To comprehend how the circular economy achieves its sustainability objectives, it must be possible to observe and assess the effects of its actions from a holistic standpoint. For this reason, comprehensive assessments are essential for honest decision-making, which identifies possible trade-offs.

Calzolari et al., (2022) observed from the different tools available that those that focus on energy, resources, and waste in a system incorporate an eco-centric perspective of value where production and consumption systems are in close interaction with it. These tools can also help measure and show CE potential linked to regenerative and restorative resource flows in supply chains to reuse material flows and waste.

Different indicators serve different goals, and some techniques are better for analyzing the influence of materials on circularity performance than others (Niero & Kalbar, 2019). Howard et al., (2022) noted that Value Stream Mapping (VSM) can often be used to examine the performance of circularity in various processes. VSM facilitates the definition of value creation as a strategic activity by using a common nomenclature to highlight stakeholder engagement and supply chain involvement.

3.3.1 Value Stream Mapping

VSM is a Lean process mapping technique that enables the sequence description of activities and information flows that occur throughout the production or service process (Locher, 2008). Using a VSM helps to understand the underlying value of its products or services and the processes that go into making them, as well as how to make improvements that will last (Peña Moreno & Salgado, 2012).

Depending on the requirements, the VSM can be designed for a complete system or to study particular operations. A VSM depicts the flow of materials and information to appreciate how activities and operations interact and to aid in the analysis of the process (Langstrand, 2016). The purpose is to enable understanding of what constitutes value or waste and to optimize flow by differentiating value-adding from non-value-adding activities. The elimination of waste is important to the notion of value, where the value stream is the sum of all operations required to supply a product, from the extraction of raw materials to the delivery of the product to the customer (Howard et al., 2022). Analyzing value streams could cut costs, enhance production flow, save time, and improve environmental performance and workplace health and safety (EPA, 2007).

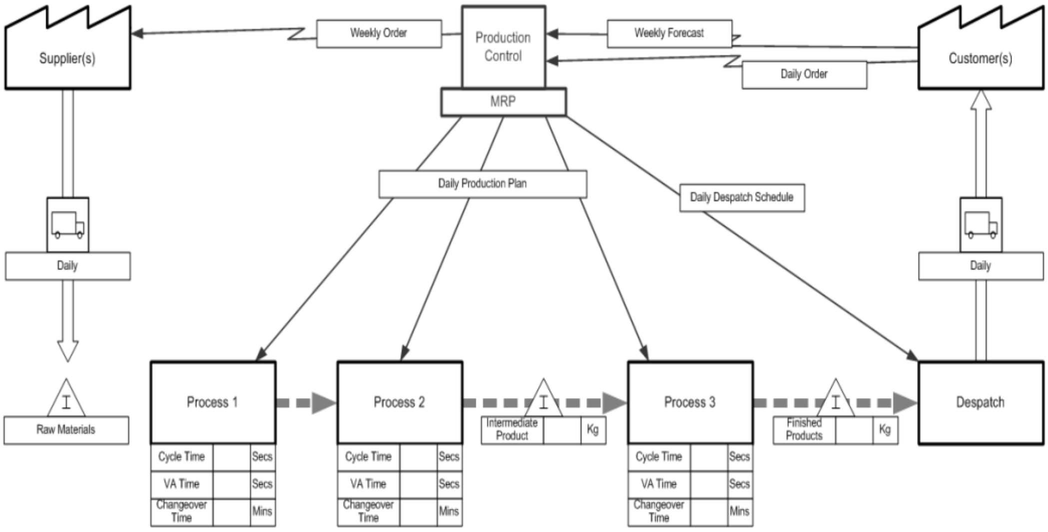


Figure 3.7 General example of a VSM (Norton & Fearne, 2007)**.**

The definition of value is not precisely defined within the VSM literature. According to Womack and Jones (1996, as cited by Hedlund et al., 2020) *value can only be defined by the ultimate customer, but manufacturing companies build value into their products*. Identifying the value stream and defining value creation is difficult in Lean techniques. Ultimately, the questions posed about value generation will lead to a better value stream, and when value is defined and understood, the value stream can be improved (Hedlund et al., 2020).

In RL chains, VSM can increase organizational performance and make product recovery more real. RL chains require a different analysis. Other activities than the supply chain determine the flow of materials and information, which aims to recover the value of exploited items or redirect them to harmless disposal (Kruczek & Zebrucki, 2015).

Moreover, Peña Moreno & Salgado, (2012) studied the coffee value chain and proposed a framework to assess its sustainability performance. To evaluate the sustainability of the coffee industry's supply chain, they used the VSM and the use of certain sustainable indicators in the triple bottom line areas of social, environmental, and economic primarily based on the most prevalent VSM indicators and key performance measurement principles. Table 3.1 outlines the current configuration of the VSM.

Table 3.1. Selected Sustainable KPI's (Peña Moreno & Salgado, 2012)**.**

Economic	Environmental	Social
• Economic performance • Lead time/process time • Productivity • Local suppliers/ Investment in local infrastructure	• GHG emissions • Water usage • Water and solid discharges • Energy consumption	• Freedom of association & bargaining • Working hours compliance • Wages compliance • Labor equity/ non discrimination

To foster a more circular economic model, VSM is increasingly being incorporated into more projects. According to Hedlund et al. (2020), VSM's visual components of a product's life cycle and value may assist businesses in making better decisions regarding how to transition to a circular economy.

Moreover, Hernandez Marquina et al., (2021) investigated the implementation of a VSM to demonstrate that Lean Manufacturing highlights waste produced in a circular industrial system, hence allowing for its improvement. It was demonstrated that a system made of several loop closures can be described and analyzed using the VSM and that a Lean approach can aid in the improvement of a circular system.

According to Howard et al., (2022), VSM can depict a current state map showing existing flows and waste in the system, followed by a future state map depicting an improved process flow with all waste eliminated and material return loops. The difference between current and future circular economy creates a waste action strategy (e.g., materials, heat). Although technically speaking 'waste' does not exist in circular economy, as all nutrients are supposed to be recirculated, VSM can help managers understand the extent and depth of circular economy 's difficulty.

3.4 Chapter Conclusions

Due to its novelty, circular economy in a bioenergy context can be perplexing because there is no framework for its application and multiple concepts are combined to create sustainable energy. In a circular economy, materials can be reused, reprocessed, and reintegrated back into the economy, instead of being thrown away in a linear model of production and consumption (take-make-use-dispose). The bioeconomy, on the other hand, refers to an economy that produces biofuels and bioproducts employing biotechnology and knowledge-based innovations to maximize economic, environmental, and social benefits. Finally, the Low Carbon Economy focuses on leveraging and monetizing atmospheric carbon through photosynthetic sequestration in biomass feedstock, closing the carbon loop. Adopting a circular economy and related principles could have social, environmental, and economic benefits. However, embracing a circular economy and the previously outlined ideas could result in positive social, environmental, and economic outcomes.

A considerable shift in SCM is necessary as one of the most crucial success elements. CSCM combines the circular economy with supply chain management, offering a new viewpoint on supply chain sustainability. The objective is to build more sustainable supply chains and to recover valuable materials for reintegration and reprocessing. In this regard, RL is of fundamental importance. It is necessary to ensure the RL system, hence the primary processes have been outlined. The elements of collection, inspection, selection, recovery, and redistribution were explored to gain a better understanding of what is necessary for an RL system.

Lastly, a concise summary of the implications of the CSCM assessment. As a result, the VSM approach was examined. VSM is well-recognized in the business world and is used to show the reduction of the amount of waste produced, as well as the consumption of materials, and to facilitate the production of goods in a more productive manner. The VSM is being used more frequently in circular economy evaluations as a technique to help comprehend the scope and depth of the challenge posed by the circular economy.

4 METHODOLOGY

The purpose of this chapter is to explain the methodological procedure used to accomplish the description and development of this dissertation. Figure 4.1 provides an overview of the proposed procedure used in this master's thesis to illustrate the stages more clearly.

The research case involved the development of a RL system to collect SCG and use it as feedstock to create biodiesel in a circular economy scenario. The research was based on the analysis of the supply chain; consequently, the first section covers the data collection of the information required to analyze the forward supply chain in the study case. Followed by the approach of the analysis method for the diagnosis. Next, the process of the reverse logistic proposal is discussed. Finally, the strategy for assessing the reverse supply chain is examined. These actions are described in further detail in the paragraphs that follow.

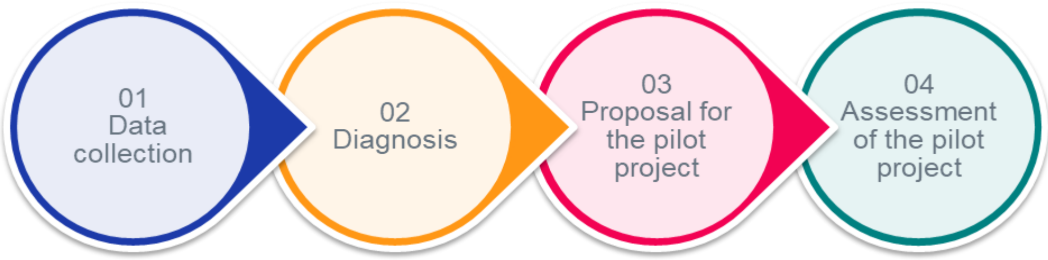


Figure 4.1. Proposed methodology.

4.1 DATA COLLECTION

In this section, the outline of the case study was conducted along with the description of the motivations and objectives for developing this project. This section is also meant to establish the information necessary to identify the most key information of the forward supply chain in the case study and to plan the RL process. According to the literature research, the essential data to collect and the collection procedure are detailed in the table below.

Table 4.1 Data collection and information required

	Information required	Data collection method
01	Identify the stakeholders	Contact with managers
02	Identify the sources of origin	Contact with managers
03	Identify the destination facilities	Contact with managers
04	Calculate the volume of SCG that will be recovered	Documentation
05	Description of coffee brewing process	Observation

All required data was obtained through personal contact with the responsible managers and observation. In addition, the study utilizes data collected from business documentation. This data was used to diagnose the current stage of the process and plan the RL.

Moreover, inspections to stores and warehouses were restricted because of the Covid-19 pandemic, limiting movement and the number of visits as part of the public restrictions to mitigate the infection.

In the case of the volume of SCG to be collected, an approximation was made based on coffee sales using the method described below:

- First the estimation of the coffee consumption was computed based on the coffee consumption of prior years per store using the linear regression technique in Excel. Moreover, to estimate the SCG generation was assumed 1 g of coffee generates 1.4 g of SCG, this information was provided by the company in charge of providing the technology information. In addition, the seasonal index was used to estimate SCG generation for each month. The average seasonal index of each month was computed by dividing the consumption of each month by the total consumption of the year, and then taking the average of all the years analyzed per month. The seasonal index was then multiplied by the estimation of coffee consumption for each month.

All the data presented above was used in the following sections to provide the most accurate diagnosis of the forward supply chain and to suggest a viable pilot project.

4.2 Diagnosis

According to the literature review, VSM contributes the comprehension of a system's information and material flow. Furthermore, the typical VSM technique can be extended by incorporating environmental sustainability evaluation at the process line level. According to Hernandez Marquina et al., (2021) VSM methodology provides a holistic view of the system's interactions and it can be adapted to a circular context, highlighting waste creation. The integration of these indicators permits the evaluation of aspects of sustainability and the identification of opportunities for enhancing sustainability performance.

The forward supply chain was evaluated using VSM, according to the methodology suggested by Langstrand, (2016) and Megayanti et al., (2018). The methodology is described below:

- In this first step, the VSM's "backbone" was created. The operations were listed, then customers and suppliers were added. Starting and ending points of the process were specified within this step. Figure 4.2 depicts the VSM symbols that are used to symbolize the various processes.

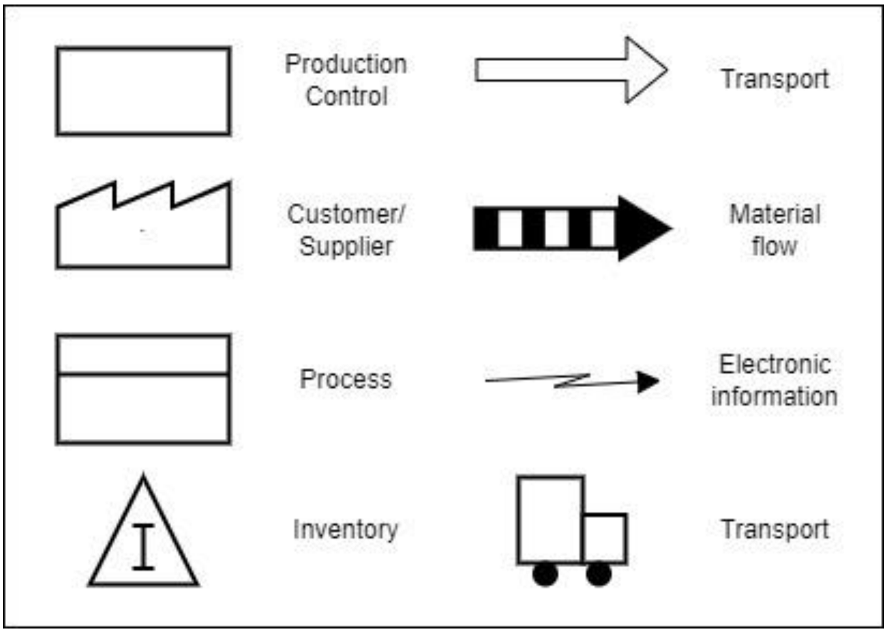


Figure 4.2 VSM symbols.

- In the second step, information regarding the flow of materials and data were processed to determine the KPIs. Based on the literature review, the proposed KPI were listed in Table 4.2. This data was latter incorporated into the mapping.

Table 4.2 Proposed KPI

Economic KPI	
Lead time / process time	The lead time/process time indicates how long it takes from the time a consumer places an order until it is delivered. This method's major reference is to determine how much time was spent on activities that contributed value (value added) and how much time was spent on activities that did not (non-value added). In order to compute the lead time, the cycle time of each business operation must be measured.(Megayanti et al., 2018).
Environmental KPI's	
Energy consumption	The energy consumption is correlated with the GHG; therefore, it is necessary to measure the amount of energy used in each step. The following formula can be used to calculate the energy used at each stage (Megayanti et al., 2018): $Q = \sum_{i=1}^{n} P_i \cdot t_i$ **Equation 1** Where: Q = Amount of energy consumed [kWh] Pi = Energy needed for device i [W] ti = Operating period of the device i [h]

Waste management	For the waste management the value added is the waste generated during the production process and had been manage and the non-value added is the waste generated during the production process but had not been manage. Management of waste can be calculated by weighing waste before and after management (Megayanti et al., 2018).
GHG emissions	The GHG emissions are identified with the purpose of reducing the CO2 emissions linked with the product. In this case, the value-added emissions are generated during the manufacturing process, which adds value to the product. Those activities that don't produce value-added products also contribute to non-value-added emissions (Megayanti et al., 2018). The following formula can be used to estimate greenhouse gas emissions at each process for electric appliances (European Environment Agency, 2020; GHG Protocol, 2013). $GHG\ Emission = Energy\ consumption\ [kWh] \cdot Emission\ factor\ [g\frac{CO_2}{kWh}]$ **Equation 2** The emissions associated to the waste generated during the process were also estimated based on the waste going to each disposal method and an average emission factor for each disposal method (GHG Protocol, 2013; US EPA, 2021).

- In the third step, the material flow, and the data of the KPI's are used to depict the VSM. This was included within the latter technique were the categorization of activities as value adding (VA) and non-value adding (NVA) were depicted in the map.

The forward supply chain was then evaluated based on the performance of each KPI assessed throughout the process. The aforementioned to identify the most essential activities of the current system and adapt accordingly while proposing RL. Furthermore, the analysis will be used in the evaluation to compare the process differences between the forward and reverse supply chains.

4.3 Proposal for the pilot project

Based on the conceptual framework outlined in section 3.2.1, the collected data, and the results of the VSM, a reverse logistic plan was proposed for the pilot project. The pilot's RL plan was thoroughly evaluated, amended, and approved by both the PRIO and Delta teams. This was initially given in a conceptual flow that allowed for a general comprehension of the system. This section details the system's information flow. Furthermore, a detailed process flow chart was created to organize and describe the activities within the processes involved in the reverse logistic system. Table 4.3 presents a summary of the processes and description requirements that were considered to develop the proposal of the reverse logistic system.

Table 4.3 Activities activities required within the RL process.

Collection	• Description of the boxes for collection • Specify the volume of SCG • Specify the number of boxes required
Transport	• Specify transport characteristics
Warehousing	• Indicate the storage characteristics within each store • Indicate the storage characteristics within the warehouse • Describe the process of sorting the boxes
Recovery	• Establish formal recovery options for SCG • Comparison of the SCGO characteristics versus WCO

After the reverse logistic system was proposed, it was implemented for approximately six months as part of a pilot project. It is essential to note that the RL procedure examined in this project was merely the pilot's outline. It progressed from SCG collection to SCG warehouse and box storage. The recovery description was entirely theoretical to serve as a guide of the methods and principal characteristics of the extraction of oil from SCG.

4.4 Assessment

The assessment is separated in three stages, first is the outcomes of the pilot project, followed by the analysis of the RL VSM and closing with a business model canvas to summarize the ideas.

The results from the pilot project were analyzed following the structure of the proposal for the pilot project and then integrated into a the VSM that evaluated the RL system proposed. The data analyzed is showed in the following (Table 4.4):

Table 4.4 Activities evaluated after the development of the pilot project.

Collection	• Comparison of the SCG volume collected versus the estimation
Transport	• Evaluation of the specifications during the transport
Warehousing	• Evaluation of the specifications of the warehousing

The recovery was not evaluated because, as stated previously, the recovery description was purely theoretical to serve as a reference for the procedures and primary characteristics of the oil extraction from SCG.

After the construction of the VSM to analyze the reverse logistic was developed following the process described in Section 4.2. This was useful to illustrate what the process looks after implementing the reverse logistic system by depicting the changes within the process. The inputs and outputs of RL comprised waste management, transportation, and the recovery process. This was followed by a VSM map based KPI calculation. In a real-world case study, the implementation of a reverse logistic system produces a variety of useful data. By examining the provided method's results, a significant deal of helpful information may be established, such as which intervention contributes the most to the supply chain's sustainability and how sensitive the supply chain is to each intervention.

Moreover, a comparison from the current and future state maps were developed to identify the challenges and opportunities associated with implementing this procedure into a business and analyze the real value obtained.

Finally, in order to evaluate the business possibility for the stakeholders, a business model canvas based on the one created by Baldassarre et al., (2020), as shown in Figure 4.3. Compressing the data within a canvas chart is beneficial when presenting the benefits and requirements of undertaking a project like this to stakeholders. Overall, this methodology is a useful tool for assessing the sustainability of a RL system within the framework of a circular economy.

The business model canvas focus on how to propose new business models in the early stages of a design phase and identify users and partners, value perception and then mapping and visualizing these (Brown et al., 2021). The tool uses an existing business model idea as a starting point, allowing users to focus on the details required to construct a pilot. As a result, it combines business experimentation and strategic design theory. The tool's layout and content fields integrate the notions of attractiveness, feasibility, viability, and sustainability in a way that significantly departs from the business canvas approach. Problematically, although Business Model Canvas–type frameworks seem to be useful to identify the different elements of the business model, these frameworks do not directly guide experimentation (Baldassarre et al., 2020; Bocken et al., 2021).

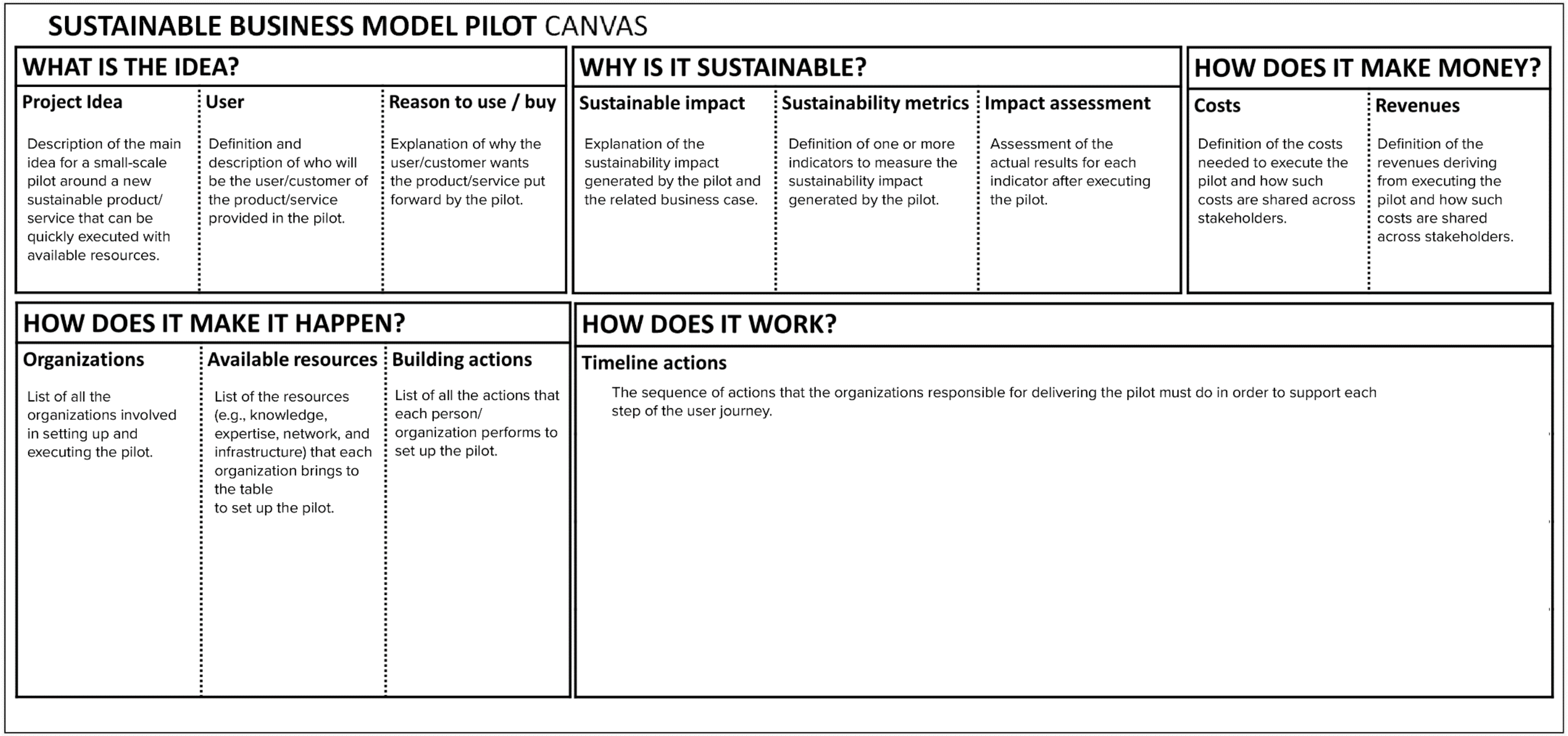


Figure 4.3. The SBM Pilot Canvas (adapted from Baldassarre et al., 2020)

5 RESULTS

PRIO has developed an open innovation challenge called PRIO Jump Start to scout and collaborate with entrepreneurs to build solutions that can improve and contribute to PRIO's value chain. Using PRIO as a testbed, the Competition aims to enable energy and mobility entrepreneurs. Pursuing sustainable solutions for PRIO's products and services through an energy transition focused on long-term sustainability.

Among the winners of the 2020 competition was Ecobean, a Polish startup. PRIO selected the innovative idea to design a project that aims to satisfy consumer demand and boost biodiesel's market share. Therefore, a pilot test was developed to test the collection of SCG and its availability to produce biodiesel. It also involves a collaboration with Delta Cafés, PRIO's coffee supplier company associate. The development of the pilot project was scheduled to take place over a period of five months, beginning in May 2021 and ending in October 2021.

5.1 DATA COLLECTION

5.1.1 IDENTIFICATION OF STAKEHOLDERS

Below can be found an identify the stakeholders and prepare a brief description as well as the main intentions regarding the pilot test. The following is a brief description of PRIO Energy, Delta Cafés, and Ecobean:

Figure 5.1. Involved parties in the Pilot Test.

- PRIO Energy, S.A. is a Portuguese company created in 2006 that became part of the Spanish group Disa in 2020. PRIO'S primary purpose is to distribute and sell liquid fuels and to produce biodiesel in Portugal and Spain. Furthermore, PRIO operates more than 200 convenience stores and cafeteria services within gas stations. Moreover, PRIO owns and operates a biorefinery, PRIO Bio, S.A., which opened a biodiesel factory in 2006 with an installed capacity of 113.880 t/year of biodiesel. The biodiesel facility now transforms 33.000 tons of Wasted Cooking Oil (WCO) per year and seeks to diversify its source of feedstock to transform more volumes in the future. Figure 5.2 depicts a simplification of the biodiesel manufacturing process in the biorefinery. PRIO is looking into alternate feedstocks due to the rising cost of WCO (PRIO, 2020) utilizing the approximately 50 tons of SCG that is produced annually by the cafeteria services.

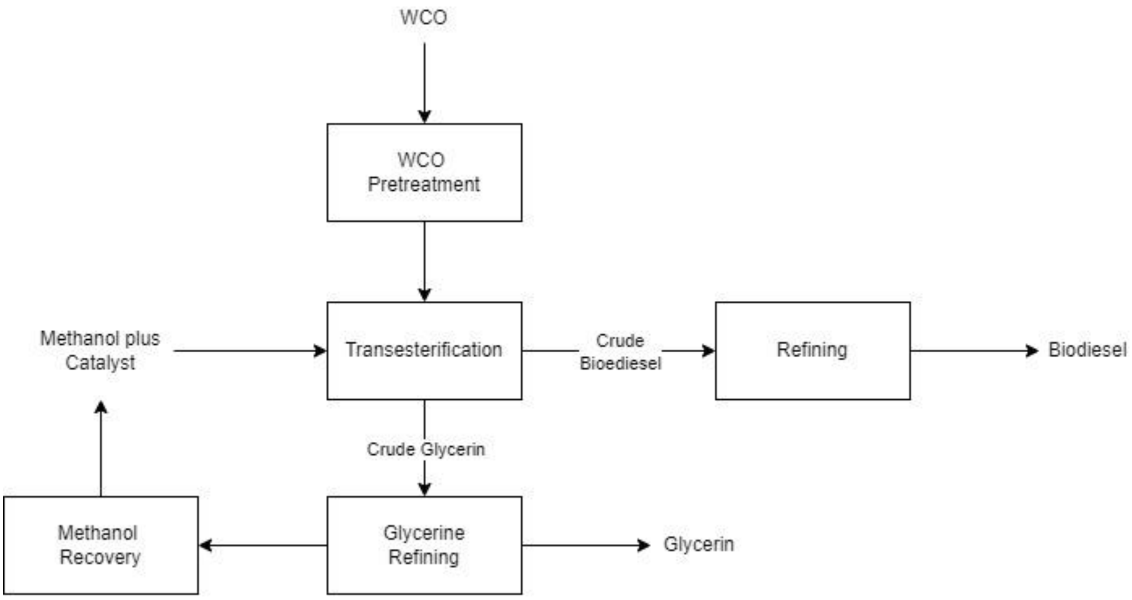


Figure 5.2 PRIO's biodiesel production process layout (Adapted from do Carmo Albuquerque, 2012).

- Delta Cafés is a Portuguese company founded in 1961. Delta Café's primary activities are coffee roasting, packaging, and marketing in Portugal. The company has operations in Spain, France, Switzerland, Brazil, China, Luxembourg, and Angola. It is the market leader in coffee roasting in Portugal and a distribution company focusing on the retail and restaurant sectors (Grupo Nabeira, 2018). In Portugal, the Delta Cafés market is segmented into four divisions. The HoReCa category (Hotels, Restaurants, and Catering) accounts for most businesses (76%), followed by Institutional (18%), Retail (3%), and Wholesale (2%) (Brito Neves, 2011). Delta cafés supply PRIO's convenience stores with coffee and other related products for its cafeteria services.
- Ecobean specializes in collecting and processing spent coffee grounds, converting them into coffee logs as a renewable energy source, and replacing wood or vegetable coal for open fires, BBQs, stoves, and fireplaces (PRIO, 2021).

The partnership strategy consisted of adopting PRIO stores as collection points where coffee is sold and SCG is created as usual. Delta Cafes managed the coffee supply as usual as well as the transport and storage of collected SCG within its warehouses. Moreover, Ecobean contributed to the initiative with expertise and technology.

5.1.2 Sources of origin

The RL testing system was evaluated in six PRIO convenience stores located in the Lisbon district. Each PRIO convenience store offers cafeteria services where expresso coffee and other beverages containing coffee are served. The company selected these stores based on their location and coffee sales metrics. The locations of the stores that participated in the study are depicted in Figure 5.3. This information is later used in the following sections.

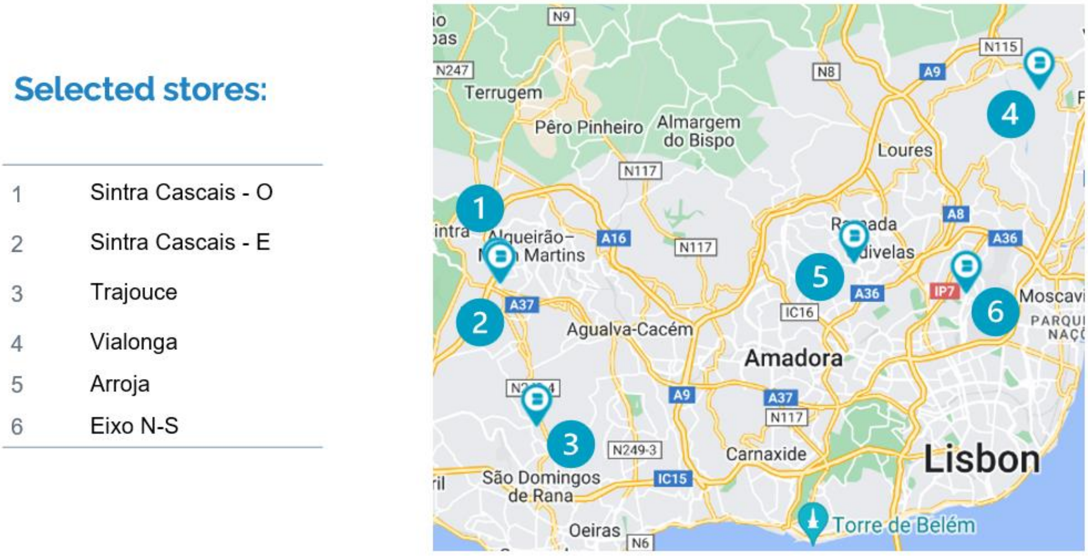


Figure 5.3. Points of sources and collection.

5.1.3 DESTINATION FACILITIES

As indicated previously, Delta Cafes supplies the PRIO convenience stores' cafeteria services with coffee and related products. As a result, the warehouses of Delta Cafes closest to the PRIO stores that regularly supply coffee were chosen as a suitable solution for this project. The locations of the participating warehouses are depicted in Figure 5.3.

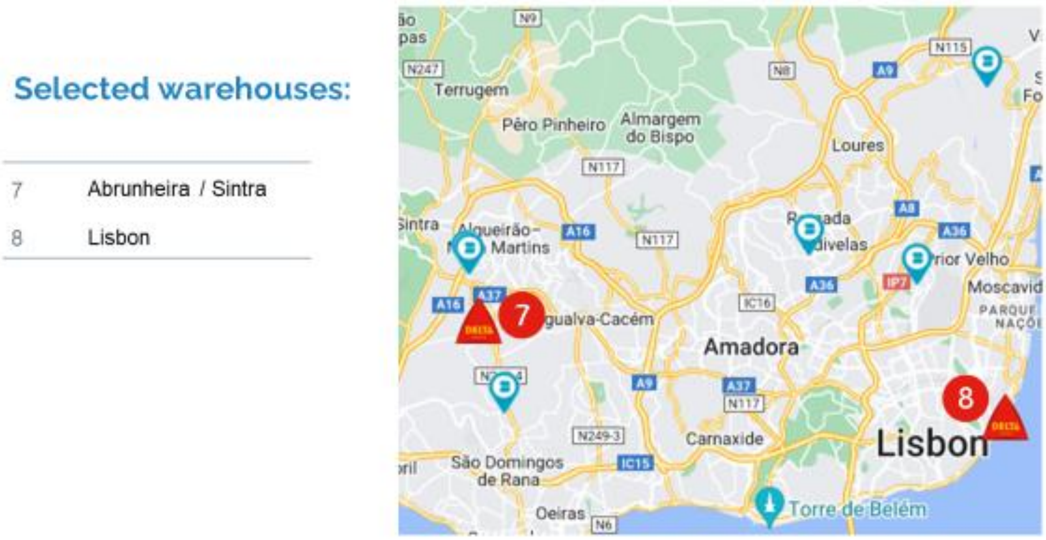


Figure 5.4 Warehouses locations.

PRIO biorefinery is another key facility where the SCG can be processed and converted into biodiesel. The biorefinery is located in the port of Aveiro, which is situated roughly 260 kilometers to the north of Lisbon in Portugal.

5.1.4 VOLUME OF SPENT COFFEE GROUND TO COLLECT

Using the approach outlined in section 4.1, the volume of SCG was estimated. Linear regression in Excel was first used to estimate 2021 coffee sales per store based on previous years' consumption (years 2018-2020). Figure 5.5 illustrates the coffee sales of the previous years as well as the estimated coffee sales for 2021. Based on last year's data, each store has quite distinct coffee sales. This can influence the amount of storage and transport space required. Furthermore, due to the ongoing pandemic, coffee sales declined in 2020; therefore, it was projected that coffee sales in 2021 would be equivalent to the pilot test and determining the requirements of the reverse logistic system.

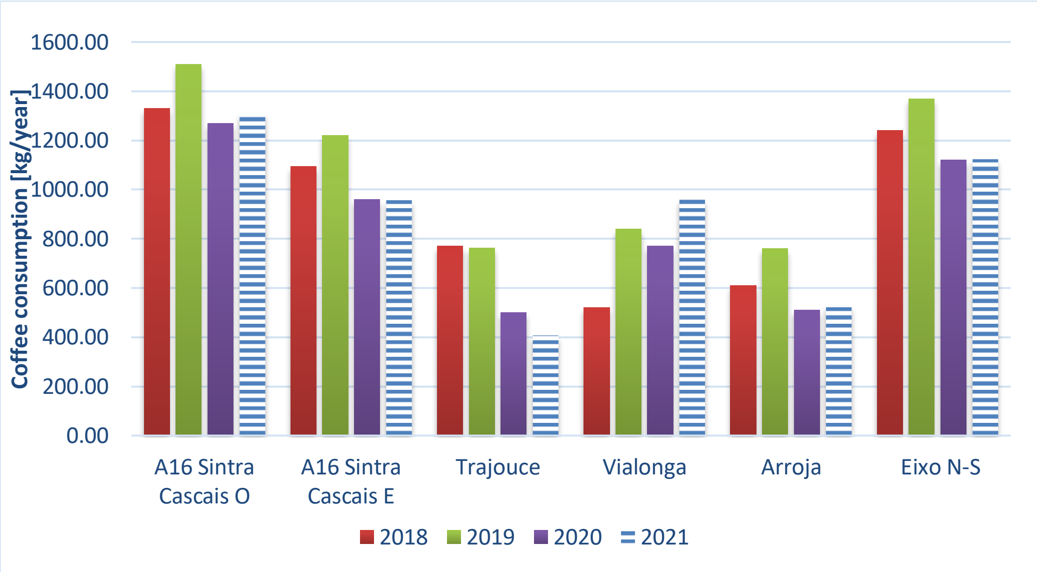


Figure 5.5. Coffee consumption from 2018 to 2020 with a forecast for 2021 in PRIO'S selected stores.

Below can be observed Figure 5.6 which shows the SCG generation per store throughout the pilot time. It is possible to observe the estimated SCG generation for each month based on the 2021 coffee sales estimate and the seasonality indicator. Additionally, month-to-month variations in SCG generation are anticipated. This may have repercussions and an effect on the transportation and storage of SCG in the points of the collection as well as in the warehouses.

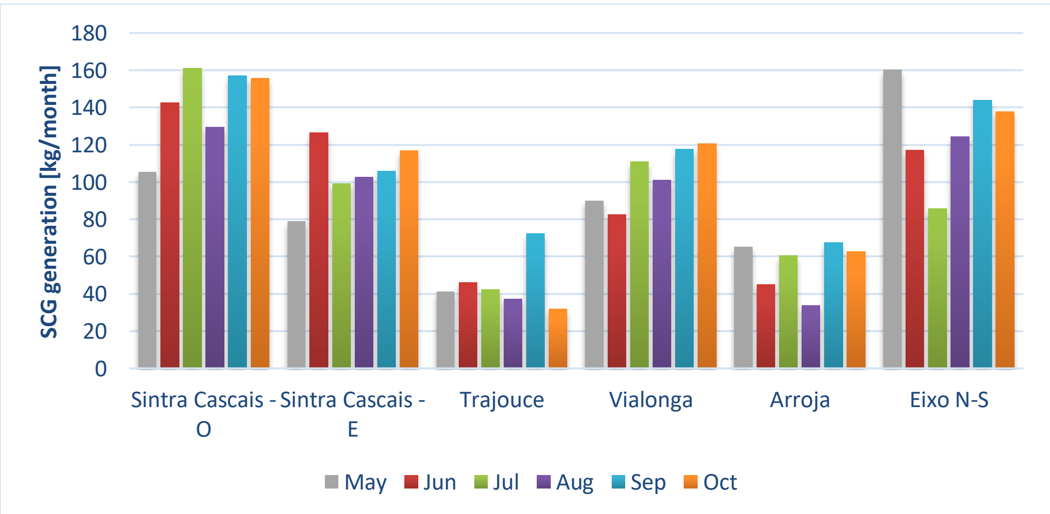


Figure 5.6. Expected SCG generation in the period from May to October 2021.

5.1.5 Coffee preparation

This process was observed in each store during the visits. All stores feature the same coffee bar arrangement, as shown in Figure 5.7. It consists of a grinding machine, an espresso coffee machine, and areas beneath it to store the SCG. In general, the procedure is as follows: the coffee is brewed in the espresso machine, and the residue is collected in a bin beneath the bar. To keep the area clean, each of these containers includes a plastic bag that is replaced when the container is full or at the end of the day.

Figure 5.7. Generic coffee bar.

To summarize, the project stakeholders were identified, and a brief description of the functional areas that each of these stakeholders should be conducting within the scope of the project was provided. Furthermore, the sources of origin and destination facilities important for project development were identified as well as, the estimated SCG generation. The information gathered in this section will be useful in the next sections.

5.2 Diagnosis

The diagnosis consisted in evaluating the forward supply chain including the process information and material flow. The development was carried out following the methodology described in Section 4.2.

As a first step, the process operations within the forward supply chain flow (Figure 5.8) were identified and the backbone of the VSM was established.

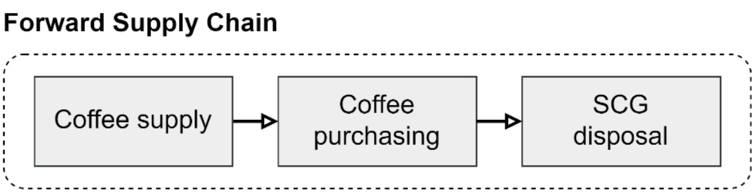


Figure 5.8 Conceptual forward supply chain of study.

- The process associated with coffee supply included the transportation of coffee to the store; in this case, Delta Cafes distributes coffee to each PRIO store once a week.
- The activities within the coffee purchase included grinding, brewing, and selling coffee.
- As a result of the consumption of coffee, SCG is produced which is collected by a waste management company every week. For this study, it was assumed that all waste is landfilled as the final disposal solution.

The next step involved analyzing the information regarding the flow of materials and data. The analysis was conducted using the estimated months' worth of average coffee supply, consumption, and SCG generation. The information that was used and provided by the companies involved is summarized in the table that may be found below (Table 5.1).

Table 5.1 Stakeholders information for VSM analysis.

Main activity	Information	Value	Unit
Coffee supply	The average velocity of vehicles	55	km/h
Coffee supply	Average distance store-warehouse	10	km
Coffee purchase	Average time of coffee purchase	112	sec
Coffee purchase	Average coffee supplied	80	kg/week
Coffee purchase	Factor of SCG generated per unit of coffee	1.4	SCG/coffee
Coffee purchase	Factor of expresso units per kilogram	125	unit/kg
SCG disposal	Average distance to landfill	35	km

Finally, information from external references was used to get the information needed to process the KPIs. The details of the information utilized to further process and add to the VSM are listed in the table below (Table 5.2).

Table 5.2 Information from references for VSM analysis.

Main activity	Information	Value	Unit	Reference
Coffee supply	Average fuel consumption of Delta's standard vehicle	6.80	L/100 Km	(Emissions, 2022)
Coffee supply	Gasoline fuel factor	9.61	KWh/L	(EAUC, 2010)
Coffee supply	Gasoline CO_2e emission factor	2.33	kg CO_2e/L	(GOV.UK, 2022)
Coffee purchase	CO_2e electricity intensity Portugal factor 2020	198.40	gCO_2e/kWh	(European Environment Agency, 2020)
Coffee purchase	Coffee machine power	3000	Watts	(Casadio, 2022)
SCG disposal	Average fuel consumption (Truck)	35	L/100 Km	(Webfleet, 2020)
SCG disposal	Diesel fuel factor	10.96	KWh/L	(EAUC, 2010)
SCG disposal	Diesel CO_2e emission factor	2.70	kg CO_2e/L	(GOV.UK, 2022)
SCG disposal	Landfill emission of SCG	0.68	kg CO_2e/kg	(Kamil, Ramadan, Ghani Olabi, et al., 2019)

Lastly, the system of the forward supply chain is depicted in the VSM in Figure 5.9, which is presented below. This helped to highlight the most critical activities during the study phase by creating a visual depiction of the process. The coffee supply transport was estimated assuming only the emissions of the trip and neglecting the weight of the cargo. The value added was defined as the portion of the transportation process that takes goods from the warehouse to the retailer. The non-value added, on the other hand, was seen as the vehicle returning to the storage empty. The coffee purchase was considered added value since gridding, brewing, and selling coffee are considered value-added operations. Finally, SCG disposal was viewed as a non-value procedure because the final destination was assumed to be a landfill. The results table is in Appendix B.

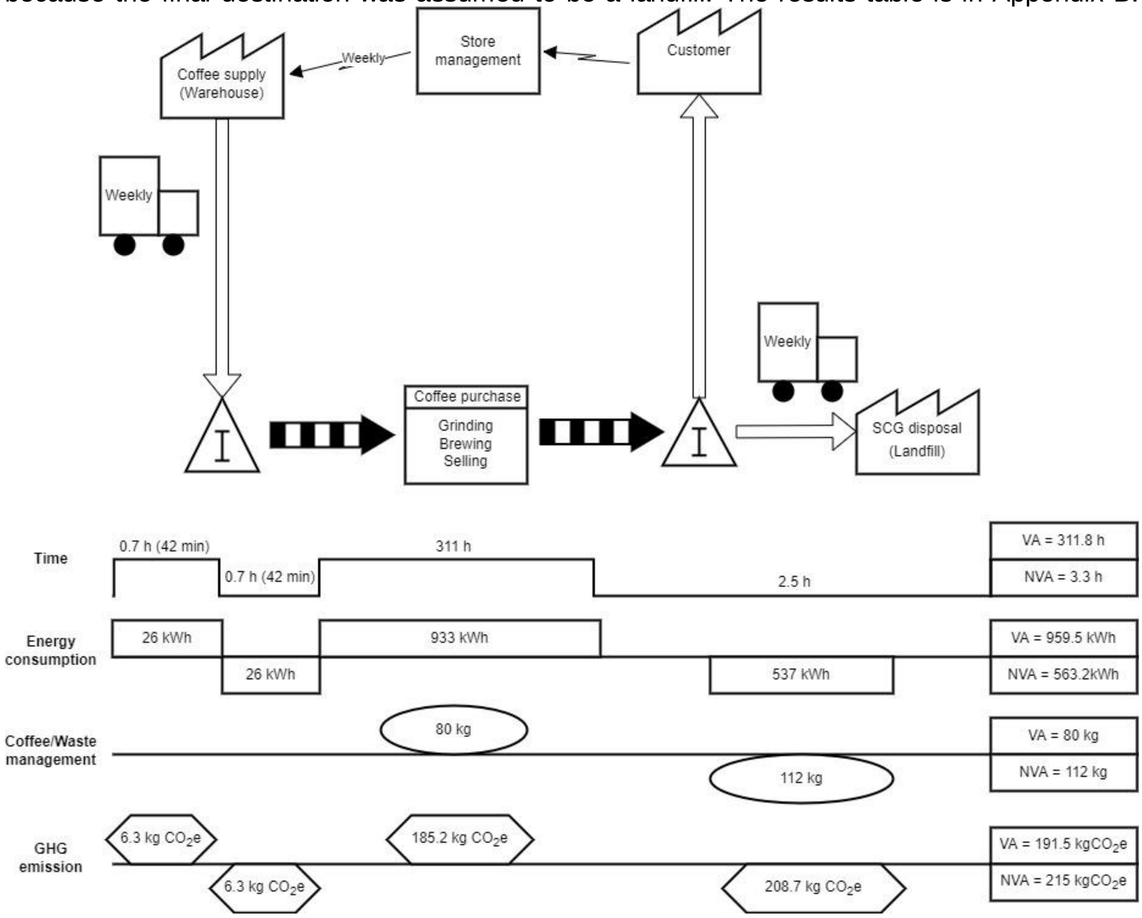


Figure 5.9 VSM – forward supply chain.

As a result, the findings of the analysis of the forward supply chain were as follows:

- As half of their time, energy consumption, and GHG emissions are spent on non-value-adding activities, the transport of the coffee supply can be optimized into a more sustainable process.
- The coffee purchase process is the one that adds the most value, is the most time-consuming, and demands the most energy, accounting for 99% and 61% of the total, respectively.
- In contrast, the disposal of the SCG disposal process generates more GHG emissions and energy consumption, 58%, and 51%, respectively, in comparison to the total.

Consequently, the SCG disposal results in a significant opportunity to improve the process's sustainability.

5.3 Proposal for the pilot project

The reverse logistic plan was proposed following the stated in Section 4.3 based on the collected data, and the results of the VSM which findings centered on improving transportation and the SCG's destination. The reverse logistic plan for the pilot was proposed as part of this dissertation and was thoroughly reviewed, modified, and approved by the PRIO and Delta teams. Figure 5.10 depicts the reverse logistical strategy, which includes the process described below.

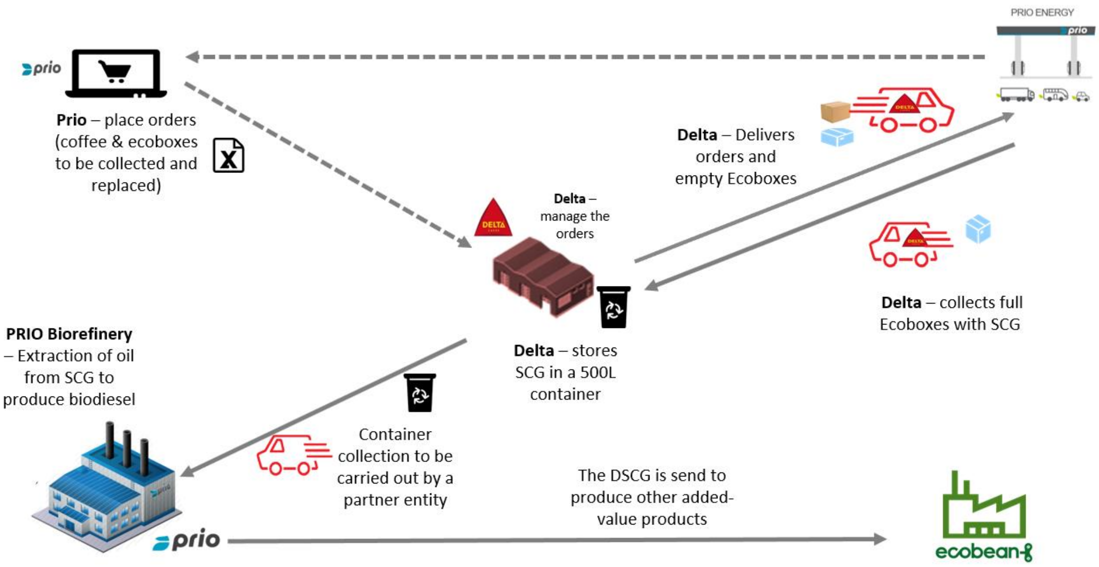


Figure 5.10 Conceptual reverse logistic flow

Listed below are the associated activities:

- PRIO collects the SCG after each coffee consumption by customers, gathering the SCG within the bin with a plastic bag under the counter. This is to ensure that just SCG is collected and avoid pollution with other wastes.
- PRIO keeps SCG boxes ready for transport within the stores.
- PRIO places the SCG bag into the box at the end of the day/or when the plastic bag is full.
- PRIO places an order for coffee supply and collection of boxes with SCG.
- Delta supplies coffee and empty boxes to PRIO stores.
- Delta collects and transports full boxes to Delta warehouse.
- The boxes containing SCG are then emptied into a container and kept in the warehouse.
- The empty boxes are stored and prepared to be replaced in the PRIO stores. In case the box is dirty this should be cleaned before being stored.
- Delta informs PRIO of the need to collect the container full of SCG.
- The SCG container is transported by a third party.

- The SCG is then processed to transform into biodiesel in PRIO biorefinery and bio-briquettes.

The RL process is depicted in further detail in Figure 5.11, which shows the various processes of the RL system.

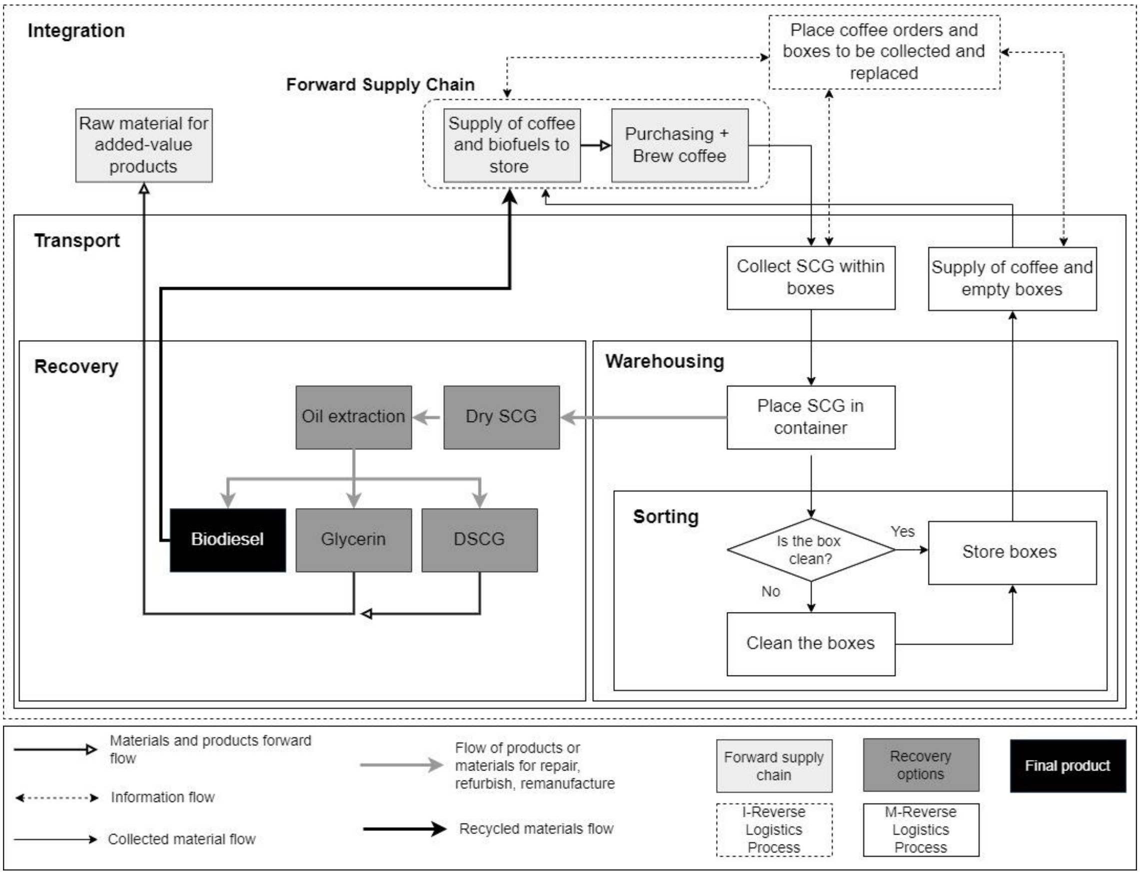


Figure 5.11 Detailed process flow chart.

The activities of the reverse logistic system are classified then in the different operations as follows:

Collection:

- PRIO collects the SCG after each purchase, gathering the SCG within the bin with a plastic bag under the counter. This is to ensure that just SCG is collected and avoid pollution with other wastes.
- PRIO places the SCG bag into the box at the end of the day/or when the plastic bag is full.

Transport:

- Delta supplies coffee and empty boxes to PRIO stores.
- Delta collects and transports full boxes to Delta warehouse.
- The SCG container is transported by a third party.

Warehousing:

- PRIO keeps SCG boxes ready for transport within the stores.
- The boxes containing SCG are then emptied into a container and kept in the warehouse.
- The empty boxes are stored and prepared to be replaced in the PRIO stores. In case the box is dirty this should be cleaned before being stored.

Recovery:

- The SCG is then processed to transform into biodiesel in PRIO biorefinery and the DSCG is sent to other supply chains as raw material.

Regarding the flow of information, this relates to the actions of PRIO placing an order for coffee supply and the collection of boxes from SCG, and Delta advising PRIO of the need to collect the container containing SCG. Each store manager and Delta's warehouse management were to communicate by email, as was usual. In addition, it was determined that Delta's warehouse management would notify PRIO of the container's situation so that PRIO could arrange for its pickup and delivery to its biorefinery.

Furthermore, the next sections provide a detailed breakdown of the activities of collection, transport, warehousing, and recovery. Appendix A contains the photographic memory of the inspections of stores and warehouses as part of the pilot project.

5.3.1 Collection

The collection includes the following activities: PRIO collecting the SCG after each coffee purchase, putting it in a plastic bag under the counter, and then putting the bag in the box at the end of the day/when the plastic bag is full. Therefore, it was important to describe the features of the boxes, estimate the volume of SCG generation and estimate the number of boxes required per store to ensure a proper collection.

The SCG is a material with high moisture content (80-85%) (Bottani et al., 2019). The boxes suggested by Ecobean for the pilot's project, depicted in Figure 5.12, were selected to protect against spills or contamination in compliance with current regulations (852/2004, 2004).

Figure 5.12. Box to store and transport SCG.

The box's main characteristics are the attached lid that protects products from pollution and contamination. Furthermore, security seals and covers that support strapping contribute to safe and secure transportation. In addition, the design features bumpers on the ends, which helps prevent containers from piling up on conveyors. Moreover, Ecobean stated that each box may hold up to 15 kg of SCG. The physical characteristics of the boxes given by the vendor are listed in Table 5.3.

Table 5.3. Characteristics of the Box (Schoeller Allibert, n.d.).

Features	
Outer dimension [mm]	400 x 300 x 250
Interior dimension [mm]	352 x 258 x 238
Usable volume [L]	21
Gross weight [kg]	1,6
Docking rate [%]	51

The estimated volume of SCG generated was determined by computing the weekly average of SCG generation from the information gathered in section 5.1.4.

Table 5.4 Estimated SCG generation.

Store	Average SCG/ week [kg]	Max SCG/ week [kg]
Sintra Cascais - O	35	55
Sintra Cascais - E	26	45
Trajouce	11	34
Vialonga	26	40
Arroja	14	31
Eixo N-S	32	51

Next, the number of boxes was calculated based on the highest value estimated for SCG generation and the estimated volume that each box can hold. This determined the number of boxes required in each store per week, in addition to a spare. The boxes in the warehouse were estimated to have the same number of replacement boxes as stores. Moreover, a safety stock was calculated to mitigate the risk of breaking or damage. The safety stock was calculated with the equation below:

$$Safety\ Stock = (Lead\ Time * Max\ of\ Boxes\ required) - (Lead\ Time * Average\ of\ Boxed\ required) \quad \textbf{Equation 3}$$

Where the lead time is the estimated period to restock the boxes after the manager of the store places an order; the max of boxes required is the max of boxes required per week based on the max estimated SCG generation, and the average boxes required is the average estimated number of boxes based on the average estimated SCG generation.

Table 5.5 displays the total number of boxes for each station, and served as the basis for determining how many boxes needed to be ordered and distributed to each store.

Table 5.5. Estimation of boxes per store

	Boxes in store	Boxes in warehouse	Spare in store	Safety stock	Total required
Sintra Cascais - O	4	4	1	2	11
Sintra Cascais - E	4	4	1	4	13
Trajouce	3	3	1	4	11
Vialonga	3	3	1	2	9
Arroja	3	3	1	4	11
Eixo N-S	4	4	1	2	11
Total					66

Then, the above-mentioned number of boxes were transported to each store, and the remaining boxes were stored in the warehouse, as described in Section 5.3.1.

Regarding the collection, it is suggested that:

- Keep track of the amount of time that elapses between the provision of empty boxes and the collection of filled boxes and the boxes are delivered on time to avoid SCG pollution over accumulation.

5.3.2 Transport

Transport operations included the following activities: Delta distributes coffee and empty boxes to PRIO stores; Delta collects and transports full boxes to the Delta warehouse, and a third party transports the SCG container. This section is described the transport approach which includes the description of the coffee supply (business as usual) and the modification to transport the collected SCG from PRIO stores.

Delta usually provides PRIO stores on weekly visits via vans that deliver coffee and other goods, as represented in Figure 5.13. Moreover, it was agreed to employ the already developed logistic system as an efficient technique for reducing routing expenses and the environmental impact of transportation.

Figure 5.13. Delta’s van type.

The vans transported the empty boxes while supplying coffee and other items. The empty boxes needed to replace the full boxes were previously ordered and delivered with the new supplies, as stated previously. After the products were delivered, the full boxes were returned to the warehouse, where the SCG was kept in the containers, as shown in Figure 5.14.

Empty boxes inside the van

Full boxes inside the van

Full boxes arriving at the warehouse

Figure 5.14. Transportation of boxes.

Finally, after the container is full, transport from Delta warehouse to PRIO's biorefinery is organized with a third party.

Regarding the transport operations, it is suggested that:

- The number of boxes must be tailored to the vehicle's capacity.
- Ensure that the boxes contain the SCG and that no spillage occurs during transportation.
- Maintain a record of any issues that arise while the SCG is being transported.
- Ensure that the containers are transported promptly to avoid difficulties or any concerns within the facility.

5.3.1 WAREHOUSING

The following are the activities associated with warehouse operations: PRIO storing SCG boxes ready for transport; transferring the SCG from boxes to a container and storing them in the warehouse; and ensuring that the boxes are stocked and ready for replacement within the warehouse to the PRIO stores. Sorting procedures are included in warehousing operations, which in this case is related to the condition when the box is dirty and should be cleaned before storage. The subsequent sections detail the operations required to store the SCG, the storage of the boxes within the stores and the warehouse, as well as the sorting procedure.

Storage within stores

Each PRIO location collects SCG and places it in the SCG bin, which is covered by a plastic bag. To avoid contamination, only SCG residue should be placed in the bag. At the end of the day/or when the plastic bag is full, the SCG bag is placed into the box. Depending on the available space in each store, each PRIO station should determine the appropriate location for the Boxes. Figure 5.15 depicts evidence of the collecting within the stores.

Eixo N-S

Vialonga

Trajouce

Arroja

Sintra Cascais - E

Sintra Cascais - O

Figure 5.15. Storage of boxes inside stores.

During one of the visits was observed that the boxes were at their total capacity at the time of the visit, with some of the SCG outside of the boxes. The manager requested the collection of four boxes plus one due to the increased generation of coffee waste. Figure 5.16 shows images of the above-mentioned finding.

Figure 5.16. Arroja storeroom.

As a result, the store's manager requested an extra box in addition to the standard number of boxes. The boxes were distributed immediately. The incident was a one-time occurrence owing to external management issues.

STORAGE WITHIN THE WAREHOUSE

The warehouses store the empty boxes and the SCG. The warehouse area was calculated based on the number of boxes estimated to be stored. In this case, the boxes from Sintra Cascais – O, Sintra Cascais – E, and Trajouce were managed in the Lisbon warehouse for three stores, and the boxes required in Arroja, Eixo Norte-Sul, and Vialonga in the Abrunheira/Sintra warehouse. Table 5.6 indicates how many boxes each warehouse ideally should have. The boxes were stored within the warehouses on top of euro pallets (800x1200 mm) to facilitate the movement. Figure 5.17 presents the possible arrangement of stacking four boxes in a pile height of 65 cm.

Table 5.6. Boxes to be stored in each warehouse.

	Replacement boxes	Safety stock	Total
Lisbon Warehouse	11	10	**21**
Abrunheira/Sintra Warehouse	11	8	**19**

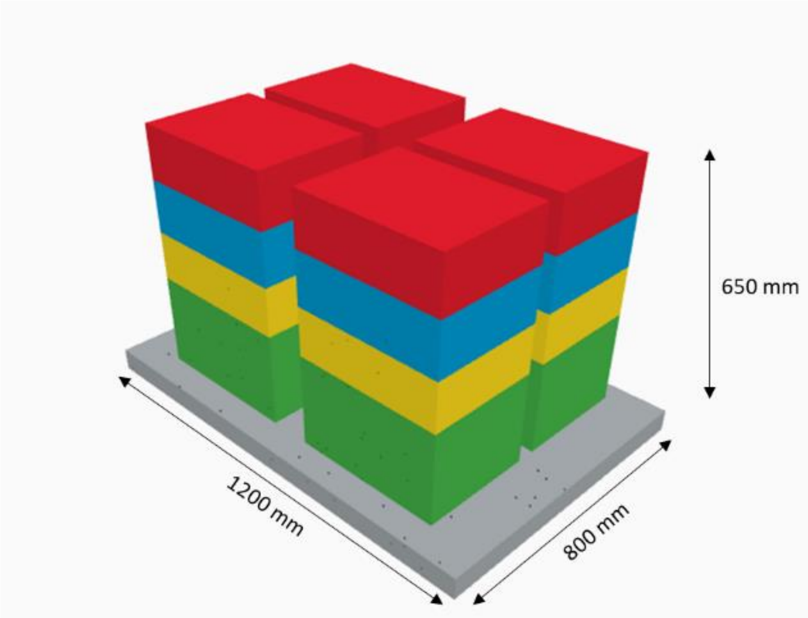


Figure 5.17. Suggested arrangement of storage within the warehouses.

Figure 5.18 shows the storage of the boxes in the warehouse. The empty boxes were later returned to their rightful locations.

Boxes storage at the Lisbon warehouse

Boxes storage at the Abrunheira/ Sintra warehouse

Figure 5.18 Storage of boxes in the warehouses.

In the case of the SCG storage, each warehouse had a 500L container in which the total of SCG from the boxes was collected. Figure 5.19 shows images of the containers. After the collection in the warehouse, the SCG was sent to PRIO'S biorefinery in Aveiro, Portugal.

SCG storage at the Abrunheira/ Sintra warehouse

SCG storage at the Lisbon warehouse

Figure 5.19. Storage of SCG in the warehouses.

Figure 5.20 depicts a Delta employee emptying boxes and collecting the SCG in a container.

Figure 5.20. Cleaning process of boxes.

SORTING OF BOXES

Once the boxes are emptied, a visual inspection was made. If the box was clean and no SCG residue was in the sight, then, it was stored within all the other boxes. Figure 5.21 shows the empty box clean after clearing bags with SCG.

Figure 5.21 Clean box after emptying the SCG

If the boxes were not clean, the employee was required to clean them before they could be stored. This procedure takes at least ten minutes. This is a manual procedure consisting of taking the boxes to the cleaning area, cleaning and drying them, and then returning them to storage. Figure 5.22 shows part of the process.

Box with SCG residues **Cleaning boxes**

Figure 5.22 Box contaminated with SCG residues and cleaning boxes process.

Regarding the warehousing operations, it is suggested that:

- Each PRIO store maintains an extra box on hand to avoid running out of empty boxes for proper collection.
- Designate an area within each PRIO store to keep empty and full boxes.
- PRIO places the SCG in plastic bags before placing it in the box, maintaining cleanliness and making box sorting easier.

5.3.2 Recovery

Biodiesel production, as described in Section 2.2.3, is a potential recovery strategy for SCG. In this scenario, the focus of the study is on feedstock diversification for biodiesel production at PRIO's biorefinery. Following is a theoretical description of the extraction of oil from SCG and a comparison of the characteristics of SCGO to those of the WCO currently utilized in PRIO's biorefinery.

Oil extraction from SCG is the first and most crucial step in biodiesel production (Passadis et al., 2020). The first concern is that SCG contains around 66% moisture (Giller et al., 2017). Because moisture affects oil solubility in the hydrophobic solvent, the lack of water is critical to achieving high oil extraction yields in the following process (Yeoh & Ng, 2022). Drying SCG would most likely result in a simpler transfer, smaller equipment due to decreased volumetric flow, and cheaper flash vessel energy costs (Giller et al., 2017).

In literature exists a significant number of studies that have discussed the extraction of SCG using different techniques tested at a laboratory scale and in less number on the pilot and industrial scale. Figure 5.23 shows the different extraction methods analyzed by Atabani et al., (2019) which depicts the average yield extraction and the number of publications reviewed.

The Soxhlet extraction process is the most often used method for extracting SCG oil. Soxhlet extraction, also known as continuous extraction, is the most often used liquid-solid extraction process and is mostly used for solid sample extraction and separation. It has many advantages, including the fact that it is simple, inexpensive, and ready to be used in combination with a solvent such as hexane. As a result, this approach was selected for use in laboratory tests during the execution phase of the project. (Georgieva et al., 2018).

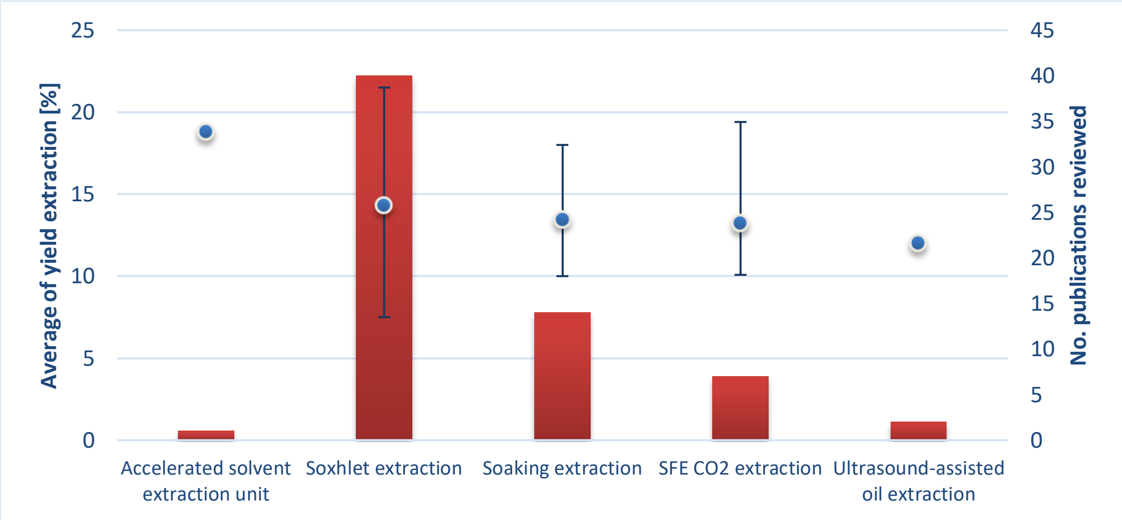


Figure 5.23. Methods of oil extraction from SCG and yield extraction.

The advantage of SCG is better stability when compared to other oils due to the lower degree of polyunsaturated components (low iodine number) (Yeoh & Ng, 2022). Figure 5.24 shows the comparison between different types of oils. Only oil palm is more stable however, it is a first-generation biofuel with numerous drawbacks, as established in Section 2.1.3.

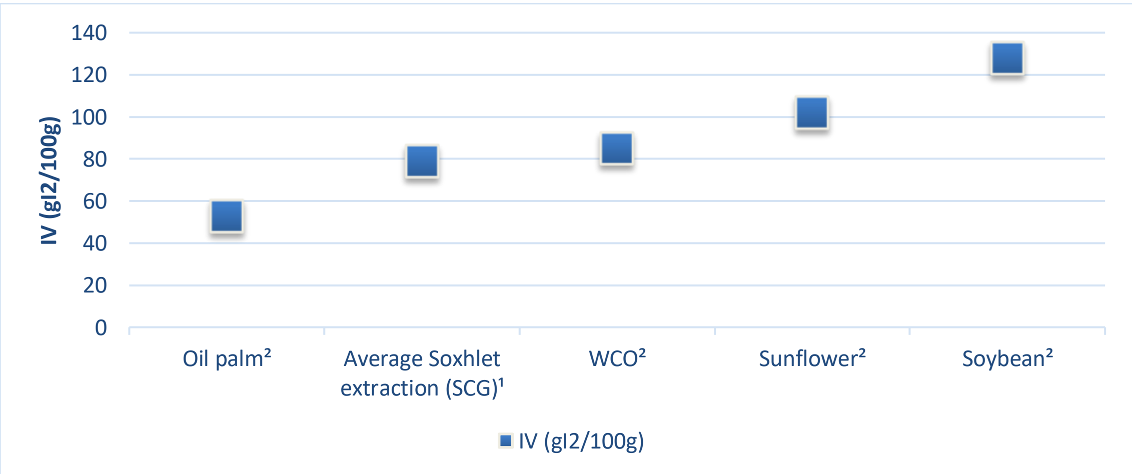


Figure 5.24 Iodine value comparison of different types of oils ([1] Atabani et al., 2019; [2] Dang & Nguyen, 2019)**.**

Several publications have looked at the SCG as a resource in different ways. For example, Giller et al. (2017) conducted a feasibility assessment for an SCG biorefinery capable of producing 1.03 million liters of coffee biofuel and 2.56 million kg of bio pellets per year. The study focused on the plant's profitability analysis, which comprised material and energy estimates and equipment cost calculations. Regarding the logistics, it was projected a linehaul collection (forward flow—outbound) throughout 5 trucks that would collect roughly 17.5 tons from around 438 stores per day. However, due to the biodiesel market price and SCG accessibility, the Net Present Value at the time of the study proved negative (-6.8 million dollars). As a result, the decision was made not to pursue this project; nevertheless, if the price of biodiesel rises to $1.05/kg in the future and a capacity of five times as much SCG per year is attained (6400 tons/year), the investment may be viable. In addition, there are no examples in the literature of using only SCGO to generate biodiesel and then selling the DSCG to other industries, which is a possibility as the market continues to develop increasingly sustainable options.

However, experimental testing is required to have a greater knowledge of how the SCGO can be implemented into PRIO's biorefinery, which is outside the scope of this work.

5.4 Assessment

5.4.1 Reverse logistics system analysis

The pilot's logistics model duration was of one month for the planning and approval of the logistics model and six months for execution, from March to October 2021 for a total of seven months. The SCG was generated in the PRIO stores within their fuel stations through the cafeteria services. After the collection, the SCG was transported through the supply chain from Delta, which distributed coffee and other products to PRIO'S convenience stores. The next section summarizes the essential features of RL, as defined in Section 4.4.

Regarding the collection, the total SCG gathered from all the stores during the project was 3.180 kg. As seen in Table 5.7, there was a significant variation in half of the stores' total collection per store as compared to the earlier estimates. The fluctuations can be explained as a result of seasonality or the impacts of the COVID-19 pandemic, which affected coffee consumption. However, there was consistent coffee consumption, which means SCG was generated, ensuring the flow of SCG collected.

Table 5.7 Estimated versus real generation of SCG.

Store	Av. est. generation SCG/ week [kg]	Av. real generation SCG/ week [kg]	Variation
Sintra Cascais - O	35	39	10%
Sintra Cascais - E	26	31	16%
Trajouce	11	12	8%
Vialonga	26	18	-44%
Arroja	14	10	-40%
Eixo N-S	32	22	-45%

In addition, there were issues with the required quantity of boxes. This is unexpected because it occurred at the Arroja shop (Figure 5.25), which generated fewer SCGs than anticipated.

Figure 5.25 SCG stored outside boxes in Arroja storeroom.

It may indicate that the information flow was inefficient, resulting in an accumulation of SCG. The frequency of delivery ranged from once per month to once per week. This can differ between stores. However, based on the results, it is suggested that new boxes be refilled and collected once every two weeks to seven days.

Regarding transport, there were no reports of problems with the boxes or the vehicle's capacity. During the visits, the drivers were asked if they had encountered any problems while transporting the boxes, such as spillage or box-related issues. It demonstrated that the boxes safely held the SCG during shipping, with no leakage events occurring within the test period. The transport of SCG from the warehouse to the biorefinery occurred every two months from the Abrunheira/Sintra warehouse and every three months from the Lisbon warehouse.

Regarding the storing of boxes within the stores, store managers did not report issues usually. This was primarily because of the available space within each store. There was one store where the storage space was too insufficient to accommodate the boxes (Figure 5.26). However, in most cases, they indicated that the boxes did not pose a space problem because they were stored in storage rooms or other suitable areas within the establishment.

The storage operations within the warehouses did not indicate any difficulty observed. In the event of the sorting of the boxes if the boxes were not cleaned it resulted in a time-consuming task (approximately 20 minutes to clean and take back) which was intended to avoid the usage of bags. It was demonstrated that plastic bags are not leak-proof, hence it is recommended that another option be considered.

Figure 5.26 Trajouce's storeroom.

5.4.2 Reverse logistic system – value stream mapping

The analysis of the RL system was carried out in accordance with the approach outlined in Section 4.4. The RL operations outlined in Section 5.3 were employed to form the "backbone" of the VSM (Figure 5.11).

The next step involved analyzing the information regarding the flow of materials and data. The analysis was conducted based on the information of one month. The information that was used and provided by the companies involved is summarized in the table that may be found below. Moreover, information from external references was used to get the information needed to process the KPIs. The details of the information utilized to further process and add to the VSM are listed in Table 5.8.

Table 5.8 Information used in VSM – RL system.

Main activity	Data of the company	Value	Unit	Reference
Sorting	Time of sorting boxes	15	min/weekly	
Sorting	Cleaning boxes	20	min	
Transport of SCG	Distance from warehouses to biorefinery	296	km	
Transport of SCG	Max velocity vehicle	80	km/h	
Transport of SCG	Times of collection	1	month	
Transport of SCG	SCG generated	530	kg/month	
Transport of SCG	Biodiesel CO_2e emission factor	0.17	kg CO_2e/L	
Biodiesel production	Factor of electricity used per kg of biodiesel processed	0.13	kWh/kg	(Giller et al., 2017)
Biodiesel production	Time factor to produce biodiesel	0.01	h/kg	(Giller et al., 2017)
Biodiesel production	Biodiesel produced per SCG	0.11	kg Biodiesel/ kg SCG	(Giller et al., 2017)

Main activity	Data of the company	Value	Unit	Reference
Biodiesel production	GHG biodiesel production from SCGs factor	-2.1	kg CO2e/ kg biodiesel produced	(Massaya et al., 2019)

The VSM of the RL system proposed is depicted in Figure 5.27, which is presented below. By developing a visual representation of the process, this helped to highlight the most vital activities throughout the study phase.

The coffee supply and transport from the warehouse were computed according to the VSM for the forward supply chain (Table 5.1 & Table 5.2). Changes in the analysis involve replacing disposal with recovery. In addition, the transfer of boxes to the warehouse has been reevaluated as an action with added value because, rather than returning empty, it now transports SCG. The SCG management is now collected from the shop and stored in the warehouse until it is transported to the recovery once per month. The transport of the SCG was calculated as a value-added trip to the biorefinery and a non-value-added trip back. In addition, the GHG emissions from transportation were computed assuming the usage of a diesel/biodiesel (85/15) blend, which is commercially available. Furthermore, the sorting operation in the warehouse was evaluated as an added-value activity. Due to the test results, it was assumed that the cleaning of the boxes occurred once per month, which has no added value. The biodiesel conversion was computed using data from the research conducted by Giller et al., (2017) & Massaya et al., (2019). The results table is in Appendix B.

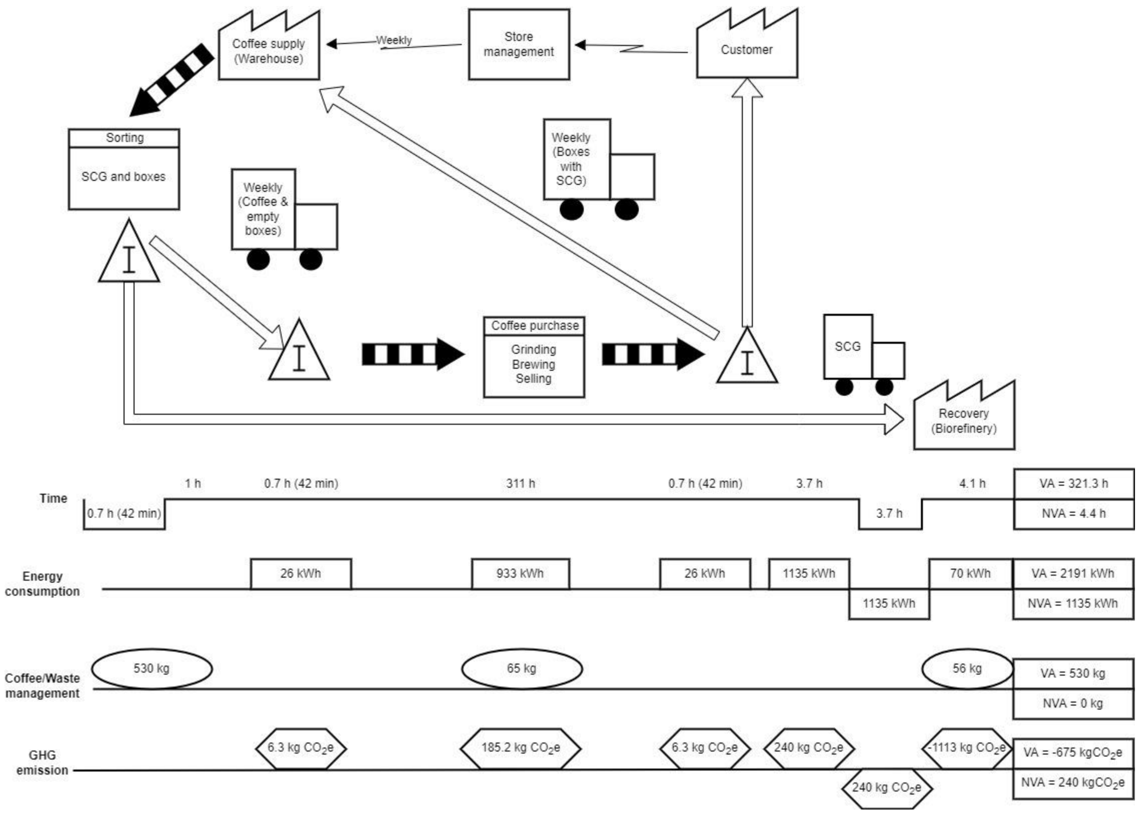


Figure 5.27 VSM – RL system.

As a result, the findings of the analysis of the RL system were as follows:

- Lead time, energy usage, and material management were nearly all value-added operations (99%, 66%, and 100% respectively).
- The SCG recovery has a positive impact, reducing GHG emissions where only biodiesel production credits were considered, which may be greater due to the DSCG's application in other industries.

Table 5.9 shows the comparison between the results of the forward supply chain VSM and the RL system analysis.

Table 5.9 Comparison of the analysis of the forward supply and RL chain.

	Forward supply chain			RL chain			Units/
	VA	NVA	Total	VA	NVA	Total	month
Lead time	311.8	3.3	**315.1**	321.3	4.4	**325.7**	hour
Energy consumption	959.5	563.2	**1522.7**	2191.1	1135.5	**3326.6**	kWh
Coffee/SCG management	80	112	**192**	956.7	0.0	**651.7**	kg
GHG Emission	191.5	215.0	**406.5**	-674.8	240.4	**-434.4**	$kgCO_2e$

The comparison between the two supply chain flows is presented as follows:

- The results form the lead time present almost no change between one and the other in the total time implemented.
- The energy consumption assessed in the process represents almost double the energy consumption of the RL chain. This is most likely due to the energy consumed during the transport of SCG to the biorefinery.
- Regarding the coffee/SCG management, the change is since, in the forward supply chain, coffee and SCG are consumed on average per store, whereas, in the RL system, the collection is stored in the warehouse until its monthly transport to the biorefinery. Therefore, the material management in the RL system is modified many times, resulting in the complete utilization of the coffee and SCG.
- The most notable difference is the reduction of the GHG if SCG is transformed into biodiesel. It is essential to recognize that this is a theoretical approximation, however, it was shown that the RL system for collecting SCG and transforming it into biodiesel has positive environmental implications.

5.4.3 Business model canvas

Following the business model canvas to design small-scale pilots by (Baldassarre et al., 2020). Figure 5.28 shows the development of the pilot's outline following the mentioned methodology and the description of each section below. The project was developed as part of the JumpStart initiative to develop innovative business models. As such, the pilot project aimed to conduct research and test a reverse logistical system on SCG as a potential biomass source for biodiesel and other sustainable products. It aimed to reduce GHG emissions in compliance with national and international sustainability objectives.

- What is the idea?

This section shows the value proposition and objectives of the project. The work was developed as part of a pilot project from PRIO'S Jump Start innovation program. The pilot project aims to implement a reverse logistics operation to collect SCG and assess the feasibility of transforming it into value-added energy products such as biodiesel and bio pellets.

The main idea of the project is to:

> Conduct a pre-industrial study of the SCG valorization chain to close the loop in the coffee circular economy.

The reason to deploy this project is that it is an innovative and convenient source of feedstock to produce biofuels. Moreover, it is a circular economy practice, which allows reducing waste while also generating wealth.

- Why is it sustainable?

This section explains the pilot's impact on sustainability and the business case that supports it. The indicators used to assess the sustainability impact are defined in this part, as is the assessment of the actual findings for each indicator after the pilot has been completed.

- How does it make money?

This section describes the viability of the project and the financial and value capture system of the project.

- How does it make it happen and how does it work?

This section discusses the feasibility of the project. As part of this process, it was essential to recognize the organizations that would be participating in the pilot's setup and implementation, as well as the resources each would bring to the project. Furthermore, a list of actions to be completed during the project is prepared.

Moreover, the sequence of actions to follow during the execution of the project is depicted.

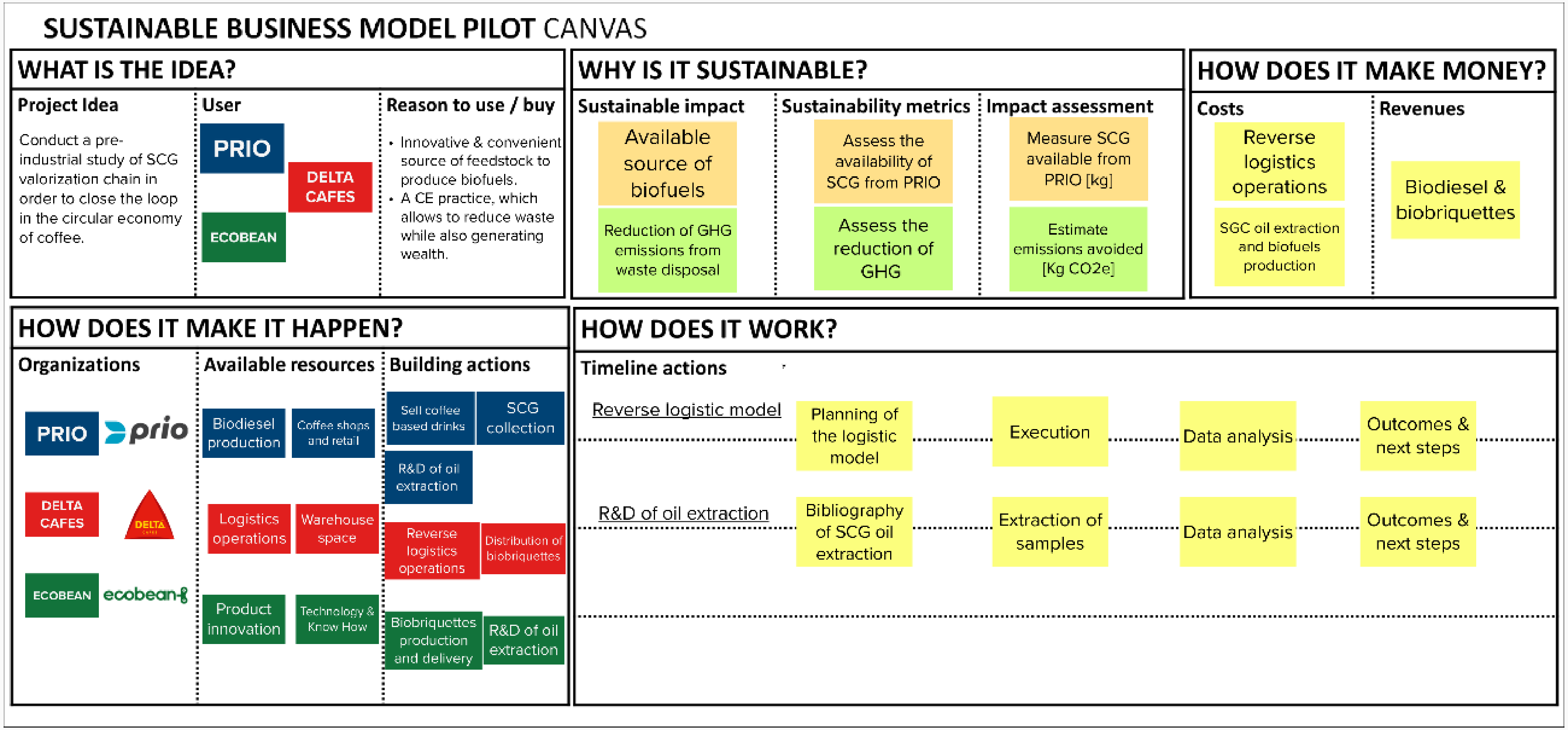


Figure 5.28. SBM Pilot Canvas of the project.

5.5 CHAPTER CONCLUSIONS

After the development and evaluation of the pilot project conducted to test the RL system to collect SCG as feedstock for biodiesel production, it was possible to identify the primary elements of the forward supply chain in a case study, propose an RL system to collect SCG, and evaluate it for comparison.

The data collection was required to comprehend the project's evolution, where project stakeholders were identified, and their functional areas were briefly described. The origin and destination facilities, as well as the estimated SCG generation.

The analysis of the VSM from the forward supply chain enabled the classification of time, energy consumption, material management, and greenhouse gas emissions as value-added or not. The transportation of coffee supplies can be made into a more environmentally friendly process by optimizing the time, energy, and greenhouse gas emissions they spend on non-value-adding activities. In addition, the disposal of SCG typically results in higher GHG emissions, 58%, and 51%, respectively, compared to the total. Consequently, SCG disposal presents a huge potential to enhance the sustainability of the process.

A logistical system for the pilot project was proposed using the information collected and the available elements. The pilot's logistics model lasted seven months, from March to October 2021, for a total of one month for preparation and approval of the logistics model. Over the course of the entirety of the project, a total of 3,180 kg of SCG was collected. Throughout the course of the pilot project, there were not any major problems were reported. Nevertheless, there were discovered areas with the need for improvement, particularly those related to the storing and sorting of the SCG.

In addition, the VSM analysis from the RL system was evaluated using the same parameters as the forward supply chain. Important to note from the RL system is that lead time, energy consumption, and material management were nearly all value-added tasks. Also, the SCG recovery showed to have a beneficial impact, lowering GHG emissions when only biodiesel production credits were examined, which could be higher due to the possible applications of the DSCG in other industries.

In addition, a business model canvas that summarizes the advantages gained and the obligations incurred because of a project having these features has been developed. The business model canvas is well known for its tendency to emphasize the desirability, practicability, viability, and long-term viability of the enterprise. This was done to provide the various stakeholders with a graphical tool that can be used for decision-making in the future.

6 CONCLUSION & FUTURE WORK

The demand for sustainable energy supply has pushed the exploration of innovative solutions where the circular economy has been recognized as an opportunity. Circular economics allows materials to be reused, reprocessed, and returned to the economy rather than being thrown away under the linear model of production and consumption (take-make-use-dispose). The circular economy is combined with supply chain management in CSCM, providing a new perspective on supply chain sustainability. The goal is to create more sustainable supply chains while also recovering valuable materials for reintegration and reprocessing. The possibilities for doing so are limitless, but their implementation presents many obstacles, especially within the supply chain operations.

Moreover, the chemical composition of SCG and its widespread availability enables the production of biofuels, such as biodiesel, and other products with added value, making it a highly exploitable resource. As addressed in this dissertation, the evidence supporting exploitation is clear. However, feedstock availability has received little research. RL is crucial when discussing CSCM and closing material loops, particularly for bioprocessing.

In this context, PRIO, in conjunction with Delta Cafés and Ecobean, decided to examine the use of SCG as a feedstock for biodiesel production. A VSM analysis from the forward supply chain made it possible to classify value-added or not time, energy usage, material management, and greenhouse gas emissions. The VSM is being used more frequently in circular economy evaluations as a technique to help comprehend the scope and depth of the challenge posed by the circular economy.

Using the data collected an RL system for the pilot project was proposed. The elements of collection, inspection, selection, recovery, and redistribution were explored to gain a better understanding of what is necessary for an RL system. The logistics model for the project lasted seven months, and a total of 3,180 kg of SCG was collected.

After the development and evaluation of the pilot project to test the RL system to collect SCG as feedstock for biodiesel production, it was possible to identify the major aspects of the forward supply chain in a case study, propose an RL system to collect SCG, and compare it. Moreover, the RL system was analyzed throughout the VSM analysis using the same parameters as the forward supply chain. The RL system resulted in lead time, energy consumption, and material management being practically all value-added jobs. Also, when only biodiesel production credits were considered, SCG recovery had a positive impact, cutting GHG emissions, which could be higher due to the DSCG's potential usage in other industries.

The aspects associated with the RL in the framework of a circular economy were successfully analyzed and evaluated according to this study. In addition, it emphasizes the benefits of collaboration between enterprises and the success of that collaboration in facilitating the circular economy. Furthermore, the VSM has proven to be a useful instrument for assessing processes and emphasizing the benefits and challenges of implementing a circular economy framework.

The areas for future research suggested are the following:

- Based on the findings from the pilot project, it would be relevant to model and simulate the implementation of this project on an industrial scale using the proposed RL system.
- To gain a clearer understanding of how the SCGO may be implemented in PRIO's biorefinery, practical testing is necessary due to the purely theoretical nature of the recovery study.
- In addition, there are no examples in the published research of using only SCGO to make biodiesel and then selling the DSCG to other businesses. This is a potential opportunity worth exploring as the market continues to develop increasingly sustainable solutions.

REFERENCES

852/2004, R. (EC) N. (2004). *Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the Hygiene of Foodstuffs*. Off. J. Eur. Union. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32004R0852&qid=1647830844145

Agrawal, S., Singh, R. K., Murtaza, Q., Abecassis, J., Cuq, B., Escudier, J. L., Garric, G., Kondjoyan, A., Planchot, V., Salmon, J. M., & de Vries, H. (2015). A literature review and perspectives in reverse logistics. *Resources, Conservation and Recycling*, *97*, 76–92. https://doi.org/10.1016/j.resconrec.2015.02.009

Aminoff, A., & Kettunen, O. (2016). Sustainable supply chain management in a circular economy—towards supply circles. *International Conference on Sustainable Design and Manufacturing*, 61–72.

Arruda, E. H., Melatto, R. A. P. B., Neto, W. L. B. da S., & Conti, D. de M. (2021). CIRCULAR ECONOMY: A BRIEF LITERATURE REVIEW (2015-2020). *Sustainable Operations and Computers*, *2*, 79–86. https://doi.org/10.1016/j.susoc.2021.05.001

Asgari, N., Nikbakhsh, E., Hill, A., & Farahani, R. Z. (2016). Supply chain management 1982-2015: A review. *IMA Journal of Management Mathematics*, *27*(3), 353–379. https://doi.org/10.1093/imaman/dpw004

Atabani, A. E., Al-Muhtaseb, A. H., Kumar, G., Saratale, G. D., Aslam, M., Khan, H. A., Said, Z., & Mahmoud, E. (2019). Valorization of spent coffee grounds into biofuels and value-added products: Pathway towards integrated bio-refinery. *Fuel*, *254*(February), 115640. https://doi.org/10.1016/j.fuel.2019.115640

Athar, M., & Zaidi, S. (2020). A review of the feedstocks, catalysts, and intensification techniques for sustainable biodiesel production. *Journal of Environmental Chemical Engineering*, *8*(6), 104523. https://doi.org/10.1016/j.jece.2020.104523

Azizan, A. (2020). Where would our biodiesel stand in our technology? *IOP Conference Series: Materials Science and Engineering*, *845*(1). https://doi.org/10.1088/1757-899X/845/1/012013

Baldassarre, B., Konietzko, J., Brown, P., Calabretta, G., Bocken, N., Karpen, I. O., & Hultink, E. J. (2020). Addressing the design-implementation gap of sustainable business models by prototyping: A tool for planning and executing small-scale pilots. *Journal of Cleaner Production*, *255*, 120295. https://doi.org/10.1016/j.jclepro.2020.120295

Bendall, S., Birdsall-Wilson, M., Jenkins, R., Chew, Y. M. J., & Chuck, C. J. (2015). Showcasing chemical engineering principles through the production of biodiesel from spent coffee grounds. *Journal of Chemical Education*, *92*(4), 683–687. https://doi.org/10.1021/ed500824z

Bernard, K. (2020). *The Top Coffee-Consuming Countries*. WorldAtlas. https://www.worldatlas.com/articles/top-10-coffee-consuming-nations.html

Beullens, P., Oudheusden, D. Van, & Wassenhove, L. N. Van. (2004). Collection and vehicle routing issues in reverse logistics. In *Reverse Logistics* (pp. 95–134). Springer.

BIC. (2021). *Mapping Portugal's bio-based potential Country Report Current basis of economic activities current opportunities for bio-based activities potential use/valorisation of bio-based streams appendix : Figures executive summary 1.1. Agriculture 1.2. Forest*.

Bocken, N. M. P., Weissbrod, I., & Antikainen, M. (2021). Business Model Experimentation for the Circular Economy: Definition and Approaches. *Circular Economy and Sustainability*, *1*(1), 49–81. https://doi.org/10.1007/s43615-021-00026-z

Bottani, E., Tebaldi, L., & Volpi, A. (2019). The role of ICT in supporting spent coffee grounds collection and valorization: A quantitative assessment. *Sustainability (Switzerland)*, *11*(23). https://doi.org/10.3390/su11236572

Bowersox, D., Closs, D., & Cooper, M. B. (2002). *ISE Supply Chain Logistics Management* (Vol. 1). Boston, Mass. : McGraw-Hill.

Brandão, A. S., Gonçalves, A., & Santos, J. M. (2021). Circular bioeconomy strategies: from scientific research to commercially viable products. *Journal of Cleaner Production*, *295*, 126407.

Brown, P., Baldassarre, B., Konietzko, J., Bocken, N., & Balkenende, R. (2021). A tool for collaborative circular proposition design. *Journal of Cleaner Production*, *297*, 126354. https://doi.org/10.1016/j.jclepro.2021.126354

Calzolari, T., Genovese, A., & Brint, A. (2022). Circular Economy indicators for supply chains: A systematic literature review. *Environmental and Sustainability Indicators*, *13*, 100160. https://doi.org/10.1016/j.indic.2021.100160

Casadio. (2022). *Casadio UNDICI - Expresso Machine*. https://casadio.com/eng/scheda_prodotto.asp?prod=30

Conteratto, C., Artuzo, F. D., Benedetti Santos, O. I., & Talamini, E. (2021). Biorefinery: A comprehensive concept for the sociotechnical transition toward bioeconomy. *Renewable and Sustainable Energy Reviews*, *151*, 111527. https://doi.org/10.1016/j.rser.2021.111527

Dahiya, S., Katakojwala, R., Ramakrishna, S., & Mohan, S. V. (2020). Biobased Products and Life Cycle Assessment in the Context of Circular Economy and Sustainability. *Materials Circular Economy*, *2*(1). https://doi.org/10.1007/s42824-020-00007-x

Dang, C.-H., & Nguyen, T.-D. (2019). Physicochemical characterization of robusta spent coffee ground oil for biodiesel manufacturing. *Waste and Biomass Valorization*, *10*(9), 2703–2712.

de Brito, M. P., & de Koster, M. B. M. (2004). Product and Material Returns: Handling and Warehousing Issues. In *Reverse Logistics* (pp. 135–153). Springer.

Dekker, R., Fleischmann, M., Inderfurth, K., & van Wassenhove, L. N. (2004). Reverse logistics: quantitative models for closed-loop supply chains. In *Reverse logistics*. Springer Science & Business Media.

Dellino, G., Mari, R., & Meloni, C. (2017). Waste reduction in fresh food supply chains: An operations research approach. In *Food Waste Reduction and Valorisation: Sustainability Assessment and Policy Analysis*. https://doi.org/10.1007/978-3-319-50088-1_12

do Carmo Albuquerque, C. A. (2012). *ANÁLISE E PREVISÃO DE PARÂMETROS PROCESSUAIS NA PRIO BIOCOMBUSTÍVEIS*.

Duncan, J. (2003). *Cost of Biodiesel Production*.

EAUC. (2010). *UCCCfS Unit Converter*. http://www.eauc.org.uk/file_uploads/ucccfs_unit_converter_v1_3_1.xlsx

Emissions, C. (2022). *Renault Boxer MPG*. https://car-emissions.com/cars/index/renault boxer/

EPA, U. S. (2007). *The Lean And Environment Toolkit*. United States Environmental Protection Agency Washington, DC, USA.

EU. (2020a). *Eurostat*. European Commission. https://ec.europa.eu/eurostat/databrowser/view/NRG_TI_BIO__custom_922512/default/table?lang=en

EU. (2020b). Portuguese National Energy and Climate Plan. In *Bundestag, Deutscher* (Vol. 2030, Issue 663). https://dip21.bundestag.de/dip21/btd/19/203/1920364.pdf

European Environment Agency. (2020). *Greenhouse gas emission intensity of electricity generation in Europe*. European Environment Agency. https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-9/#tab-googlechartid_googlechartid_googlechartid_chart_1111

Farooque, M., Zhang, A., Thürer, M., Qu, T., & Huisingh, D. (2019). Circular supply chain management: A definition and structured literature review. *Journal of Cleaner Production*, *228*, 882–900. https://doi.org/10.1016/j.jclepro.2019.04.303

Fleischmann, M. (2003). Reverse logistics network structures and design. *Available at SSRN 370907*.

Frishammar, J., & Parida, V. (2019). Circular business model transformation: A roadmap for incumbent firms. *California Management Review*, *61*(2), 5–29. https://doi.org/10.1177/0008125618811926

Gandhi, S. J., & Fajardo, M. L. (2016). Supply Chain Management for Engineering Managers. In

2nd edition BT - Engineering Management Handbook, 2nd edition, Huntsville (2nd editio, pp. 393–405). American Society for Engineering Management (ASEM). http://www.bidi.uam.mx:8331/login?url=https://www.proquest.com/books/supply-chain-management-engineering-managers/docview/2173843696/se-2?accountid=37347

Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, *190*, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. L. L. (2015). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega (United Kingdom)*, *66*, 344–357. https://doi.org/10.1016/j.omega.2015.05.015

GHG Protocol. (2013). *Technical Guidance for Calculating Scope 3 Emissions*.

Giller, C., Malkani, B., & Parasar, J. (2017). Coffee to Biofuels. *Senior Design Reports (CBE)*, 1–112.

Goh, B. H. H., Ong, H. C., Chong, C. T., Chen, W. H., Leong, K. Y., Tan, S. X., & Lee, X. J. (2020). Ultrasonic assisted oil extraction and biodiesel synthesis of Spent Coffee Ground. *Fuel*, *261*. https://doi.org/10.1016/j.fuel.2019.116121

González-Sánchez, R., Settembre-Blundo, D., Ferrari, A. M., & García-Muiña, F. E. (2020). Main dimensions in the building of the circular supply chain: A literature review. *Sustainability (Switzerland)*, *12*(6), 1–25. https://doi.org/10.3390/su12062459

GOV.UK. (2022). *Greenhouse gas reporting: conversion factors 2022*. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

Greer, R., Von Wirth, T., & Loorbach, D. (2021). *The Waste-Resource Paradox: Practical dilemmas and societal implications in the transition to a circular economy*. https://doi.org/10.1016/j.jclepro.2021.126831

Gutiérrez, C. D. B., Serna, D. L. R., & Alzate, C. A. C. (2017). A comprehensive review on the implementation of the biorefinery concept in biodiesel production plants. *Biofuel Research Journal*, *4*(3), 691–703. https://doi.org/10.18331/BRJ2017.4.3.6

Hadley Kershaw, E., Hartley, S., McLeod, C., & Polson, P. (2021). The Sustainable Path to a Circular Bioeconomy. *Trends in Biotechnology*, *39*(6), 542–545. https://doi.org/10.1016/j.tibtech.2020.10.015

Hazen, B. T., Russo, I., Confente, I., & Pellathy, D. (2020). Supply chain management for circular economy: conceptual framework and research agenda. *International Journal of Logistics Management*, *32*(2), 510–537. https://doi.org/10.1108/IJLM-12-2019-0332

Hedlund, C., Stenmark, P., Noaksson, E., & Lilja, J. (2020). More value from fewer resources: how to expand value stream mapping with ideas from circular economy. *International Journal of Quality and Service Sciences*, *12*(4), 447–459. https://doi.org/10.1108/IJQSS-05-2019-0070

Hernandez Marquina, M. V., Zwolinski, P., & Mangione, F. (2021). Application of Value Stream Mapping tool to improve circular systems. *Cleaner Engineering and Technology*, *5*, 100270. https://doi.org/10.1016/j.clet.2021.100270

Howard, M., Yan, X., Mustafee, N., Charnley, F., Böhm, S., & Pascucci, S. (2022). Going beyond waste reduction: Exploring tools and methods for circular economy adoption in small-medium enterprises. *Resources, Conservation and Recycling*, *182*(June 2021), 106345. https://doi.org/10.1016/j.resconrec.2022.106345

Hussain, M., & Malik, M. (2020). Organizational enablers for circular economy in the context of sustainable supply chain management. *Journal of Cleaner Production*, *256*. https://doi.org/10.1016/j.jclepro.2020.120375

ICO. (2020). The value of coffee: Sustainability, Inclusiveness and Resilience of the Coffee Global Value Chain. In *International Coffee Organization*.

ICO. (2021). Coffee Market Report. In *Coffee Market Report* (Issue March). https://www.ico.org/documents/cy2020-21/cmr-0321-e.pdf

IEA. (2017). Technology Roadmap: Delivering Sustainable Bioenergy. In *IEA Publications*. www.iea.org/t&c/

IEA. (2020). Portugal 2021, Energy Policy Review. In *International Energy Agency* (Vol. 4, Issue 1). https://webstore.iea.org/download/direct/2933?fileName=India_2020-Policy_Energy_Review.pdf

IPCC. (2014). Climate change 2014 synthesis report. In R. K. Pachauri & Meyer L.A. (Eds.), *IPCC: Geneva, Szwitzerland*.

IRENA. (2019). *ADVANCED BIOFUELS What holds them back?* (Issue November). https://www.irena.org/publications/2019/Nov/Advanced-biofuels-What-holds-them-back

IRENA. (2020a). Global Renewables Outlook: Energy transformation 2050. In *International Renewable Energy Agency*. https://www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020

IRENA. (2020b). *Recycle: Bioenergy.* (Issue August).

IRENA. (2020c). *Renewable Energy Market Update*. https://doi.org/10.1787/afbc8c1d-en

IRENA, & EU. (2018). Renewable Energy Prospects for the European Union. *International Renewable Energy Agency (IRENA), European Commission (EC), Abu Dhabi*, *February*

2018, 1–120.

Kamil, M., Ramadan, K. M., Awad, O. I., Ibrahim, T. K., Inayat, A., & Ma, X. (2019). Environmental impacts of biodiesel production from waste spent coffee grounds and its implementation in a compression ignition engine. *Science of the Total Environment*, *675*, 13–30. https://doi.org/10.1016/j.scitotenv.2019.04.156

Kamil, M., Ramadan, K. M., Ghani Olabi, A., Shanableh, A., Ghenai, C., Al Naqbi, A. K., Awad, O. I., Ma, X., Olabi, A. G., Shanableh, A., Ghenai, C., Al Naqbi, A. K., Awad, O. I., & Ma, X. (2019). Comprehensive evaluation of the life cycle of liquid and solid fuels derived from recycled coffee waste. *Resources, Conservation and Recycling*, *150*. https://doi.org/10.1016/j.resconrec.2019.104446

Khan, S. A. R. (2019). Introductory Chapter: Introduction of Green Supply Chain Management. In *Green practices and strategies in Supply Chain Management* (p. Ch. 1). IntechOpen. https://doi.org/10.5772/intechopen.81088

Krikke, H., Bloemhof-Ruwaard, J., & Van Wassenhove, L. N. (2003). Concurrent product and closed-loop supply chain design with an application to refrigerators. *International Journal of Production Research*, *41*(16), 3689–3719.

Kruczek, M., & Zebrucki, Z. (2015). *VALUE STREAM MAPPING IN REVERSE LOGISTIC ENTERPRISES*. 2–7.

Lago, C., Herrera, I., Caldés, N., & Lechón, Y. (2018). Nexus bioenergy-Bioeconomy. *The Role of Bioenergy in the Emerging Bioeconomy: Resources, Technologies, Sustainability and Policy*, *May*, 3–24. https://doi.org/10.1016/B978-0-12-813056-8.00001-7

Lahane, S., Kant, R., & Shankar, R. (2020). Circular supply chain management: A state-of-art review and future opportunities. *Journal of Cleaner Production*, *258*, 120859. https://doi.org/10.1016/j.jclepro.2020.120859

Langstrand, J. (2016). An introduction to value stream mapping and analysis. *Linköping University*, 1–28. http://www.diva-portal.org/smash/record.jsf?pid=diva2:945581%0Ahttps://www.diva-portal.org/smash/get/diva2:945581/FULLTEXT01.pdf

Locher, D. A. (2008). *Value stream mapping for lean development: a how-to guide for streamlining time to market*. CRC Press.

Lopes de Sousa Jabbour, A. B., Rojas Luiz, J. V., Rojas Luiz, O., Jabbour, C. J. C., Ndubisi, N. O., Caldeira de Oliveira, J. H., & Junior, F. H. (2019). Circular economy business models and operations management. *Journal of Cleaner Production*, *235*, 1525–1539. https://doi.org/10.1016/j.jclepro.2019.06.349

Ma, Y., & Liu, Y. (2019). Biodiesel Production: Status and Perspectives. In *Biomass, biofuels,* *biochemicals: biofuels: alternative feedstocks and conversion processes for the production of liquid and gaseous biofuels* (pp. 661–690). Academic press. http://dx.doi.org/10.1016/B978-0-12-816856-1.00027-0

Mann, H., Kumar, U., Kumar, V., & Mann, I. J. S. (2010). Drivers of sustainable supply chain management. *IUP Journal of Operations Management*, *9*(4).

Massaya, J., Prates Pereira, A., Mills-Lamptey, B., Benjamin, J., & Chuck, C. J. (2019). Conceptualization of a spent coffee grounds biorefinery: A review of existing valorisation approaches. *Food and Bioproducts Processing*, *118*, 149–166.

Mathu, K. (2019). Green Supply Chain Management: A Precursor to Green Purchasing. In S. A. R. Khan (Ed.), *Green Practices and Strategies in Supply Chain Management* (p. Ch. 4). IntechOpen. https://doi.org/10.5772/intechopen.87158

McNutt, J., & He, Q. (2019). Spent coffee grounds: A review on current utilization. *Journal of Industrial and Engineering Chemistry*, *71*, 78–88. https://doi.org/10.1016/j.jiec.2018.11.054

Megayanti, W., Anityasari, M., & Ciptomulyono, U. (2018). Sustainable suppy chain value stream mapping (Ssc-Vsm) the application in two bottle drinking water companies. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, *2018-March*, 3573–3585.

Melo, A. C. S., de Nunes, D. R. L., Júnior, A. E. B., de Lima, R. B., Nagata, V. de M. N., & Martins, V. W. B. (2022). Analysis of activities that make up reverse logistics processes: proposition of a conceptual framework. *Brazilian Journal of Operations & Production Management*, *19*(2).

Mussatto, S. I., Machado, E. M. S., Martins, S., & Teixeira, J. A. (2011). Production, Composition, and Application of Coffee and Its Industrial Residues. *Food and Bioprocess Technology*, *4*(5), 661–672. https://doi.org/10.1007/s11947-011-0565-z

Niero, M., & Kalbar, P. P. (2019). Resources , Conservation & Recycling Coupling material circularity indicators and life cycle based indicators : A proposal to advance the assessment of circular economy strategies at the product level. *Resources, Conservation & Recycling*, *140*(October 2018), 305–312. https://doi.org/10.1016/j.resconrec.2018.10.002

Nizami, A. S., Rehan, M., Waqas, M., Naqvi, M., Ouda, O. K. M., Shahzad, K., Miandad, R., Khan, M. Z., Syamsiro, M., Ismail, I. M. I., & Pant, D. (2017). Waste biorefineries: Enabling circular economies in developing countries. In *Bioresource Technology* (Vol. 241, pp. 1101–1117). https://doi.org/10.1016/j.biortech.2017.05.097

Norton, A., & Fearne, A. (2007). *Sustainable Value Stream Mapping: A Practical Aid to Sustainable Production*.

OEC. (2019). *Coffee (HS: 0901) Product Trade, Exporters and Importers | OEC*. The Observatory of Economic Complexity. https://oec.world/en/profile/hs92/coffee?growthSelector=value1&yearSelector2=tradeYear4

Papadis, E., & Tsatsaronis, G. (2020). Challenges in the decarbonization of the energy sector. In *Energy* (Vol. 205, p. 118025). Elsevier Ltd. https://doi.org/10.1016/j.energy.2020.118025

Peña Moreno, C. A., & Salgado, O. (2012). Sustainability indicators along the coffee value chain: A comparative study between Mexican & Colombian retail. *Journal of Management*, *50*(8), 65–75.

Philp, J., & Winickoff, D. E. (2018). *Realising the circular bioeconomy*. OECD. https://doi.org/https://doi.org/10.1787/31bb2345-en

Portugal, G. de, Republica Portuguesa, Patermann, C., & Aguilar, A. (2016). Green Growth Commitment. *Ministry of Environment Spatial Planning and Energy*, *101*(2003), 16. https://doi.org/10.1016/j.bioeco.2021.100005

Rachih, H., Mhada, F. Z., & Chiheb, R. (2019). Meta-heuristics for reverse logistics: A literature review and perspectives. *Computers and Industrial Engineering*, *127*, 45–62. https://doi.org/10.1016/j.cie.2018.11.058

Rosa, P., Sassanelli, C., & Terzi, S. (2019). Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes. *Journal of Cleaner Production*, *236*. https://doi.org/10.1016/j.jclepro.2019.117696

Ruan, R., Zhang, Y., Chen, P., Liu, S., Fan, L., Zhou, N., Ding, K., Peng, P., Cheng, Y., Anderson, E., & Wang, Y. (2019). Biofuels : Introduction. In *Biomass, biofuels, biochemicals: biofuels: alternative feedstocks and conversion processes for the production of liquid and gaseous biofuels* (p. 24).

Salvador, R., Puglieri, F. N., Halog, A., Andrade, F. G. d., Piekarski, C. M., & De Francisco, A. C. (2021). Key aspects for designing business models for a circular bioeconomy. *Journal of Cleaner Production*, *278*. https://doi.org/10.1016/j.jclepro.2020.124341

Salvador, R., Vetroni Barros, M., Mendes Da Luz, L., Piekarski, M., & Carlos De Francisco, A. (2019). *Circular business models: Current aspects that influence implementation and unaddressed subjects*. https://doi.org/10.1016/j.jclepro.2019.119555

Sangwan, K. S. (2017). Key Activities, Decision Variables and Performance Indicators of Reverse Logistics. *Procedia CIRP*, *61*, 257–262. https://doi.org/10.1016/j.procir.2016.11.185

Santos, M. J., Amorim, P., Marques, A., Carvalho, A., & Póvoa, A. (2020). The vehicle routing problem with backhauls towards a sustainability perspective: a review. *Top*, *28*(2), 358–401. https://doi.org/10.1007/s11750-019-00534-0

Schoeller Allibert. (n.d.). *No. 1 supplier of returnable transit packaging*. Retrieved March 17, 2021, from https://www.schoellerallibert.com/

Silveira, S. D. C. (2019). The role of bioenergy in a circular bio-based economy. In *Applied Energy Symposium: MIT A+B* (Issue May).

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., De Vries, W., De Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223). https://doi.org/10.1126/science.1259855

Sunggyu, L. S., & Shah, Y. T. (2012). Biofuels and bioenergy: Processes and technologies. In *Biofuels and Bioenergy: Processes and Technologies*. https://doi.org/10.1201/b12510

Tan, E. C. D., & Lamers, P. (2021). Circular Bioeconomy Concepts—A Perspective. *Frontiers in Sustainability*, *2*(July), 1–8. https://doi.org/10.3389/frsus.2021.701509

Teixeira, J. A., & Mussatto, S. I. (2014). Coffee. In J. A. Teixeira & A. A. Vicente (Eds.), *Recovery and Biotechnological Production of High-Value- Added Products from Fruit and Vegetable Residues* (Vol. 1, p. 16). https://doi.org/10.1201/b15426-19

Thurston, R. W., Morris, J., & Steiman, S. (2013). *Coffee : A Comprehensive Guide to the Bean, the Beverage, and the Industry*. Rowman & Littlefield Publishers. https://bidi.uam.mx:2048/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=e000xww&AN=653475&lang=es&site=eds-live&scope=site

Toro O., E. M., Escobar Z., A. H., & Granada E., M. (2015). Literature Review on the Vehicle Routing Problem in the Green Transportation Context. *Luna Azul*, *42*, 362–387. https://doi.org/10.17151/luaz.2016.42.21

Tseng, M. L., Ha, H. M., Tran, T. P. T., Bui, T. D., Chen, C. C., & Lin, C. W. (2022). Building a data-driven circular supply chain hierarchical structure: Resource recovery implementation drives circular business strategy. *Business Strategy and the Environment*, *January*, 1–25. https://doi.org/10.1002/bse.3009

U.S. Department of Energy. (2006). Biomass Basics: The Facts About Bioenergy. *Energy Efficiency & Renewable Energy*, 2006.

Ubando, A. T., Felix, C. B., & Chen, W. H. (2020). Biorefineries in circular bioeconomy: A comprehensive review. *Bioresource Technology*, *299*. https://doi.org/10.1016/j.biortech.2019.122585

US EPA. (2021). *Emission Factors for Greenhouse Gas Inventories* (Vol. 2, Issue April). papers2://publication/uuid/FDF7F83F-129C-44B6-AD7E-9620A9C9ED08

Venkata Mohan, S., Varjani, S., Pant, D., Sauer, M., & Chang, J. S. (2020). Circular bioeconomy approaches for sustainability. In *Bioresource Technology* (Vol. 318, p. 124084).

https://doi.org/10.1016/j.biortech.2020.124084

Vlachokostas, C. (2020). Closing the loop between energy production and waste management: A conceptual approach towards sustainable development. *Sustainability (Switzerland)*, *12*(15), 1–15. https://doi.org/10.3390/su12155995

Walker, A. M., Vermeulen, W. J. V., Simboli, A., & Raggi, A. (2021). Sustainability assessment in circular inter-firm networks: An integrated framework of industrial ecology and circular supply chain management approaches. *Journal of Cleaner Production*, *286*, 125457. https://doi.org/10.1016/j.jclepro.2020.125457

WBA. (2020). *GLOBAL BIOENERGY STATISTICS 2020*. https://worldbioenergy.org/uploads/201210 WBA GBS 2020.pdf

WBG. (2021). Commodity markets Outlook, January. In *World Bank Group* (Vol. 1, Issue April). www.worldbank.org/commodities

Webfleet. (2020). *What is the diesel consumption per kilometer of trucks?* https://www.webfleet.com/en_gb/webfleet/blog/do-you-know-the-diesel-consumption-of-a-lorry-per-km/

Yeoh, L., & Ng, K. S. (2022). Future Prospects of Spent Coffee Ground Valorisation Using a Biorefinery Approach. *Resources, Conservation and Recycling*, *179*(December 2021), 106123. https://doi.org/10.1016/j.resconrec.2021.106123

Zullaikah, S., Utomo, A. T., Yasmin, M., Ong, L. K., & Ju, Y. H. (2019). Ecofuel conversion technology of inedible lipid feedstocks to renewable fuel. In *Advances in Eco-Fuels for a Sustainable Environment* (pp. 244–245). Elsevier. https://doi.org/10.1016/b978-0-08-102728-8.00009-7

Appendix A - Photographic memory

Photo No. 1 **Location:** Eixo Norte-Sul Boxes storage within the store. **Date:** 19-May-21	
Photo No. 2 **Location:** Eixo Norte-Sul SCG is collected within bags to keep clean. **Date:** 19-May-21	

Photo No. 3 **Location:** Eixo Norte-Sul Cafeteria section. The coffee is collected after coffee brew preparation. **Date:** 19-May-21	
Photo No. 4 **Location:** Delta van arriving at Eixo Norte-Sul. **Date:** 19-May-21	
Photo No. 5 **Location:** Interior of the van with empty boxes, coffee, and other goods. **Date:** 19-May-21	

Photo No. 6

Location:

Interior of the van after collecting full boxes.

Date: 19-May-21

Photo No. 7

Location:

Vialonga cafeteria area and PRIO employees.

Date: 21-May-21

Photo No. 8

Location:

Vialonga boxes storage (empty and full boxes) within the storeroom.

Date: 21-May-21

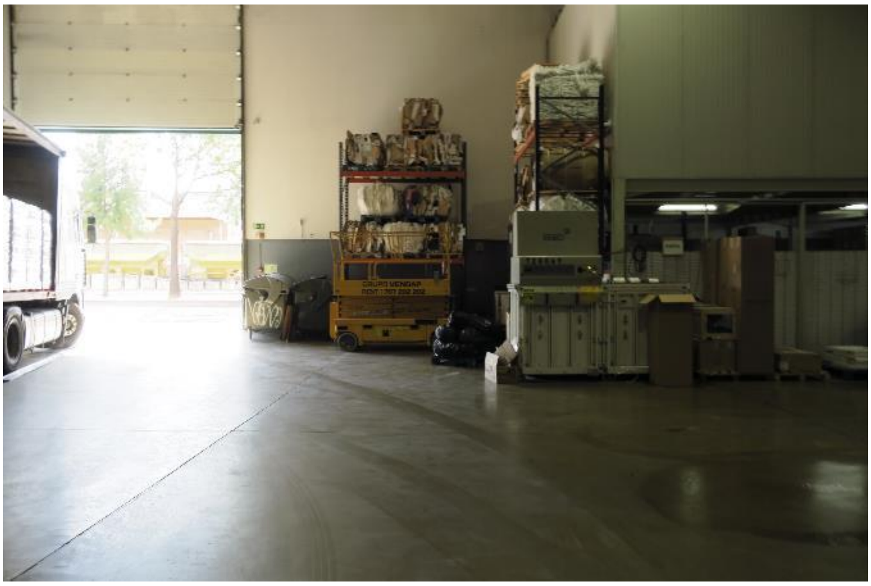
Photo No. 9 **Location:** Area of storage within Lisbon warehouse. **Date:** 21-May-21	
Photo No. 10 **Location:** Delta SCG storage in Lisbon warehouse **Date:** 21-May-21	
Photo No. 11 **Location:** Interior of the container **Date:** 21-May-21	

Photo No. 12 **Location:** Delta boxes storage in Lisbon warehouse. **Date:** 21-May-21	
Photo No. 13 **Location:** Trajouce's storeroom where boxes are stored **Date:** 02-Jun-21	
Photo No. 14 **Location:** Trajouce boxes storage. Empty (left) and full boxes (right). **Date:** 02-Jun-21	

Photo No. 15 **Location:** Trajouce SCG collected within bags to keep clean. **Date:** 02-Jun-21	
Photo No. 16 **Location:** Arroja storeroom where boxes are stored. The ecoboxes were full. **Date:** 06-Jun-21	
Photo No. 17 **Location:** SCG stored outside the boxes due to the lack of empty boxes in the Arroja storeroom **Date:** 06-Jun-21	

Photo No. 18 **Location:** Inside of Delta's van arriving at the warehouse with full SCG boxes **Date:** 06-Jun-21	
Photo No. 19 **Location:** Delta employee emptied boxes and collected the SCG in the container. **Date:** 06-Jun-21	
Photo No. 20 **Location:** Empty box clean after clearing bags with SCG. **Date:** 06-Jun-21	

Photo No. 21 **Location:** Bags containing SCG were not properly closed causing the SCG to spill into the box. **Date:** 06-Jun-21	
Photo No. 22 **Location:** Box being cleaned. **Date:** 06-Jun-21	
Photo No. 23 **Location:** Cascais Sintra – Este storeroom where boxes are stored (empty and full boxes) **Date:** 17-Jun-21	

Photo No. 24 **Location:** Cascais Sintra – Oeste storeroom where boxes are normally stored. At the time of the visit, the room was being cleaned. **Date:** 17-Jun-21	
Photo No. 25 **Location:** Cascais Sintra – Oeste bathroom where boxes were temporally stored. **Date:** 17-Jun-21	
Photo No. 26 **Location:** SCG container within Delta's warehouse Abrunheira/ Sintra. **Date:** 17-Jun-21	

Photo No. 27 **Location:** Boxes full of SCG in Delta’s warehouse Abrunheira/ Sintra. **Date:** 17-Jun-21	
Photo No. 28 **Location:** Boxes being emptied into the container in Delta’s warehouse Abrunheira/ Sintra **Date:** 17-Jun-21	
Photo No. 29 **Location:** Area of storage of boxes in Delta’s warehouse Abrunheira/ Sintra. **Date:** 17-Jun-21	

Photo No. 30 **Location:** Boxes are not directly stalked to allow the drying in Delta’s warehouse Abrunheira/ Sintra. **Date:** 17-Jun-21	

APPENDIX B – VSM RESULTS

Forward supply chain – VSM results

	Coffee supply		Coffee purchase		SCG disposal		Total			
Indicators	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**Total**	**Units/month**
Lead time	0.7	0.7	311.1			2.5	311.8	3.3	315.1	hour
Energy consumption	26.1	26.1	933.3			537.0	959.5	563.2	1522.7	kWh
Coffee/SCG management			80.0			112.0	80.0	112.0	192.0	kg
Emission	6.3	6.3	185.2			208.7	191.5	215.0	406.5	kgCO2e

RL system – VSM results

	Coffee supply		Sorting		Coffee purchase		Transport of boxes full of SCG		Transport of SCG		Biodiesel production		Total			
Indicators	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**Total**	**Units/month**
Lead time	0.7		1.0	0.7	311.1		0.7		3.7	3.7	4.1		321.3	4.4	325.7	hour
Energy consumption	26.1				933.3		26.1		1135.5	1135.5	70.1		2191.1	1135.5	3326.5	kWh

	Coffee supply		Sorting		Coffee purchase		Transport of boxes full of SCG		Transport of SCG		Biodiesel production		Total			
Indicators	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**VA**	**NVA**	**Total**	**Units/month**
Coffee/SCG management			530.0		65.0						56.7		651.7	0.0	651.7	kg
Emission	6.3				185.2		6.3		240.4	240.4	-1113.0		-674.8	240.4	-434.4	kgCO2e