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MASTER'S THESIS

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Abstract[1]

The environmental impact of food waste has been growing in interest among various environmental organizations as well as communities in the last decade. Coffee has been one of the largest consumed drinks worldwide that result in copious quantities of spent coffee ground (SCG) generated as a by-product. SCG has much nutritional value and energy that is normally not captured when dumped into a landfill in addition to the detrimental environmental impact due to the release of Methane. Therefore, valorization of SCG help create new sustainable products and reduce the environmental footprint. The waste recycling approach to producing high-value product also promotes a circular economy.

This study is focused on understanding the SCG generation potential in the Stavanger region of Norway. Various data related to SCG generation, consumption, and recycling effort have been collected from different coffee shops as well as restaurants in the region. There is a SCG potential of about 54 – 75 tonnes/year in the Stavanger region from various coffee shops and restaurants, whereas the total potential is in the range 600 – 2000 tonnes/year. The study compares a few key valorization routes such as industrial composting, fuel pallets, and oyster mushroom production for their technical and economic feasibility. The economic analysis is performed based on a very conservative amount of 37.5 tonnes/year SCG that is assumed to be available for free.

Composting and fuel pallets are not profitable whereas oyster mushroom can be profitable with reduced raw materials cost. The future work should extend the data collection to the other regions of Norway as well as various sources of SCG generations to get the more accurate estimate and therefore, look for industrial-scale recycling options such as biodiesel and the respective economic feasibility.

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https://abbs-iconbhb.org/Abbs2020/index

Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations

ICO: International coffee organization

SCG: Spent coffee grounds

CD: Cow dung

GW: Green waste

C/N ratio: Carbon/Nitrogen ratio

UiS: University of Stavanger

CO2: Carbon dioxide

CS: Coffee silverskin

PHA: Polyhydroxyalkanoates

RDF: Refuse-derived fuel

ECBC: European Coffee Brewing Centre

CAPEX: Capital expenditures

OPEX: Operating expenses

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Finally, I would like to thank profusely my family and friends for their continued support and encouragement.

Chapter 1: Introduction

1.1 Overview

The world population is increasing year on year[2], and therefore, the amount of waste generated will also be increased due to higher consumption. Food waste has been a well-known issue and various methods are in place now to recycle it [1]. Most of the different organic wastes are mixed and sent to either landfill, composting, or incineration facility [1]. However, many organic wastes have a high potential to create value-added products with minimal or no environmental impact. Recycling helps by reducing the amount of waste generated and therefore less exposure of waste to the environment and their negative impact. However, the process of converting waste into other forms of usable materials or sources of energy is known as "waste valorization" [2].

Coffee is the second largest consumed beverage in the world after Tea. World coffee production is estimated to be about 10.16 billion kg in 2019/20 [3]. Brazil, Vietnam, Colombia, and Indonesia are the top four coffee exporting countries exporting approx. 36.8%, 18.2%, 8.1%, and 5.5% respectively [4]. Figure 1 – World coffee production and consumption shows the world coffee production and consumption for the last 5 years [5]. The consumption trend has been continuously increasing year-on-year for the past 5 years though actual consumption for 2019/20 might fall below forecasted consumption due to COVID pandemic. There has been a substantial increase in production during 2018/19, however, the forecasted production for 2019/20 is partly lower due to some trees are in the off-year of their biennial production cycle [5].

[2] World total population growth chart: https://data.worldbank.org/indicator/SP.POP.TOTL?end=2019&start=2011

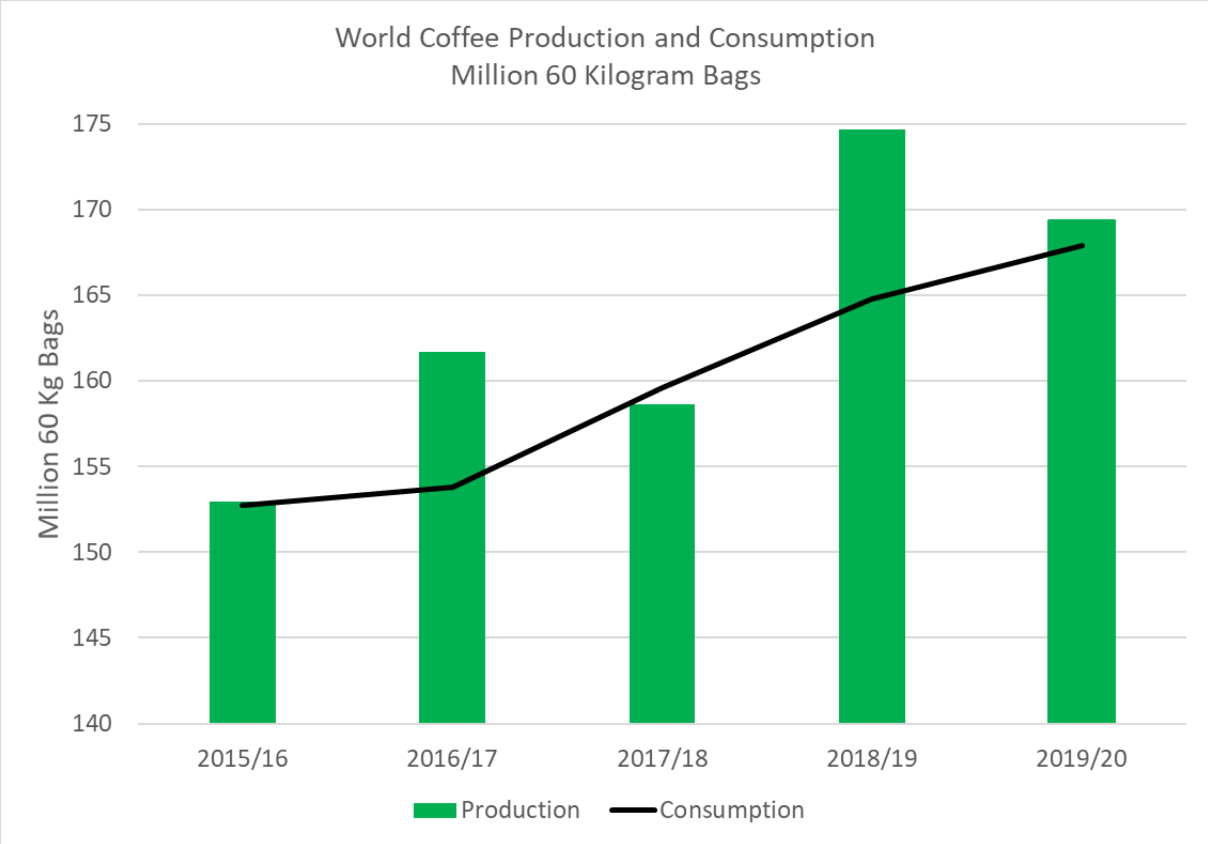

Figure 1 *– World coffee production and consumption [5]*

European Union is the largest by import with 40% of the total importing countries [6]. Though Norway contributing to less than 1% of the total import in 2018/19 [7], the consumption is high per capita [8][9]. Norway is ranked second after Finland with an average annual consumption of 8.8 kg per capita [9]. The amount of total coffee imported to Norway in 2019 is just over 47 thousand tonnes [7][9][10], out of which 72% is imported as raw green beans [10]. Figure 2 and Table 1 show the coffee consumption by selected importing countries [7]. European Union is the largest coffee consumer with USA ranking second. Norway coffee consumption is less than 1% of total coffee consumption worldwide. Stavanger region in this study consists of Stavanger, Sandnes, Sola, and Randaberg municipality[3]. It located at the South-West part of Norway. The region consists of about 230,000 inhabitants that are 4.25% of Norway's population as of 1st Jan. 2020 [11].

[3] Individual municipality population: https://www.ssb.no/433416/urban-settlements.population-and-area-by-municipality

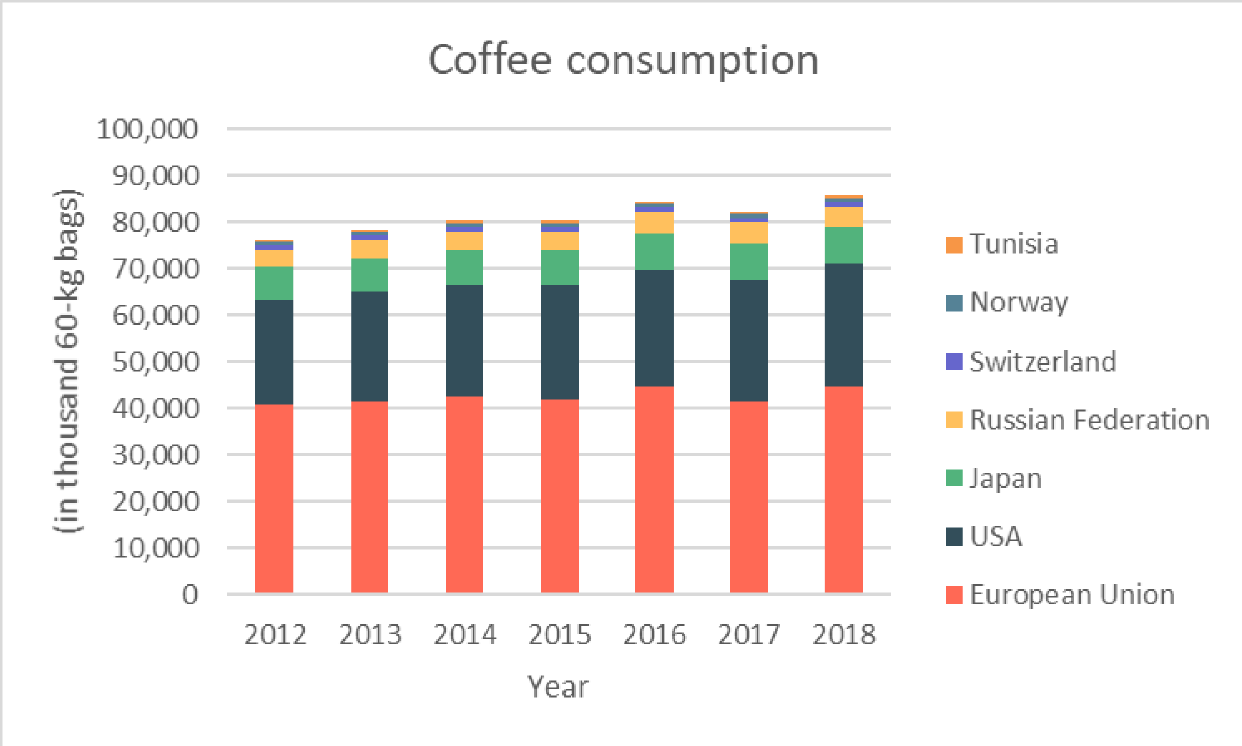

Figure 2 *– Coffee consumption trend in selected countries importing [7]*

Table 1 *– Consumption in selected importing countries (In thousand 60-kg bags) [7]*

Calendar years	2012	2013	2014	2015	2016	2017	2018
European Union	40,979	41,585	42,798	41,998	44,615	41,613	44,730
Norway	723	763	729	788	782	781	734
USA	22,232	23,417	23,767	24,438	25,243	26,183	26,514

SCG is one of the significant wastes generated in the entire coffee supply chain from a coffee cherry to a cup of coffee [12]. SCG is generated after the coffee grounds are brewed to prepare coffee. It is mostly disposed of along with the municipal solid waste (MSW). This waste powder is a useful feedstock for several value-added products to support the circular economy [12],[13]. However, it can be detrimental to the environment if it goes to a landfill. The decomposition of SCG will produce Methane (CH4) gas that is more harmful to the environment than the Carbon dioxide (CO2) gas [14]. However, valorization of SCG not only helps with the environmental aspect rather it will create an opportunity for small businesses to turn this waste into a usable product and therefore make money from it.

The chemical composition of SCG mainly consists of polysaccharides, proteins, oil, lignin, sugars, and minerals [15] [16] [17] [18]. There have been numerous studies in the literature to recover the energy and available nutrients. The various valorization routes ranging from composting, fertilizer, bio-fuels production such as biogas and biodiesel, fuel pallets, oyster mushroom, and protein extraction [12] [15] [16] [17] [19]. Table 8Table 1 in Chapter 3.3 shows the list of valorization routes that are commercialized as well.

1.2 Objective of the study

This study emphasizes spent coffee grounds valorization strategies for the Stavanger region. The open literature does not list any small or industrial scale valorization route used currently in the Stavanger region. Therefore, most of the generated spent coffee ground either goes along with food waste or is used for garden/farm composting purposes. Following are the key objectives:

- Understand the SCG generation potential in the Stavanger region.
- Current SCG management and disposal practices in the region.
- Reviewing potential valorization routes applicable in the short-term.
- Evaluate the economic feasibility of selected routes.

The following valorization routes are considered and will be discussed in this study:

1. **Industrial compositing**
2. **Fuel pallets**
3. **Oyster mushroom**

The above valorization routes have been selected based on the following criteria:

- Small scale and easy to implement.
- Minimal or no additional environmental impact by new re-usable products.
- Economically feasible even at lower SCG generation level.

These routes will be evaluated for their economic attractiveness and environmentally sustainable process.

Chapter 2: Literature review

Valorization of SCG has been a popular topic among researchers as well as some start-up companies. There is no single route that is economically attractive as well as environmentally suitable for all cases based on open literature. The economic and environmental sustainability depends on various local factors such as available SCG amounts, availability of raw materials, environmental regulations, demand for recycled products, logistics, weather, and subsidy or tax benefits. Therefore, this study reviews a few SCG valorization routes and their potential for the Stavanger region.

2.1 SCG Generation

Coffee grows in the form of cherries, it is mostly harvested in tropical countries like Brazil, Columbia, Vietnam India and many more. There are two widely popular techniques to make raw coffee from the coffee cherries, wet process, and dry process. Figure 3 shows the coffee life cycle from cherry to SCG.

Figure 3 *– Coffee processing stages*

In the wet process, ripe coffee cherries are first washed in the water and introduced to a de-pulping machine where coffee seeds are squeezed from cherries which produces mucilaginous beans and leaves coffee pulp as a waste residue to be further utilized in composting [20]. The mucilaginous beans are left for overnight fermentation to let beans break the mucilage layer on the outer skin. Later the degraded beans will be washed followed by drying and hulling process to produce the green beans [21]. The over fermentation and temperature should be controlled to avoid the alcoholic taste of the coffee [22].

The natural process, also known as the dry process, is the oldest and commonly used process to harvest coffee beans. Fully ripe coffee fruits are laid on the mesh beds to get dry, the mesh helps to circulate the air and provide uniformity to the drying process. The fermentation of the cherries starts instantly when they are picked up from the plant, and it gets accelerated when laid out in the sun. Continuous stirring and rotation of the cherries are required to avoid mould formation which could also affect the coffee taste [21]. Normally it takes around 3-4 weeks for the cherries to dry and reach a moisture content of 11% and this can be confirmed by a rattling sound when shaken in a fist. The temperature, humidity, ripe level of the cherries affects the flavor, color, and shape of the final dry beans. In the end, the dried cherries are passed into a hulling machine to separate the fruit and the parchment using friction and leaving coffee husk as the by-product [23]. Figure 4 provides a general scheme for coffee beans processing [24].

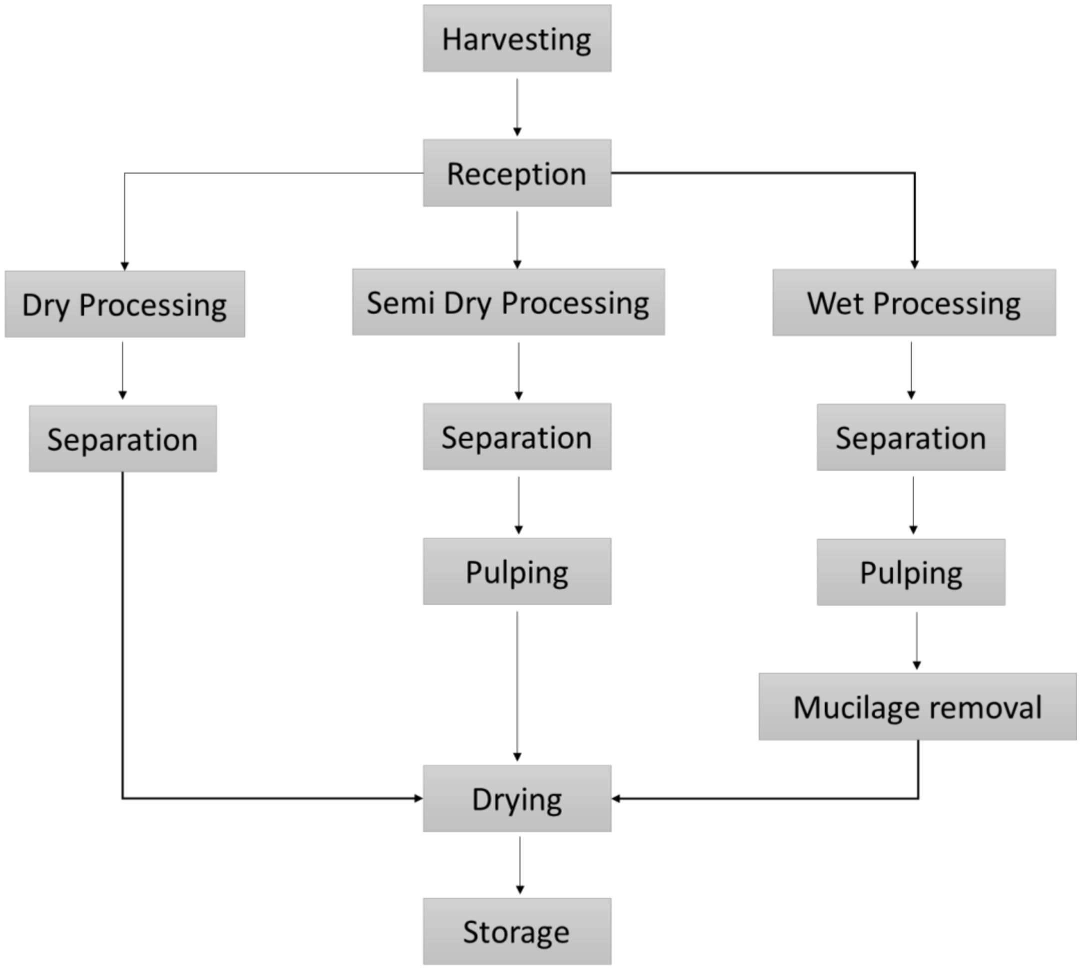

Figure 4 *– General flow diagram for coffee bean drying processes [21]*

2.2 SCG Composition

SCG is the by-product of the coffee beverage which when goes to landfill and decomposes releases tons of methane and greenhouse gases which is one of the reasons causing a hazard to the climate. This led the researchers to study the composition of the SCG and explore the possibility of utilizing it as a feedstock to the circular economy. Around 50% of SCG dry mass consists of organic compounds like polysaccharides like cellulose and hemicellulose. In hemicellulose sugar, primary components are mannose (46%), galactose (30.4%) and arabinose (3.8%) while in cellulose, glucose (19%) is the primary component [25][26]. Table 2 shows the amount of the components presents in SCG and their use. SCG also contains proteins, lipids, phenolic compounds and minerals like sodium, iron, calcium, zinc, copper, magnesium, potassium, manganese [26], [27]. Among all potassium being the most abundant contributing 40% [28] and the second being magnesium contributing 11% [29] and both produces a nutrition-rich soil fertilizer by using SCG in composting [30]. SCG also enhances the water holding capacity because of the higher packing density of the small particles [27] which helps in maintaining the moisture content in the composting.

SCG contains 9.3-16.2 wt% [31] of lipids which are a valuable feedstock in biodiesel production and can be extracted using Hexane as the solvents [32]. SCG from espresso and industrial soluble coffee contain 10-15% and 14-15.4% lipid content respectively [25]. Transesterification process can also be used to convert 15% oil in the SCG into biodiesel which leaves fuel pellets as the residue [26]. Extraction of higher oil production can be achieved by using non-polar solvents because when using the polar solvents a black gummy material is observed along with extracted oil which could be protein, carbohydrates and other compounds due to complex formation between degraded carbohydrate component and fatty acids [33]. Lignin along with other polysaccharides helps SCG to produce durable pellets by providing high adhesive and densification characteristics to the pellets [34].

The process of instant coffee uses boiling water which takes out the aromatic compounds and other minerals still leaving SCG as a valuable feedstock. For example, the abundance of polysaccharides in coffee beans are still available in large proportion in the SCG [35]. SCG is also rich in protein of about 13.6 (w/w) [35]. The protein content is determined by the presence of the nitrogen content which gets confused with the other nitrogen-containing compounds like caffeine, trigonelline, free amines [36]. Non-protein caffeine was observed to be in higher content in espresso [37]. High protein, moisture, high water holding are the favorable conditions for growing fungus which makes SCG a good feedstock to produce oyster mushrooms [38].

The composition of the SCG varies depending on the environmental condition where the coffee beans were harvested. The temperature is one the important factor while processing coffee cherries which can affect the moisture content in the coffee beans [35]. The later roasting process of the beans also changes the amount of minerals and other valuable extracted compositions.

Among various plant-based products SCG containing 19% phenolic compound is the reason behind the antioxidant, antibacterial, antiviral, anti-inflammatory, and anti-carcinogenic behavior [25]. The solid-liquid method is used to extract the phenolic content from the SCG with then a combination of water and a solvent. Isopropanol [39] solvent extracts 19%, methanol extracts the highest phenolic content with high antioxidant activity [29].

Table 2 – *SCG composition*

Components	Value	Use	Source
Cellulose (%)	41–43	Pulp, Paper Production, Ethanol, Butanol, Glycerol	[26]
Hemicellulose Mannose (%) Galactose (%) Glucose (%) Arabinose (%)	 37.03 31.90 24.08 6.99	Sugar, Pharmaceuticals, Food Industry	[27]
Lipids (%)	9–16 13 ± 0.04 13.7 ± 0.1	Glycerol, PHA, Biodiesel	[40] [41] [42]
Proteins (%)	13–17 4.9 ± 0.6 13.8 ± 0.1		[40] [41] [42]
Carbohydrates (%)	45–47 65.9 ± 6.5 54.1 ± 2.2		[40] [41] [42]
Moisture (Avg ± SD)	60.76 ± 0.04		[41]
Chlorogenic acids mg/g	1.8–5.6		[43]

2.3 SCG Valorization

There have been numerous studies around extracting valuable nutrients from the SCG and turn into high-value and environmentally sustainable products. Figure 5 shows some of the valorization routes for SCG including three routes selected for this study [17][19]. The literature available for the selected routes has been discussed in this chapter.

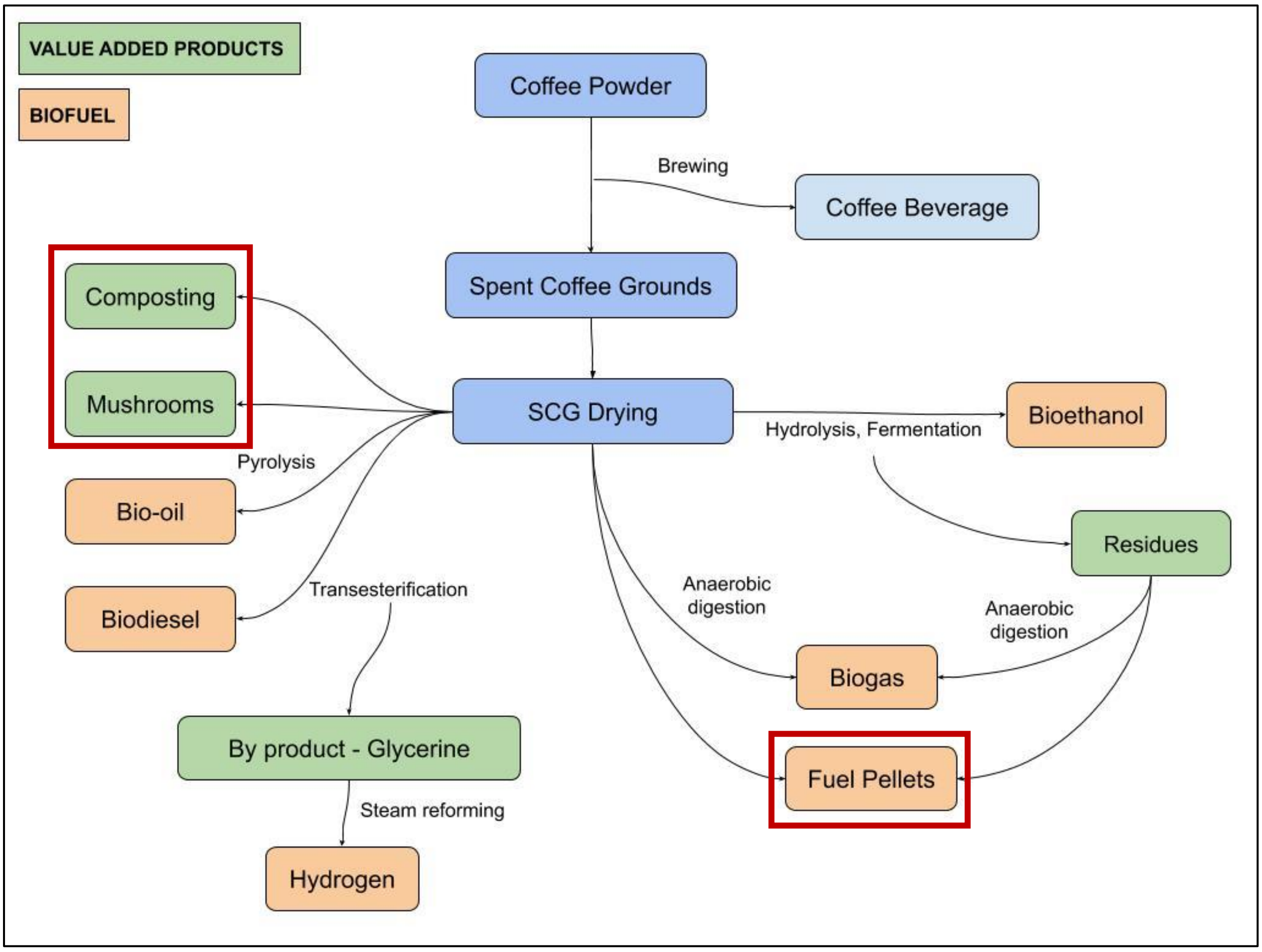

Figure 5 ***– SCG Valorization routes***

2.3.1 Industrial composting

Composting is a process of breaking down organic material in a biodegradable waste to transform into a product that can be used for soil nourishment purpose [44]. Composting has been a quite common alternative to landfilling and considered nowadays as a popular fertilizer alternative in the growth of the plants due to its rich in minerals properties. SCG being available in industry scale volume is a better option for organic farming after composting [45]. Furthermore, it will help to reduce the total SCG going to landfill and utilizing its remaining nutrients.

Along with useful minerals, the presence of caffeine and phenolic compounds makes SCG toxic for the plants [32]. This encourages SCG for composting which not only reduce the content of phototoxic compounds which are the reason for its toxic nature but also enhances its mineral contents [46]. However, SCG also contains cellulose, hemicellulose and lignin which resist degradation. They can also further degrade by using extracellular enzymes mostly produced by the microorganisms or by using fungi which will also increase the water-holding capacity of the compost [47][48].

Another reason for the increase in the water holding capacity of the compost is the presence of dietary fibers in SCG which causes higher packing density of smaller fiber particles and consequently increasing the surface area to absorb more water [39]. These encourage approaches like vermicomposting and co-composting which hints the possibility to degrade cellulose, hemicellulose, and lignin. Compost will be considered as stable when Carbon to Nitrogen ratio is less than 25:1 [30]. Therefore, the composting process should include a balanced amount of both green and brown waste material to have good compost quality. Brown composts material are the ones that are carbon-rich such as straw, paper, wood branches, etc. Whereas green compost materials are nitrogen-rich such as Coffee grounds, grass, animal manure, etc. Therefore, SCG is never composted alone.

There are three types of composting methods that are used typically: aerobic, anaerobic, and vermicomposting. Aerobic as done in presence of air (oxygen), whereas in anaerobic decomposition microorganism does not need oxygen to survive. Vermicomposting uses worms, oxygen, and moisture for safely decomposing organic material. Figure 6 shows the general composting process with raw materials, byproducts, and finished product components [50].

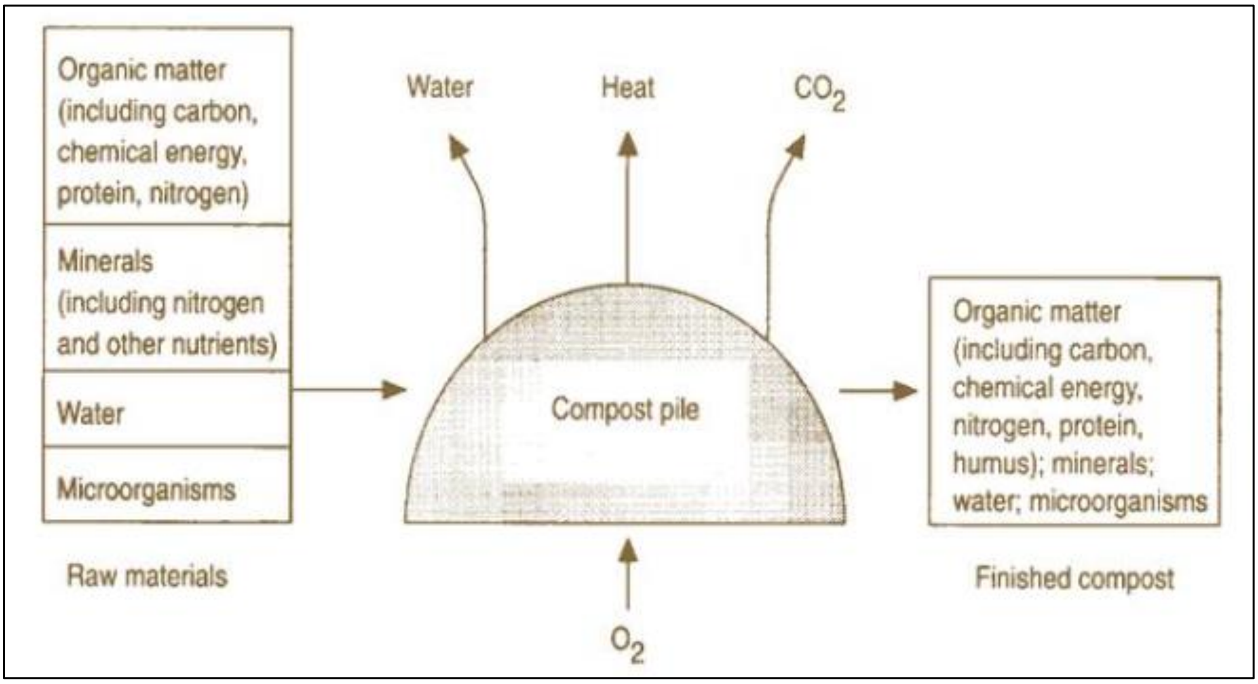

Figure 6 *– Typical composting process [50]*

Following are some of the methods that are available in open literature related to SCG composting:

1. **Mechanical In-vessel Composting** – A compost was made by mixing Spent coffee grounds and Coffee Filters with tiny pieces of a cardboard box in a 10:1 ratio. The size of cardboard was reduced to the of range 2–3 cm using hand. Additional water was added until the moisture content of the compost reaches 60%. The initial compost was kept for 47 days in the vessel while continuously stirred at the speed of 5 rpm. Furthermore, a fan is used on the cover of the vessel to maintain the moisture content. Also, the moisture content is observed every 7 days and maintained at 60%. The temperature is monitored in various places in the compost by using the sensors [30]. Temperature plays a vital role to make the quality compost and the variation in the temperature implies the microbial activity in the compost [51]. The sudden increase in the temperature is the result of microbial growth caused by the degradation of labile Carbon. The thermophilic period also known as the high-temperature period doesn't last long because of the continuous mixing of the compost [52]. This method does not see any marginal increase in the phosphorous and potassium content in the final compost. As potassium and phosphorous are non-volatile substances and their increase in the final compost suggest the overall loss of Carbon and volatile substance content during the degradation of the substrate. Therefore, this suggests that the In-vessel composting is not producing the final compost more efficiently.

   Advantages:

   - Faster decomposition of organic matter.
   - Greater control over maintaining temperature.

2. **Aerated State Pile Composting** – This method study randomly two types of a mixture to compost wet mass. The first mixture consists of spent coffee and coffee filters (SCF) and second consist of spent coffee, filter, and cardboard (SCFC). The wet mass used for SCF and SCFC is 650 kg and 800 kg, respectively. This time cardboard was grinded using a mixer instead of using hands because of its generous size. Moisture content is monitored and maintained to 60%. The compost bin used in this method is open, so the surrounding temperature is monitored to study the effect on composting. Samples were observed and taken from various places in the compost weekly until the 56th day. The final sample was

taken after 98 days [30]. Unlike In-vessel composting, state pile composting retains thermophilic period for a longer duration due to the larger volume and controlled C:N balance of the mixture. Also, the higher surface area of the SCG increases the degradation process of the substrate [53]. There was an increase in the concentration of the nutrients in the final sample by 1.5 and 2 times. SCF mixture observed a much more increase in the concentration of K than SCFC. Potassium concentration was 0.23% higher in final compost compared to 0.11% for SCFC [30]. Potassium and phosphorous are important nutrients in the growth of plants and hence are favorable for fertilizers and increase in their content in the final compost makes this method to be considered for composting [54][55].

Advantage:

- Minimum effort in maintaining the feedstock.

Disadvantage:

- Duration of the composting process takes 6–12 months for best results.

3. **Vermicomposting** – This method studies four mixture (1) spent coffee, (2) spent coffee and filter, (3) spent coffee and cardboard and (4) spent coffee, filter, and cardboard. Again, the cardboard is shredded to small pieces of 2-3 cm. This composting method uses an earthworm *Eisenia fetida*, widely used in vermicomposting. A container of capacity 2L is used as a compost bin. A container filled with wet mass is then introduced by 20 earthworms of total weight 0.3 g to start the composting process. The sample was taken fortnightly to monitor moisture. The final sample was taken after 73 days [30]. An increase in K and P concentration remains constant across all the treatments [30]. An earthworm has a low survival rate and can be increased by mixing other feedstocks in the wet mass [56]. In this study, the first sample with the only SCG shows the low survival rate of the earthworms while the addition of cardboard box increases its survival rate and biomass production [57]. Research by [58] suggests the presence of high ammonia, low oxygen content majorly during the early stage of the degradation are the reason behind the low survival rate of the earthworm. The use of cardboard here reduces the ammonia content and increases the pH and C:N and therefore increasing the survival rate.

Advantage:

- The help of another feedstock increases earthworm survival rate and gives better compost quality [49].

4. **Two-stage co-composting** – In this method Cow Dung (CD) and SCG are mixed at a different stage to enhance the duration of favorable conditions (thermophilic temperature, organic waste degradation) for better final compost. CD and SCG are used as the primary and secondary compost respectively [48]. A total of nine combinations of CD, SCG, and GW were used to study the effect on the quality of the final compost. At the first stage, CD is introduced in the Green Waste (GW) to attain the thermophilic temperature, when the temperature starts to decline, stage two is introduced where SCG was added to maintain the thermophilic period for a longer time duration [59]. The degradation rate of organic waste remains higher at stage one with CD than stage two where SCG was used [60]. Microbial degradation of organic matter causes a rise in temperature [61]. Treatment with a minimum ratio of CD and SCG hardly shows the degradation of organic matter which can be observed by its lower temperature. The presence of galactose, protein, glucose, arabinose, mannose, and phosphorus in SCG encourages microbial activity in the waste and fasten the degradation of organic waste [21]. Moisture content is maintained to 60% by adding water if required and the C/N ratio is controlled by adding urea [48]. At last microbial inoculant is sprayed evenly on all the nine combinations before starting the process [48]. Due to the soluble carbohydrates and high surface area of SCG, the mixture attains high temperature and higher degradation of the organic waste [48].

20% CD and 45% SCG considered the best combination in the two-stage composting enhances the release of nutrients and achieves the highest quality and stability of the final product [48]. The lower content of N also makes the final compost more suitable feedstock for the fertilizer. 20% CD and 45% SCG combination give the final compost in only 21 days [48].

Advantage:

- Longer duration of thermophilic period [49].
- Faster degradation of organic waste and gives final compost in only 21 days.

2.3.2 Fuel Pellets

Various human activities like the burning of fossil fuels, emission of greenhouse gases and deforestation are the many of the reason for climate change. Many governments are now taking initiatives to find an alternative source of energy, educating citizens about the benefits of recycling. The abundance of biowaste makes it a leading alternate source of energy. Recycling of biowaste could be an important step towards climate control and opening numerous opportunities to create a circular economy. SCG not only available in abundance amount for use but also has properties like high calorific value, low moisture content, high durability, and high ash melting point makes it the best feedstock for biomass energy. Therefore, adding SCG in the circular economy could solve problems many countries are facing in waste management [62].

SCG contains around 67% moisture content which affects the quality of the final fuel pellets. Higher moisture content reduces the calorific value and reduces the durability of the pellets hence resulting in tiny or broken pellets. Therefore, first, the SCG and SC are open dried until they reach 10% of moisture content [63].

We will discuss the potential of SCG in making fuel pellets and cover the feasibility of the coffee logs which could be an alternative for wood logs. The high calorific value of SCG makes it an important source for refuse-derived fuel (RDF) [34], however, pellets made from pure SCG are not exceptionally durable and energy-efficient, instead, they are responsible for NO emission in the environment. Therefore, various researchers found alternatives by making a combination of SCG with coffee silverskin (CS) or sawdust [64] which will not only reduce the toxic emission but also makes pellets durable.

1. SCG and sawdust – SCG and sawdust were mixed in an appropriate amount and introduced to the vertical pellets press to produce the fuel pellets [64]. The addition of sawdust in SCG pellets increases the combustion efficiency from 86.3% to 91.9% and boiler efficiency from 64% to 83.5%. Four samples were studied to find the ideal combination for producing pellets in the following SCG/sawdust ratios: 100% SCG, 50/50, 40/60, and 30/70 as shown in Figure 7 [64].

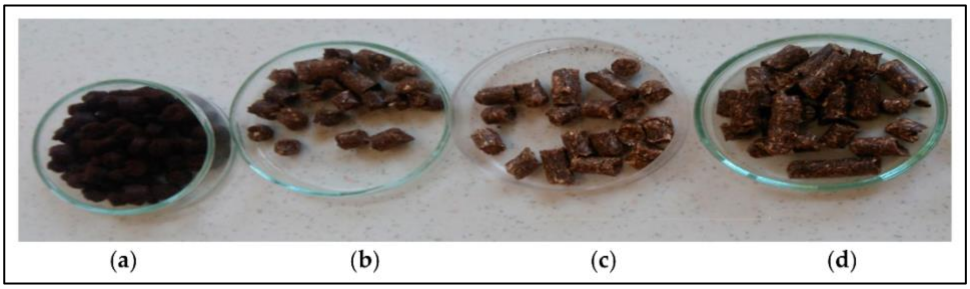

Figure 7 *– Samples (a) 100% SCG (b) 50/50 SCG/sawdust (c) 40/60 SCG/sawdust and (d) 30/70 SCG/sawdust [64]*

Pellets made from 100% SCG are the least durable and 30/70 SCG/sawdust ratios are the most durable. The moisture in the SCG has a profound impact on the density and the strength of the pellets [65] which can either dried up before palletization or can be maintained during the process of making pellets. The 100% SCG sample gives the lowest CO, which signifies the incomplete combustion and low pellet strength [64]. Sample with 40/60 and 30/70 SCG/sawdust gives similar emission as of wood pellets. From Table 3, we can conclude that the higher the combustion, higher the NO emission. However, pure SCG sample incomplete combustion provides noteworthy evidence of its lower durability.

Table 3 *– SCG and Sawdust combustion efficiency and gas emissions*

	Combustion efficiency (%)	Units	CO	NO	NO_2	Source
SCG	86.30	ppm	1785	178	28	[66]
		mg/Nm^3	3069	328	79	[66]
Sawdust	90.80	ppm	153	45	0	[66]
		mg/Nm^3	263	84	0	[66]

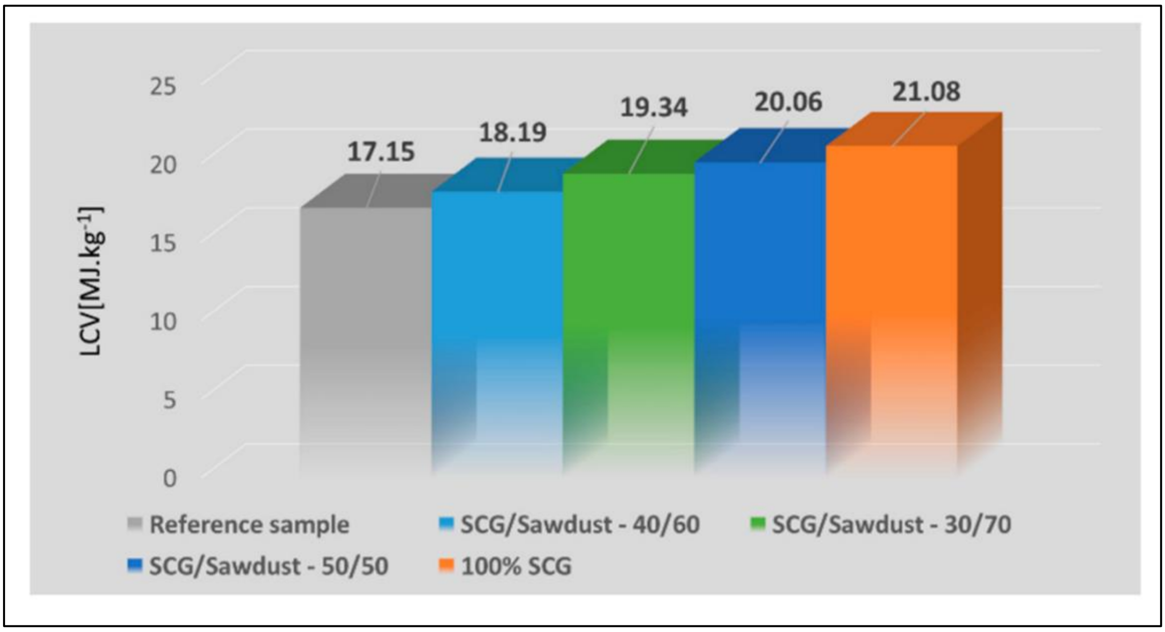

***Figure 8** – Lower Calorific Value of the samples [64]*

100% SCG also has the highest lower calorific value (LCV) among all the samples as shown in Figure 8 while a sample with 30/70 SCG/sawdust provides strength and stability to the pellets which last longer combustion and can achieve higher temperature for a considerable time. Therefore, 30/70 is the best combination of the raw materials feed into the pellet machine [64].

2. SCG and Coffee Silverskin (CS) – The coffee production process produces SCG and CS as the maximum waste [63]. SCG and CS are the residues of the brewing and roasting process [32]. CS enhances the density, durability, and combustion time of the SCG and therefore makes it a competitive additive to produce reduce derived fuel in the form of pellets. This method uses 5 samples of combinations of SCG and CS with 5% starch which acts as an adhesive. Table 4 compares the various properties for five different sample combinations.

CS has a denser structure means lower porosity which affects the compaction of the pellets unlike high porosity and low density of SCG [21]. High volatility and low moisture of CS produces faster combustion and lesser time to ignition of the SCG pellets. Lignin acts as a natural adhesive to provide exceptional reinforced structure to the pellets along with significant energy production compared to existing cellulose in the SCG. The high density of the pellets improves the storage efficiency and reduces the risk of broken pellets in transit and therefore maximizes the durability by 1.3 times [50]. Density and energy increase by 1-4 times with CS compared to pure SCG pellets [63]. CS has more Nitrogen content than SCG which requires a controlled amount of CS in SCG, sample 3 with 75% SCG and 20% CS is the perfect amount to use to produce pellets. Though mixing CS does not significantly improve the energy value but provides a longer duration of combustion, high stability, and durability to the pellets.

Table 4 – Comparison of different properties for various CS and SCG combinations

Parameters	Samples				
	1	2	3	4	5
SCG (%)	95	85	75	64	55
CS (%)	0	10	20	30	40
Starch (%)	5	5	5	5	5
Moisture (%)	13.9	13	12	11.2	10.3
Ash (%)	0.1	0.5	0.5	0.6	0.6
Density (kg/dm^3)	0.806	1.026	1.051	1.154	1.167
Durability (%)	84.7	95	99	91.2	95.9
Calorific Value (cal/ m^3)	4,018	4,803	4,855	5,001	4,957
Volatile (%)	85.5	85.7	86	86.1	86.8

Advantages of adding alternate biomass feedstock

- Higher calorific value.
- High density and durability of the pellets.
- High volatility and faster ignition.
- Longer duration of combustion.
- Energy saving in industrial palletization.

Production Process and materials

There are two ways to produce fuel pellets from the SCG. First, on a small scale by using a pelletization machine. Second, on an industrial scale as shown in Figure 9 where an infrastructure of various machinery will be required to set up that could perform various operations in the following sequence [67].

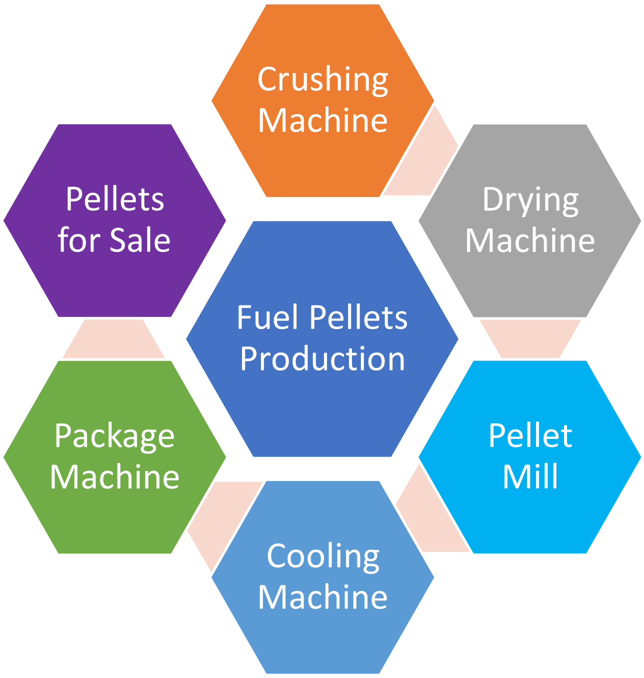

Figure 9 *– Pelletization production process*

1. **Crushing** – Raw materials will be crushed into tiny pieces providing effective compression and pelletization.
2. **Drying** – The crushed raw materials will pass into the drying machine through the conveyor belt where it will be dried to reach the required moisture content.
3. **Pelletization** – The dried material will go through the pelletizing machine consists of die and rollers which are responsible for changing the physical shape of the SCG mixture by implying the required force and transforming them into pellets. Physical qualities, durability, and density of the pellets depend on the optimization of this process. The elevated temperature during the pelletization provides natural adhesive and strong bonding of fibers and particles [68].
4. **Cooling** – The newly formed pellets allowed to cool which helps to avoid the cracking sticking to the packaging.
5. **Packaging** – Finally, the pelletized and cooled pellets will be packed into the bags followed by storage and delivery.

2.3.3 Oyster Mushroom Cultivation

Pleurotus ostreatus also called "oyster mushroom", "hiratake", "shimeji" or "houbitake" [69]. After *Agaricus bisporus*, the second most popular edible mushroom is *P. Ostreatus* [70]. Industrial waste containing lignin and cellulose is the potential source for mushroom cultivation. Not many microorganisms are capable of degrading lignin except white fungi which grew with an ability to efficiently degrade the lignin into CO_2 because of its high oxidative behavior and low substrate specificity of ligninolytic enzymes [71]. The reason for effective degradation involves mycelial growth nature that allows the fungus to transport scarce nutrients such as nitrogen and iron, to a distance into the nutrient-poor lignocellulosic substrate that constitutes its carbon source [72]. The presence of lignin, cellulose, and hemicellulose creates SCG as a potential feedstock to produce *P. Ostreatus* [73]. In the study [70], the substrate used for the cultivation is efficient with only pasteurization, sterilization is not a requirement. Cultivation of mushrooms consists of four phases; substrate preparation, inoculation, incubation, and fruiting [70].

This study will elaborate on the cultivation of oyster mushrooms on a small and large scale by using pure SCG and SCG + sawdust.

1. **Small or laboratory scale**
   - **Prepare substrate** – Various combinations of sawdust and SCG were used to create the multiple substrate samples. The raw materials, SCG, and sawdust were first dried in the oven at 60 °C followed by pasteurization. The samples were heated until the moisture content reaches 65% (w/w) [70].
   - **Inoculation** – After pasteurization, the samples were filled into the micro containers with an available air filter in the lid. While spawning, supplements are added to increase the size and quality of the mushroom [70]. The supplements should be in a controlled amount unless it could overheat the substrates. The substrate will then be inoculated with 7-day old *P. Ostreatus* mycelium in the dark for a month.
   - **Incubation** – The substrate mixture is now filled into the micro containers and kept in a dark room maintaining 25 °C where it goes to incubation for 28-30 days. Fungal colonization will then be observed with a change of some SCG substrate color to white.
   - **Cultivation** – After the incubation period, the samples will be moved to a spacious room with favorable conditions like adequate lights, maintained moisture and temperature, and kept up to 3-4 weeks until the formation of

mushroom starts. The samples were taken every 3 days to analyze cultivation progress [70].

- **Harvesting** – When the mushroom grows out of the box, they become ready for harvesting.

2. **Industrial scale**

A large amount of spent coffee grounds needs to be collected which should be used within 3 days of its collection to achieve better quality mushrooms [70]. It uses a similar approach and methodology as laboratory-scale production. Therefore, we will only be discussing the additional work and the differences. On an industrial scale, there will be the use of large containers with air filters lid or big plastic bags with tiny holes in them [70]. At the inoculation stage, an additional lime/gypsum mixture will be added along with a 7-day old *P. Ostreatus* mycelium to enhance cultivation [70]. After fungal colonization of the large containers, they will be moved to the cropping room where further fruiting will be done.

Caffeine and caffeine metabolites were found in the fruiting bodies which explain the oyster mushroom can extract caffeine from the substrate provided. The mushroom cap from the sample with 25% SCG and 75% sawdust contains the least amount of caffeine. During the final stage, caffeine was degraded however, it was found in a significant amount in the substrate after the incubation period. This suggests the role of mycelium in extracting caffeine from the substrate [70]. Consuming 250 kg of fresh oyster mushroom would contain the caffeine equivalent to one cup of espresso coffee, and therefore an extremely minimal impact on health as well [74].

Challenges and Remedies

- Unfavorable conditions like moisture, temperature, and light can cause unsuitable substrate and hence the failure of mycelium formation. Proper pasteurization, inoculation, and the uncontaminated substrate can resolve the mycelium failure [70].
- Uneven mycelium gets developed if excess CO_2, fast pasteurization, and mycelium are irregularly distributed in the substrate.

- Slow or delay mushrooming when there is a fault in the ventilation or there is bacteria formation.
- Long legs and small caps mushrooms can be formed if there is excess or limited exposure to light [70].
- Mushrooms produced in high humidity will be damaged or in a fast-decaying state. Idle ventilation, frequent monitoring of the storage humidity will improve the mushroom quality [70].
- Unhealthy spawn, rapid change in weather, size of the opening can cause a small and substantial number of unhealthy mushrooms [70].
- Water shortage, early or late harvesting of too wet mushroom will produce lightweight and speedy decay mushroom.

Chapter 3: Methodology and approach

3.1 SCG generation potential

The initial approach is to estimate the SCG generation potential in the Stavanger region. Therefore, I grouped various SCG generation sources into three groups. These groups are primary sources that generate SCG on regular basis and therefore can be considered for collecting SCG related data:

Group 1: Coffee shops and restaurants

Group 2: Organizations/Offices/Facility providers/Hotels/Catering/Gas station shops

Group 3: Home/Private users

Three different approaches have been used to estimate the SCG generation potential for the above groups for the Stavanger region as shown in Figure 10.

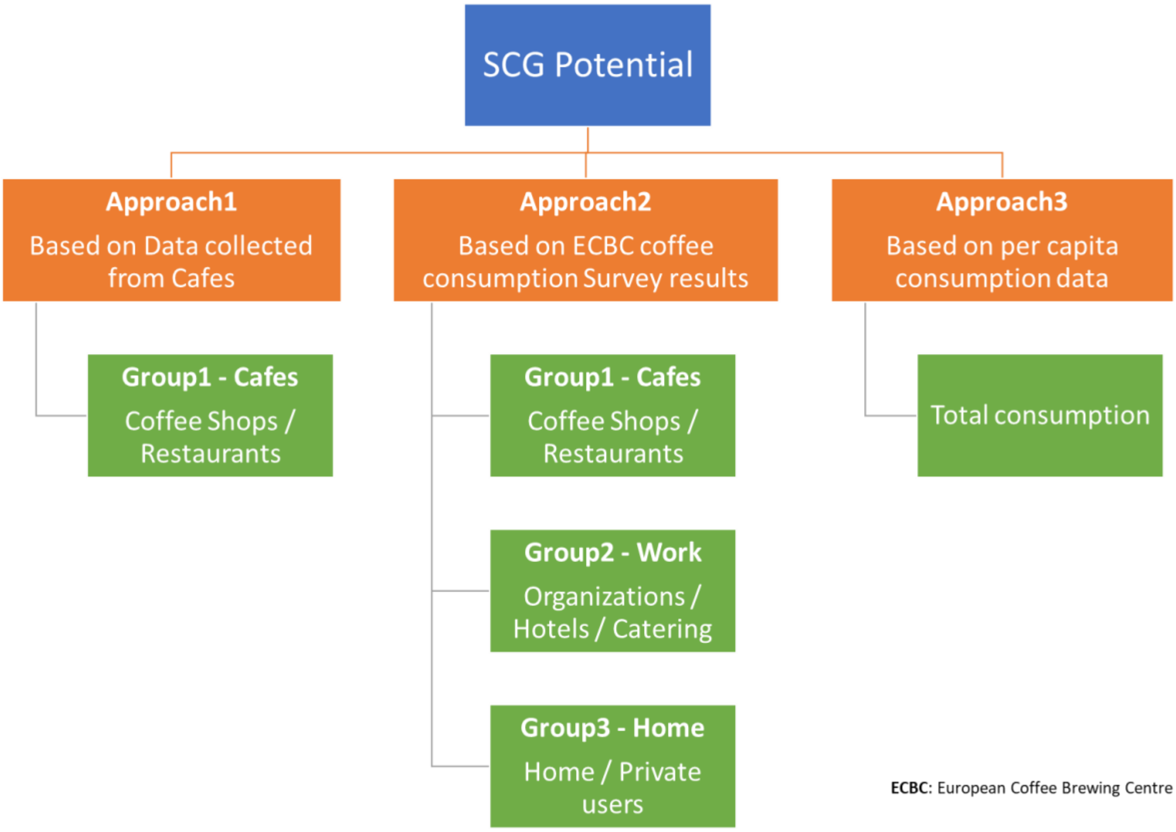

Figure 10 ***–*** *SCG generation sources and different approaches to estimate potential*

Approach 1: Field Data

A survey with a set of questions has been run to different cafes/restaurants and facility providers in the region. The list of the surveyed coffee shops and restaurants are attached as Appendix 1 – List of cafes/restaurants. Data collected from the survey are attached as Appendix 2 – Survey results. The data related to Coffee consumption in UiS has been provided by [76]. The coffee supplier for the UiS canteen and cafes are Lyreco AS and Waterlogic AS.

The survey data are available from only 17 cafes that decrease the probability of obtaining a representative overall estimate for SCG generation in the Stavanger area for group 1 (Cafes/Restaurants). SCG generation has been linearly extrapolated based on available data to estimate total SCG from the Stavanger region.

Based on the available data from 17 coffee shops and restaurants, the total amount of SCG generation is approx. 50 kg and about 1950 cups of coffee per day. Therefore, on average 3 kg SCG per day per source. The region seems to have approx. 50 - 70 active cafes and restaurants. Therefore, the estimated SCG generation is in the range of 150 – 210 kg per day. Table 5 summarizes the SCG generation data for the region from Group 1.

Table 5 *– SCG generation potential in the Stavanger region*

Region – Stavanger	Stavanger, Sandnes, Sola, and Randaberg municipality
No. of cafes/Restaurants	50 – 70 approx.
SCG generation	3 kg per day per cafe
Total estimated SCG	150 – 210 kg/day
	4500 – 6300 kg/month
	54000 – 75600 kg/year

From group 2, few coffee suppliers and facility service providers have been reached such as Lyreco & Waterlogic (UiS coffee suppliers), Compass Group – Eurest, Wilberg AS, Fazorfoods, and Toma. However, data from only UiS suppliers are available so far. The total amount of coffee purchased by the UiS in 2018 was approx. 3000 kg and there is no substantial change to that year on year [76]. However, group 2 is the biggest consumer of coffee, and therefore, data has not been extrapolated in this approach due to just one sample data available. Estimation would require the number of organizations or data from all the coffee suppliers to different organizations that can be grouped to estimate the total SCG generation potential. Furthermore, group 3 is also quite large to collect any meaningful data and extrapolate using this approach. Therefore, data from this group has been estimated in the other approaches.

Approach 2: Survey Data

According to recent survey results summarized by the European Coffee Brewing Centre, 44% of the coffee is consumed at home (Group 3), and 26% at work (Group 2) [77]. Table 6 summarizes the coffee consumption in Norway based on data available in the survey.

Table 6 *– Coffee consumption in Norway using approach 2 - survey data*

Total coffee imported in Norway, 2019 [9][10]	47,000,000 kg
Coffee consumed at work	47,000,000 * 0.26 = 12,220,000 kg

Coffee consumed at home	47,000,000 * 0.44 = 20,680,000 kg
Coffee consumed - Other	47,000,000 *0.3 = 14,100,000 kg
Stavanger population, 2019 [11]	228287
Norway population, 2019 [75]	5367580
% of the population in Stavanger	Approx. 4.2%

Assuming a life expectancy of 80 years, and four groups of 20 years each such as 0-20 years, 20-40, 40-60, and 60-80 years with equal population distribution. It is assumed that the major coffee drinking population age is 15-70 years range. Therefore, 68.7% (55/80*100) of the current Stavanger population is an active coffee drinker range. However, out of that 68.7%, it can be safely assumed that not everyone drinks coffee. Considering that only 70% of people from that range drinks coffee, therefore, actual coffee drinker population in Stavanger is estimated as: 4.2%*0.68*0.7 = 2%

Table 7 therefore, summarizes coffee consumption for the Stavanger region.

Table 7 – Coffee consumption in the Stavanger region using approach 2 – survey data

Coffee consumed at work in Stavanger region	12,220,000*2/100 = **244,400 kg**
Coffee consumed at home in Stavanger region	20,680,000*2/100 = **413,600 kg**
Coffee consumer – rest in Stavanger region	14,100,000*2/100 = **282,000 kg**
Total SCG generation potential in the region	**940,000 kg** per year

Approach 3: Per Capita Consumption Data

In this approach, the estimate is based on coffee consumption data available per capita [9]. In 2019, the average annual per capita coffee consumption is 8.8 kg [9].

Therefore, total SCG generation potential based on this for the Stavanger region would be:

= 228287 (Stavanger population) * 8.8 (Per capita coffee consumption in Norway)

= **2,008,926 kg** per annum

This results in approx. **2 thousand tonnes** of SCG from the region per year. The total imported coffee is 47 thousand tonnes, therefore, it is approx. 4.25% of the total imported coffee.

3.2 SCG management and disposal practices

Acquisition

One of the biggest challenges for SCG valorization is the efficient and economical collection of wet SCG from various sources [16]. There is an enormous potential for SCG generation in the Stavanger region, however, collecting this all is not practical in the short-term. It relies on numerous factors such as population density, the amount produced, available collection services, energy consumption for transporting to a local processing facility, and location of SCG sources [16]. Furthermore, businesses and community interest to participate in clean segregation of SCG at source and providing for free are also equally important [16].

Based on survey results in Appendix 2 – Survey results, it is observed that currently most of the SCG is dumped as waste along with the common organic waste. SCG is partially collected by local farmers for use as a fertilizer. As a result, most of it is not segregated at the source and therefore, requires an initial investment to properly segregate SCG at the source itself. The local municipality can work with local organizations to promote clean SCG segregation at source. There is no information in open literature showing any SCG collection initiative or company to do that in the Stavanger region. Recently, an organization "Topp Sopp"[4] in Stavanger area is utilizing SCG to produce mushrooms. In Oslo, a non-profit organization "Gruten AS"[5] has been actively collecting SCG from partner coffee shops and organizations. Gruten AS has been utilizing SCG to create products such as Oyster mushrooms, and soaps.

A similar approach in the Stavanger region would require providing an SCG collection bin to selected entities and collect the SCG waste from them at regular intervals. According to survey results in Appendix 2 – Survey results, it is observed that not all the entities might be willing to give SCG for free. To keep the lowest possible start-up cost, it would be better to initially consider SCG collection from those entities that provide SCG for free assuming that they are provided with proper sorting, storage, and transportation facility. About 60% or more entities are likely to support the recycling of SCG. About 50% have shown some interest as

[4] https://www.toppsopp.no/

[5] https://www.gruten.no/bli-med/finn-kaffegrut

well in contributing to the waste collection box initiative. This would help bring down the sorting and storage cost of SCG partially.

Based on survey response for question no. 4, it can be safely assumed that 50% of the cafes/Restaurants might be willing to give away the SCG for free. This is a conservative assumption to account for uncertainty in SCG generation potential. The SCG estimate from Group1 is 54000 -75600 kg per year. Considering 50% of that would result in **2250 - 3150 kg per month** or **27000 – 37800 kg SCG per year** from Group1. In the longer term, this approach could be expanded to groups 2 and 3 entities. For group 2, it would be setting up an SCG collection bin in different organizations, factories, and hotels. For home users, the best approach would be to set up a common SCG collection box in public places such as grocery stores, nearby shopping centers, and few places in the city center area. after discussion with the local municipality. The local municipality can help promote the clean segregation of SCG at home and make people aware of separate SCG waste collection bins for each area.

Kaffe Bueno is Denmark partnered with collection companies to collect SCG for free if the amount generated per month is 300 kgs or more [78]. Nespresso has set up various recycling points as well as offers pickup for facilities that are consuming 2500 or more coffee capsules per month. They separate the coffee grounds from the capsules and deliver it to the Norsk Matretur at Lørenskog for biogas production [79]. Various UK-based waste recycling companies (E.g. "Paper Round"[6], "First Mile"[7], and The Coffee Recycling Co.[8]) allows companies to set-up coffee recycling tailored to their individual needs. This includes providing them with different waste collection bins such as wheeled bins, caddies, and kerbside sacks. The waste is collected at the desired frequency and delivered to Bio-Bean storage factory for creating bio-fuels [80][81].

Similar arrangements can be made with coffee suppliers to collect it and deliver the wet SCG to a central storage place. The government can provide such events through subsidies or other incentives to coffee suppliers. This will help to recover most SCG from all the sources at a lower cost and therefore promote a circular economy.

[6] https://www.paper-round.co.uk/service/coffee-recycling
[7] https://thefirstmile.co.uk/service/coffee-ground-recycling
[8] https://werecycle.coffee/

Storage and Transportation

The SCG collection bin will provide temporary storage at the source. However, once acquired from the source, it needs to be transported to the storage facility for further treatment. Figure 11 shows the typical SCG acquisition and storage schematic.

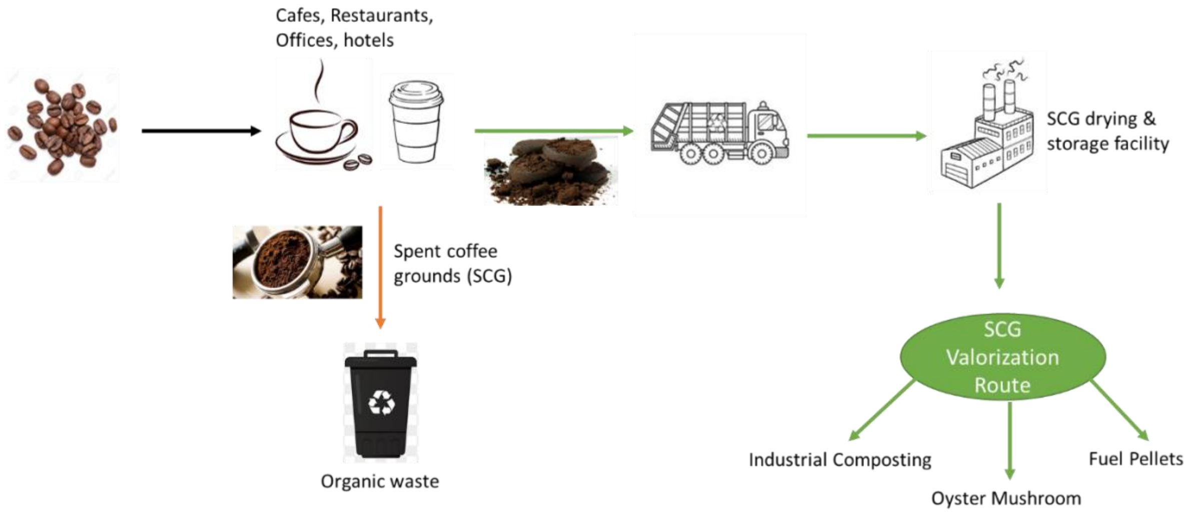

Figure 11 *– SCG acquisition and storage*

On small scale, the waste can be collected by driving to different cafes and restaurants once a week. However, valorization routes such as oyster mushroom would require fresh SCG collected within 24-48 hours [82][83]. Keeping the SCG longer than that would increase the chances of contamination due to the growth of mould [82][83]. Therefore, scaling up the business would require collaboration with local waste collection agencies for frequent collection. One such example is UK based company "BioBean" that has been partnering with various local waste recycling companies [81]. The economics of the collection process will be reviewed later in this chapter.

It is estimated that 1 kg of instant coffee is expected to generate around 2 kg of wet SCG due to the presence of the moisture content in it [16]. Therefore, the collected waste would require substantial drying for most of the valorization routes except the Oyster mushroom and composting. The wet SCG needs to be dried first at the processing facility after arrival to remove the moisture content and safely storing it for longer periods. The presence of moisture can contaminate the wet SCG due to microbial growth. Therefore, the wet SCG should go through the drying oven method at 105 °C for 24 hrs to inhibit the microbial growth [84]. The dried SCG then can be sealed in airtight containers or bags and refrigerated until ready to be consumed for further processing. The pre-treated SCG can be stored safely for a year or two without any degradation in properties. However, the pre-processing would add extra costs to those valorization routes.

[84] has compared three different drying processes for the removal of moisture from SCG. The three processes compared are oven drying, open-air sun drying, and solar drying. The results concluded that the open-air sun drying would take about 10 hours to reach the final moisture content of 37%, whereas the solar dying process produced SCG with 10% moisture content for the same time duration. The oven-drying needed about 6 hours to reach the final SCG with 7% moisture content. The temperature in the oven dryer and the solar dryer was about 75 ◦C [84]. Open-air and solar drying is not the best option for the Stavanger region due to the local weather all year round. The local weather is mostly cloudy with high humidity and therefore, the applicability of open-air and solar drying is very limited.

3.3 Potential valorization routes

Figure 12 shows the waste treatments that have been used in Norway over the years [85]. As incineration, recycling, and landfill are the three main methods used for waste management. Incineration and recycling help reducing the amount of waste that goes for landfilling. Landfilling of organic matter will generate many toxic and greenhouse gases, however, generated gases (e.g. methane) are now collected and used for energy generation.

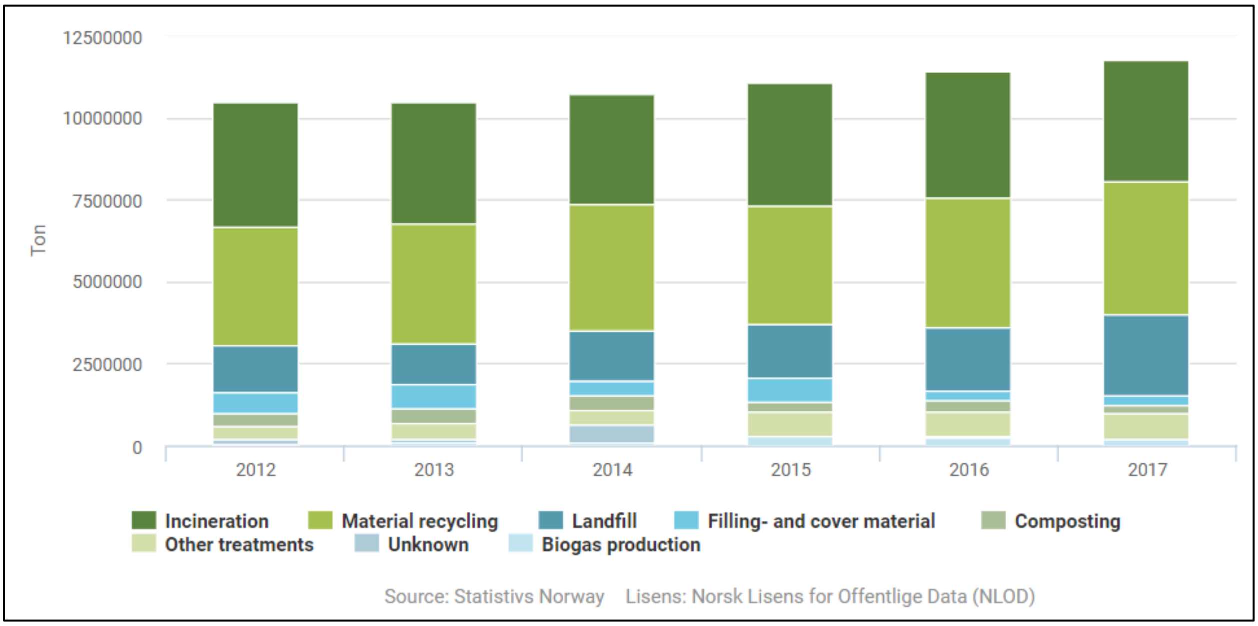

Figure 12 *– Waste treatment in Norway [85]*

For SCG, there are multiple valorization routes with value-added products that are covered in Figure 5. However, for the scope of this study only three key valorization routes have been considered based on the criteria given below:

- Small scale and easy to implement.
- Minimal or no additional environmental impact by new re-usable products.
- Economically feasible even at lower SCG generation level.

The routes selected are industrial composting, fuel pallets/logs, and oyster mushrooms. Some of the selected routes are also commercially used in various places around the world for marketable products and summarized in Table 8 below:

Table 8 *– SCG used commercially for marketable products*

	Company	Country	Products	Reference
1	Gruten AS	Norway, Oslo	Soap, body scrubs, mushroom cultivation set, cups	[86]
2	Kaffe Bueno ApS.	Denmark	Oil, flour, cosmetic raw material	[87]
3	Bio-bean	UK, London	Coffee logs, biomass pellets, biodiesel, and biochemicals	[16]
4	LifeCykel	Australia, Melbourne	Mushrooms	[16]
5	Recyworks	Greece, Athens	Mushrooms	[16]
6	GroCycle	UK, Devon	Mushrooms	[16]
7	Green Cup Ltd	UK, London	Garden products (soil conditioners) and Çurface[9] for furniture	[16]
8	Blanc de Gris	Canada, Montreal	Mushrooms	[16]
9	Pine Mountain Hearthmark	USA	Java log	[16]
10	S.Café®		Fabric yarn	[88]

[9] Çurface is a special material made for interior surfaces and panels.

11	EcoBean	Warsaw, Poland	Coffee briquettes	[96]
12	Topp Sopp	Stavanger, Norway	Mushrooms	[89]
13	Beyond Coffee	Copenhagen, Denmark	Mushrooms	[90]
14	Helsieni	Helsinki, Finland	Mushrooms	[91]

3.4 Technical feasibility

3.4.1 Oyster mushroom

SCG is used as one of the substrates for the cultivation of oyster mushroom [92]. The method has been used in both developed as well as developing countries for the easy valorization of SCG as well as generating income from low initial investments. The oyster mushroom is cultivated in 3 key stages [92] as shown in Figure 13:

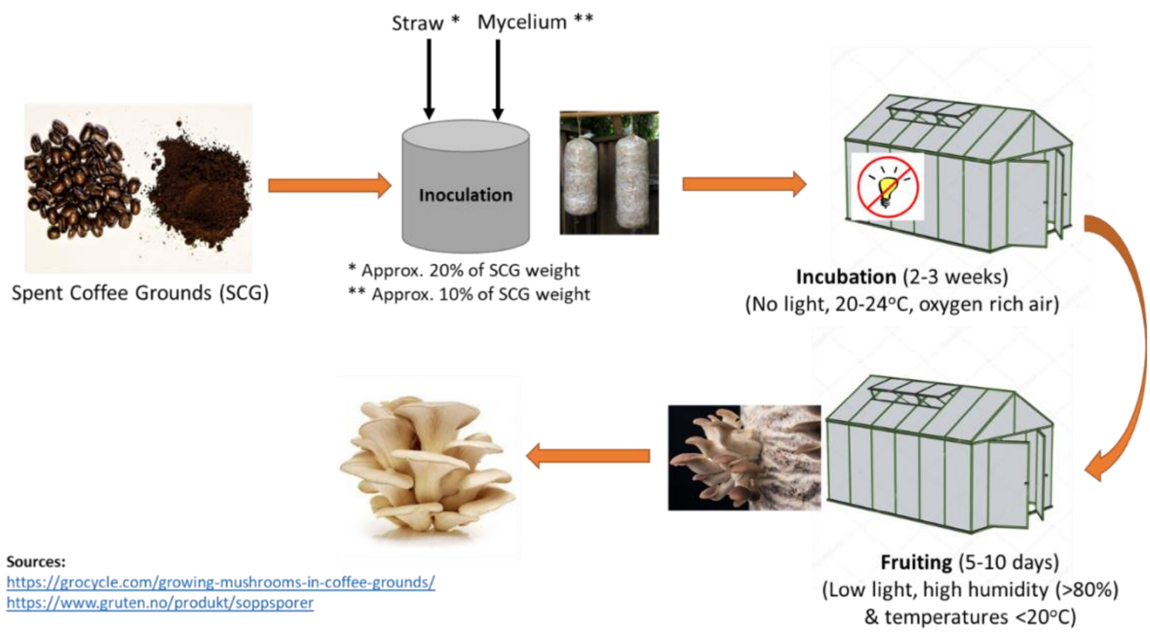

Figure 13 *– Oyster mushroom cultivation process*

Inoculation: In this stage, oyster mushroom spawns and substrate material such as SCG are mixed. Pasteurized straw or hydrated sawdust pellets are better to add if the SCG substrate quantity per bag is more than 1 Kg as that allows better airflow during the fruiting condition. It is important to use the fresh SCG that is brewed and collected in the last 24 hours as the mould starts growing thereafter and outcompete mycelium growth. The mixture is then transferred into cultivation bags with small holes of 0.5 mm and 10 cm apart or with an air filter in them for proper air exchange.

Incubation: The bags are placed in a dark room with a temperature around 20-24 ℃ for the incubation phase to begin. In the incubation phase, the spawns grow to colonize the whole substrate material creating white web-like threads called mycelium. The proper conditions in the room are important for substantial mycelium growth and to avoid other fungal or bacterial growth. The incubation lasts for 10-14 days.

Fruiting Phase: Once the bags are fully colonized by spawns, the fruiting phase starts. The bags are now exposed to fresh air, high humidity, low light, and low-temperature conditions. The oyster mushroom will start to emerge from the small holes in the bags after 5-7 days and ready to harvest when the top of the caps begins to flatten out.

The same bags can be harvested three times before it can be disposed of for further treatment or recycling. Here are some of the key advantages and disadvantages of this method are as below:

Advantages:

- Most applicable and economical at low to mid SCG volumes.
- Low initial investment cost since it requires a closed facility that can maintain a desired temperature and humidity.
- Takes about 3-5 weeks to harvest and about 7 weeks for 3 harvests.
- No need to pasteurize or sterilize the substrate as SCG is already pasteurized by the brewing process. Therefore, energy spent to pasteurize, and related equipment cost is saved.
- The SCG is easily available and most cases free of cost.
- High protein and nutrient source.
- Short production time and grown in a closed facility. Therefore, can be produced for all year.
- Jobs creation in the local community.

Disadvantages:

- Since fresh SCG collected within 24 hours is required, it is only applicable to local production and collecting from fewer facilities (low-mid volumes) as transporting and storing SCG for a longer time might contaminate it.
- Need high local demand as mushrooms will start decaying after a few days. Therefore, best to consume fresh oyster mushroom.
- Labor-intensive production process without any automated systems.

Considering the SCG availability of approx. 2250 - 3150 kg per month, this valorization route is technically viable. There are few suppliers in Norway or nearby countries that can provide the required spawns. The economics of this route has been discussed in 3.5.1.

3.4.2 Industrial composting

Composting can be used as the last step in extracting remaining nutrients after applying other valorization methods with coffee grounds. This would provide the maximum utilization of SCG. For example, utilize SCG to extract oil content and then use it for biogas, fuel pallets, or composting purpose. Composting can be done both at a small scale or an industrial scale. This study is focused on identifying how the coffee grounds can be used and their role in the composting process.

Based on the literature review in Chapter 2, the two-stage co-composting method seems to be the fastest to produce the compost in 21 days as well as providing the highest quality compost as well. Therefore, the co-composting method has been considered to check the technical viability of the Stavanger region. The method requires additional materials such as cow Dung, composter, microbial inoculant, and green waste in addition to SCG. Cow dung and green waste such as fallen leaves and plant branches can be collected from local farms. For approx. 3150 kg SCG per month, 1400 kg of cow dung (about 20%), and 2450 kg of green waste (about 35%) would be required based on literature review. A composter to accommodate a total of 7000 kg would be required. Depending on the cost and size of the composter available, the quantity of the raw material can be adjusted. Alternatively, instead of having one big composter, it is better to have multiple small composters to run the batch each week. SCG can be collected once a week along with other raw materials and therefore, storage of materials would not be necessary. The method, therefore, seems technically feasible for the Stavanger region.

This method has an advantage over the oyster mushroom method in terms of the collection as this requires only once a week trip whereas, for oyster mushroom, SCG needed to be collected end of each day and use the quantity next day.

3.4.3 Fuel pallets

Dried coffee grounds can be used as a fuel source for various industrial as well as home heating applications in the form of fuel pellets or logs. SCG pellets possess high energy content in the range of 19.3–24.913 MJ/kg [19] that is higher compared to wood pellets (9 -14 MJ/kg). Due to an increase in particle emission and decrease in burning efficiency [66], mixing SCG with pine sawdust (50/50 wt%) seems to yield desired results [64][66] related to emission. However as highlighted in Chapter 2, 30/70 (SCG/Sawdust) can be used as the best alternative considering pellets stability.

The generation of fuel pellets or coffee logs from SCG essentially requires dry SCG with a moisture content of about 10% for better storage and avoid mould growth. Dried SCG is then mixed with an additive such as glycerin for fuel pellets, wax, and molasses for coffee logs production. The SCG fuel pellets process has been shown by [93] that follows the oil extraction from SCG. Pelletizing and extracting oil content from SCG in the same facility makes the process economical due to two main products available for sale as well as glycerin generated as a byproduct that can be utilized for fuel pellets. However, oil extraction from SCG is not part of this study.

The fuel pellets are generated in four stages as summarized in Table 9 are drying wet SCG, pelletizing process, cooling process, and packing process. The requirement for raw material is very minimal with SCG is being used as the primary material listed in Table 10.

Table 9 *– Fuel pellet process stages*

Process	Equipment required	Comments
Drying	Oven dryer	Oven dry wet SCG to 10% or below moisture content. Typically, at 75°C for 6 or more hours [84]

Pelletizing	Pelletizer	To create SCG fuel pallets of the desired size
Cooling	Cooler	A counter flow cooler to avoid pellets surface cracking by cooling the hot pellets

Table 10 *– Feedstock for fuel pellet method*

Raw Material	Comment
Wet SCG	Collected only from free sources to reduce the raw material, transportation, as well as labor cost.
Glycerin [94]	Acts as a binding agent in addition to already present lignin in SCG.

Typically, pelletizer can process[10] from 500 kg/hr to 2000 kg/hr. However, the currently available volumes of SCG about 2250 - 3150 kg per month in the Stavanger region is quite low that can be processed within a few hours. Therefore, the generation of fuel pellets based on the current SCG amount may not be economically viable due to the low SCG volumes available in the initial phase. Furthermore, if SCG collection is extended to "work" and "other" group from approach 2 as well then total SCG available is about 44,000 kg/month or about 1500 kg/day. This amount is still not sufficient to operate the pelletizer at full efficiency.

3.5 Economic feasibility

Economic feasibility requires estimating capital expenditures (CAPEX) as well as operating expenses (OPEX). Capital expenses include the cost of land acquisition, site development, facility construction, and buying the required equipment [93]. Operating expenses include the cost of acquiring raw materials, transportation, storage of feedstock as well as end-product, the cost to market and sale of end products, labor, utilities, waste treatment & disposal, insurance, and local taxes [93]. Some of the operating cost is fixed irrespective of the amount produced whereas the other is variable and depends on the quantity of raw materials processed or product quantity produced.

Net present value (NPV)[11] is used as a financial indicator for techno-economic assessments to evaluate the project or investment worth over a period. Positive NPV shows

[10] https://wood-pellet-line.com/ring-die-wood-pellet-mill/
[11] https://www.investopedia.com/terms/n/npv.asp

that the project is financially worthwhile whereas negative NPV highlights the investment with a net loss. Calculating NPV would require investment amount, future cash flow, and a discount rate. A cash flow[12] is consists of various components related to revenues, and costs. Therefore, NPV as well as other financial indicators such as internal rate of return (IRR), and payback period have not been calculated in this study.

For this study, a simple profit calculation is performed. The unit contribution is first calculated to see if there is any profit per unit without accounting for the overhead costs. A positive % margin would be required to cover the overhead costs from the operation. A positive net profit is required for the valorization route to be economically feasible. Following are some of the equations used:

Unit Contribution[13] = Unit selling price – Variable cost (or cost per unit)

% Margin[11] = Unit contribution / Unit selling price

Total contribution = Unit contribution * total unit sold for the year

Net Profit = Total contribution – total overhead costs

3.5.1 Oyster mushroom

The price of Oyster mushroom (Østerssopp) is approximately in the range of NOK 100 – 255 per kg. It is available in Meny[14] grocery store for NOK 129/kg whereas Gruten AS in Oslo, and Topp Sopp in Stavanger sale them for about 255 and 250 NOK/kg, respectively. The price might vary slightly between different stores and in the local market. The price might also be affected by produced quality and taste. The demand for oyster mushrooms in restaurants and shops is not available as part of this study but it can be estimated based on a survey. According to survey results from Statista[15], oyster mushroom amounts to 3 million NOK of sales value in Norway in 2018. Therefore, the oyster mushroom sale is about 1.5% of the total mushroom sale in Norway in 2018[7].

[12] https://www.investopedia.com/investing/what-is-a-cash-flow-statement/
[13] https://www.investopedia.com/terms/c/contributionmargin.asp
[14] https://meny.no/varer/frukt-gront/sopp/sopp/osters-sopp-2000464900005
[15] https://www.statista.com/statistics/647629/total-sales-value-of-mushrooms-in-norway-by-type-of-mushroom/

Raw materials costs

1. **Wet SCG** = 0 (For the first phase, plan to collect SCG from cafes that provide for free).
2. **Pasteurized straw**. Amount of straw added to the substrate is about 20% of SCG weight [92]. Therefore, approximately, 3150 of SCG * 0.2 = 630 kg of straw would be required. Due to the unavailability of local straw cost, it has been ignored for this evaluation.
3. **Fungal mycelium** = 100 NOK for 500 grams and 190 NOK for 1 kg from Gruten AS [95]. Amount of mycelium added is about 10% of SCG weight [92]. Therefore, based on 3150 kg/month of SCG, approximately 315 kg of mycelium would be required. This would cost 315*190 = **59850 NOK**.

   The spawn cost is substantially high and may not be economical for this method. However, in the long term, it is recommended to have it grown locally or get a better deal for buying bulk quantity. This would reduce the cost substantially.

   If the direct bulk purchase from the supplier would reduce the cost by almost half, the new cost estimate would be 315*100 = **31500 NOK**
4. **Cultivation bags** (with filter) = 20 NOK for 1 large bag that holds 2 kg of the substrate (coffee grounds and mycelium) is available at Gruten AS[16] [95]. Therefore, to hold 4095 kg (3150+315+630) of substrate amount, approximately 2047 large bags are required. This would cost 2047*20 = 40950 NOK.

   This is another big expense that could be reduced by directly contracting with the main supplier and discounts on bulk purchases[17]. The new price of the bag is therefore assumed as 10 NOK. Since one crop can be harvested 3 times, the same quantity of bags will be reused. Therefore, their cost per cycle is (2047*10)/3 = **6823 NOK**.

Revenue per unit = **129 - 250 NOK/kg**

According to Gruten AS [95], total Oyster mushroom produced are approx. 20% in weight of substrate amount. Therefore, the total substrate of 4095 kg would generate about 819 kg of oyster mushroom.

Total revenue per month: 819 kg*129 or 250 NOK/kg= **105,651 – 204,750 NOK**

[16] Cultivation bag price: https://www.gruten.no/produkt/dyrkingsposer

[17] Cultivation bag types: https://cultivarhongos.com/en/sale-of-mushroom-grow-bags/

Unit contribution = 105651 – 59850 – 6823 = 38978 NOK or

= 204750 – 59850 – 6823 = 138,077 NOK

% Margin = (38978 / 105651) *100 = 37% or

= (138077/204750) *100 = 67%

% Margin range = **37% - 67%**

The above amount is to cover the overheads and capital expenses in addition to the profit. This cost includes labor, utility, lease on facility, administration, and interests. Therefore, the overall % margin would reduce, and net profit would go down. Below are some additional aspects to consider.

Facility: A facility with two large environmentally controlled areas is required to cultivate the mushrooms. Additionally, a separate room for preparing, mixing the substrate with mycelium, and transferring to bags, is required. An additional room to store the harvested mushroom with low temperature is also required.

Labor: Team of 2 people at least required to manage the entire process. One person would be dedicated to collect fresh SCG from various locations and transport it to the processing center. Also, deliver the harvested mushrooms to the sales point. The other person mainly to work through the 3 stages of mushroom production and managing the facility.

3.5.2 Industrial composting

Compost price can range from 100 – 500 NOK per m3 depending on quality. E.g., 1 m3 of compost cost about 490 NOK from Reve Compost[18]. whereas 1 m3 cost 100 NOK from the IVAR recycling plant[19]. Therefore, an average price of NOK 300 has been considered for the economic estimates. The data on compost produced for given raw materials could not be found in the literature. However, it is expected to have at least 60% of compost weight based on total weight. For the total amount of 7000 kg total waste, the expected compost mass is 4200 kg.

[18] Reve Compost: https://revekompost.no/salg-kompost/
[19] Ivar Plant compost: https://www.ivar.no/priser/

Assuming a compost density of about 600 kg/m3, the volume is about 7 m3. This would result in 300*7 = 2100 NOK. Therefore, the composting method is not very attractive economically as the cost to acquire raw materials, facility cost, labor cost will outweigh the cost of product sold. This is mainly due to the amount of time it takes to generate the final product.

3.5.3 Fuel pallets

The economic feasibility of SCG fuel pallets has not been discussed in detail since the feedstock volumes are quite low compared to typical processing quantities by a pelletizer. The cost components of this method are the acquisition of SCG, facility for storage, oven drying of SCG, cost of utility, cost of pelletizer, and feedstock cost for an additive such as glycerin, labor cost, and packing and material cost. The coffee ground fuel pellet cost for the local market is estimated to be in the range of 6 – 20 NOK per kg based on wood pellets value. Therefore, total revenue is in the range of NOK 18900 – 63000 per month based on 3150 kg/month SCG or 264,000 – 880,000 based on 44,000 kg/month SCG from approach 2.

Chapter 4: Results and discussion

Table 11 below lists the various results based on technical and economical parameters of all the methods considered in this study.

Table 11 *– Valorization methods results comparison and SWOT analysis*

Parameters	Oyster Mushroom	Industrial Composting	Fuel pellets or logs
SCG Amount	3150 kg/month	3150 kg/month	3150 kg/month
Price per unit	129 – 250 NOK/kg	100 - 500 NOK/m3	6 - 20 NOK/kg
Total Revenue (in NOK)	105651 – 204750/month	700 – 3500 NOK/month	18900 – 63000 NOK/month
Profitability	Small margins	Very small margins for small scale.	Could be profitable in long term but not enough SCG volumes in the Stavanger region.
Strengths	1. Technically not complex; can be used at small & large scale 2. Does not require any expensive equipment's or advanced facilities and therefore, less capital expenditure	1. Low capital and operating costs compared to other methods 2. An environmentally friendly product that helps improve soil quality	1. Technically straightforward process to produce fuel pellets & logs. 2. Varying throughput range 3. Higher heat energy compared to

	3. An environmentally friendly way to valorize SCG	3. Product suited for the local market 4. A technically straightforward process that requires low resources to manage.	conventional wood pellets 4. Environmentally sustainable as a replacement for wood pellets.
Weaknesses	1. SCG needs to be collected and used on daily basis otherwise possibility of feedstock contamination due to microorganism growth 2. Potential to sale in the local market only as transporting and storing mushrooms for more than few days loses its freshness and quality 3. Profitability depends on the cost of mycelium and local market demand. 4. Takes about 7 weeks to get end-product	1. Low compost volumes and therefore lower revenues. 2. Require an equal amount of brown compost material. 3. Takes about a month to get the compost ready. Therefore, requires bigger or multiple facilities to increase output.	1. Requires larger volumes of SCG to increase product output to maintain sufficient profit margins. 2. Requires oven drying of SCG locally as open-air and sun drying is not best suited locally due to cold and humid weather year-round.
Opportunities	1. Generate mycelium in-house to maintain or increase profits		1. Combine it with the extracting oil process to produce a bio-oil product for sale. 2. Useful is areas with decent sunlight and warmer temperatures that help naturally drying wet SCG and avoid drying costs.
Threats	1. Cost of mycelium and plastic bags for incubation 2. Not enough demand in the local market year around 3. Loss in production due to contaminated wet SCG	1. Low-cost fertilizers	1. Potential constraints due to local environmental regulations & laws. 2. Local market adoption of this new product compared to traditional wood logs or pellets.

			3. Seasonal demand can affect revenues during summertime
Byproducts	Used substrate for composting	CO2, Heat	
Environmental concerns	The used SCG can go into composting and plastic bags can be recycled		Release of particulate matter and ash content after burning
Possibility to scale up	This would require setting up additional facilities in a different location as transporting and storing longer would promote microbial growth.	Yes, from small scale to industrial scale	Yes, from small scale to large scale

Three valorization routes have been considered in this study based on their ease of implementation and potential to use at a small scale. Based on surveying different cafes in the Stavanger region, the SCG generation potential in the region is estimated on average 6300 kg/month. However, it is not expected to get SCG from all the sources for free since some of them provide them to local farmers or reuse it elsewhere. Therefore, an optimistic estimate would be about 3150 kg/month of wet SCG from local cafes and restaurants. According to [16], about 2 kg of wet SCG is obtained for each kg of soluble coffee produced. This would reduce the dry SCG amount to about 1575 Kg/month.

Both Oyster mushroom and composting methods would be used with wet SCG whereas the fuel pellets require drying SCG to reduce moisture content below 15%. All three methods are technically feasible with minimal capital expenditures. However, only the oyster mushroom method seem profitable with the SCG amounts available in the short-term. The three methods are environmentally sustainable leaving minimal to no adverse impact on the environment.

Chapter 5: Conclusions and recommendations

There has been growing interest in waste valorization lately due to environmental issues, pressing new laws and regulations, as well as promoting a circular economy. Coffee has been a popular drink throughout the world that generates a substantial amount of wet coffee grounds that create environmental concerns if dumped straight to landfill in addition to the lost value contained by coffee grounds. There have been various SCG valorization studies in the literature. However, three methods have been selected for this study.

The total SCG generation potential from three approaches ranges from 54 – 2000 tons/year. Based on the comparison in the results chapter, the Oyster mushroom method would be most appropriate at a small scale given that the mycelium and required bags are available at a discounted price (almost half the current price) from suppliers to make the process profitable. The profitability also depends on the demand for oyster mushrooms in the region. The profitability in the Stavanger region ranges from 37 – 67%. Fuel pellets are a better alternative given the SCG volumes collected are large enough. However, revenues can be affected if the home heating users make the biggest portion of product consumers since, in the summer, the requirement to heat home will go down substantially. Therefore, it is important to have local industries, and power plants as the consumer to maintain a constant demand. Composting does not seem a very attractive business for SCG valorization due to very low margins and longer duration for product generation. Also, it is difficult to highlight the substantial advantage over regular compost due to the addition of SCG.

Future recommendations are as follows:

- Collect SCG generation data from various facility service providers, offices, and organizations since they are the bigger consumer of coffee.
- Evaluate alternate valorization methods such as biofuel generation based on new total SCG estimates available from different source groups.
- Evaluate the local demand for products available from different SCG valorization routes such as oyster mushroom, fuel pellets, and coffee logs.
- Evaluate the detailed economic feasibility of the selected methods with different SCG volumes to estimate the break-even SCG volume.

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Appendices

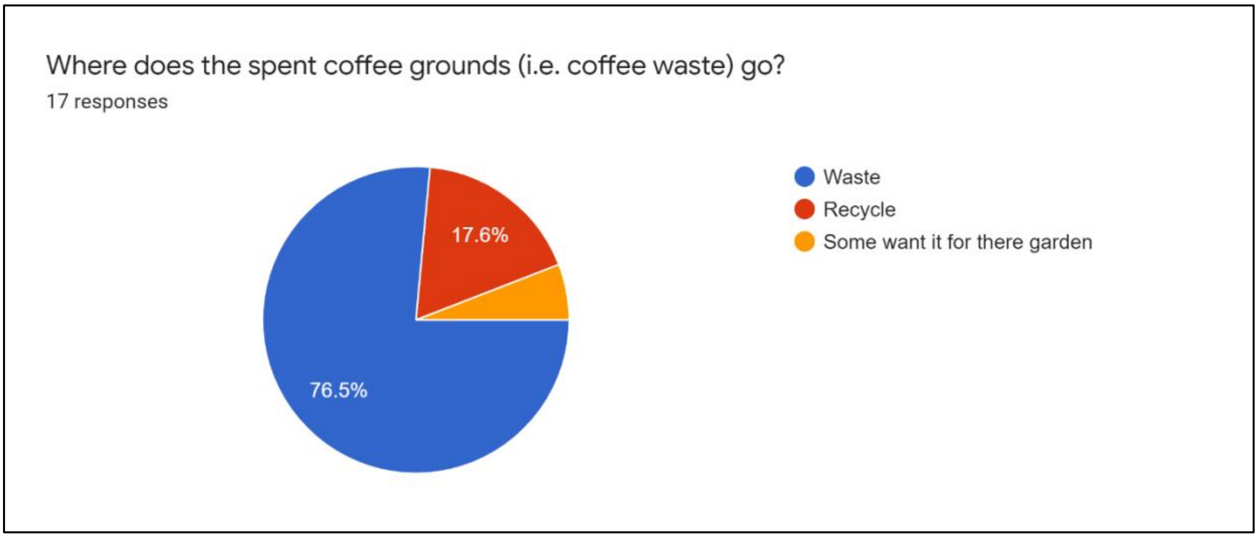
Appendix 1 – List of cafes/restaurants

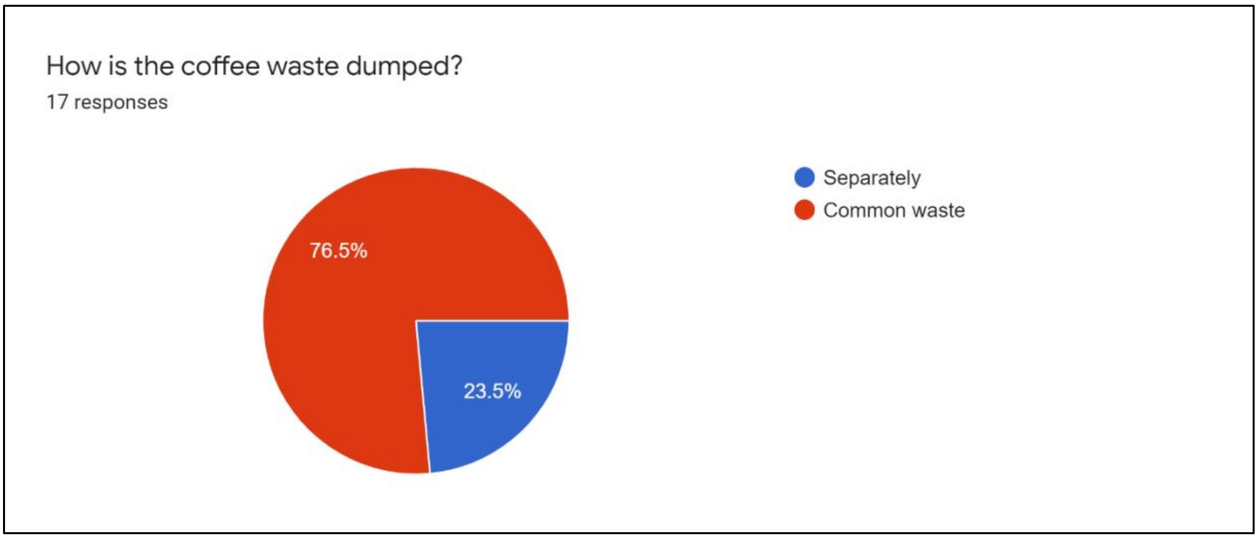
Cafes/restaurants that are surveyed to collect the data in Appendix 2.

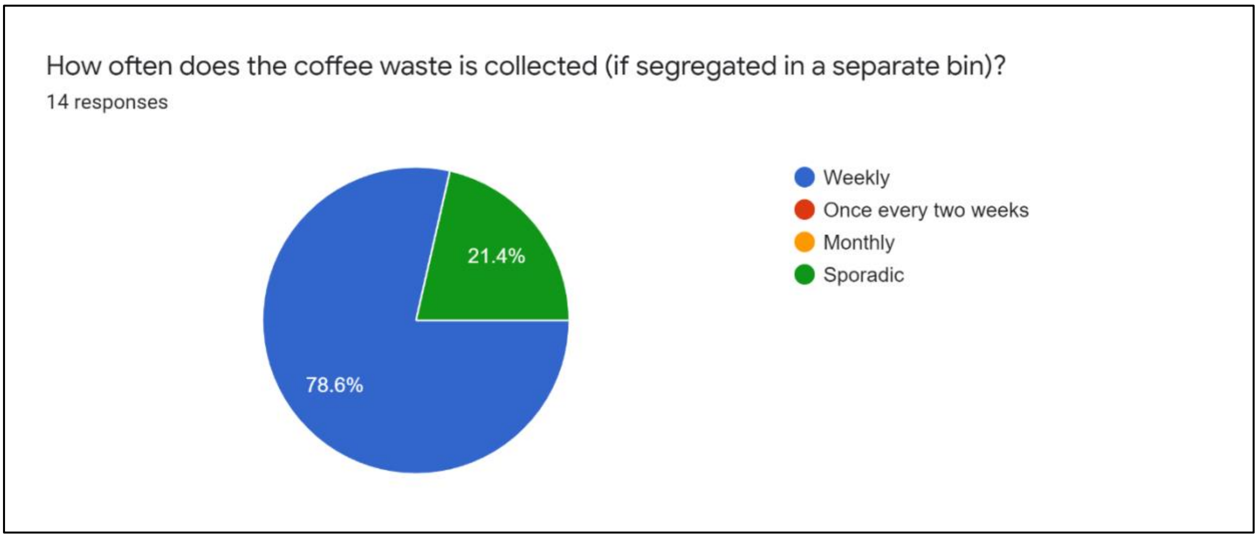
Name	Place
Jordbærpikene	Amfi Madla, Stavanger
Steamkaffebar Kvadrat	Sandnes
Adams coffee Kvadrat	Sandnes
Starbucks Kvadrat	Sandnes
Cucina italia Kvadrat	Sandnes
Cantina maxicana Kvadrat	Sandnes
Starbucks Arkedan	Stavanger
Deli de Luca	Stavanger
Vaaland dampbakeri	Stavanger
Kaffehuset	Stavanger
Cirkus	Stavanger
Kaffelade	Stavanger
Kulturkafe	Stavanger
7-eleven	Stavanger
Olivia	Stavanger
Egon	Stavanger
Starbucks	Stavanger

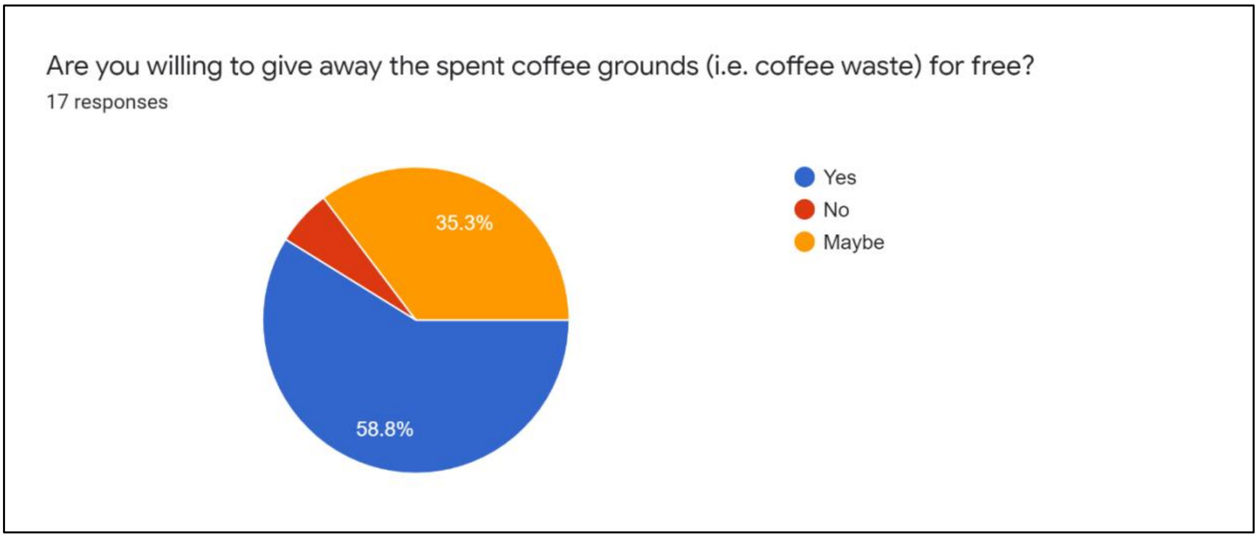
Appendix 2 – Survey results

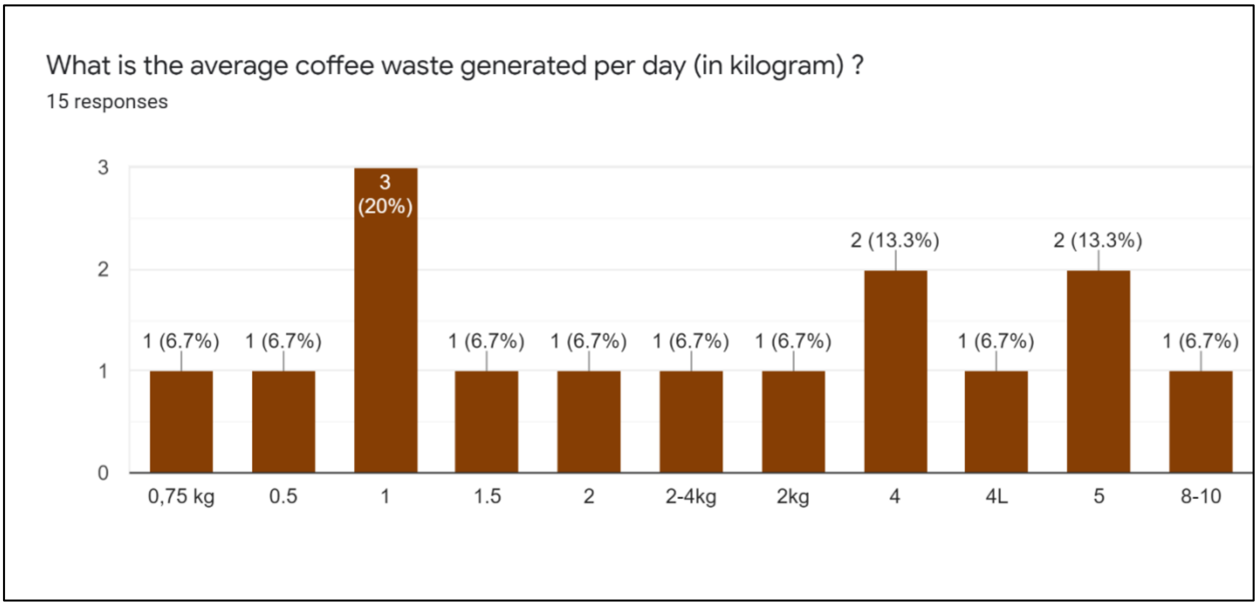
Survey results from different cafes/restaurant:

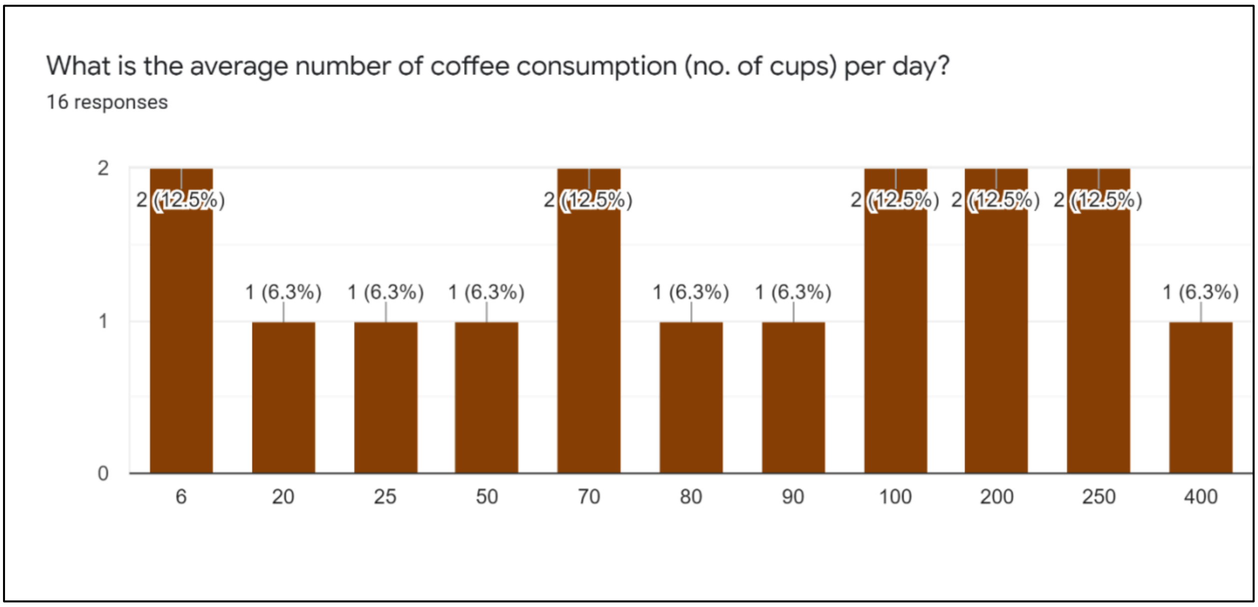


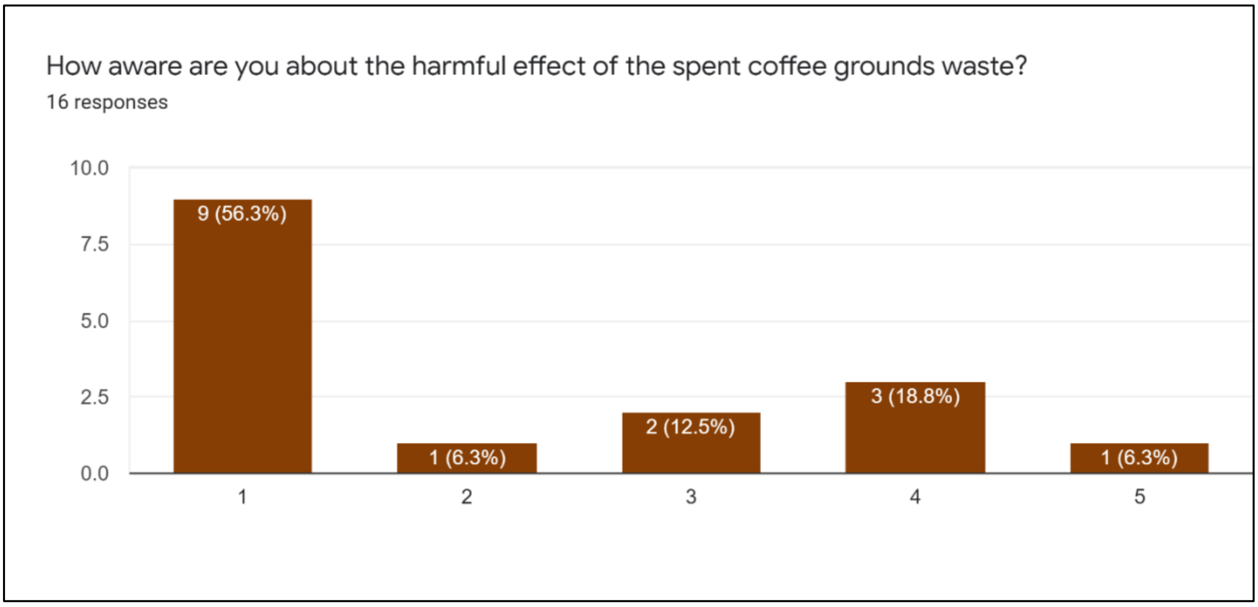


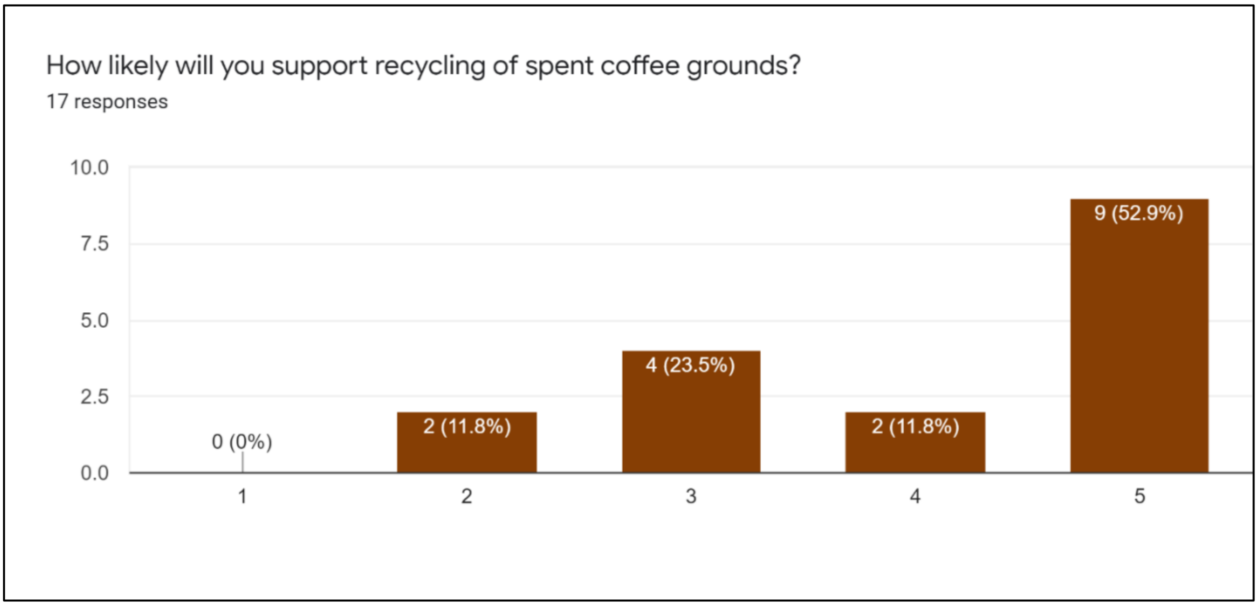


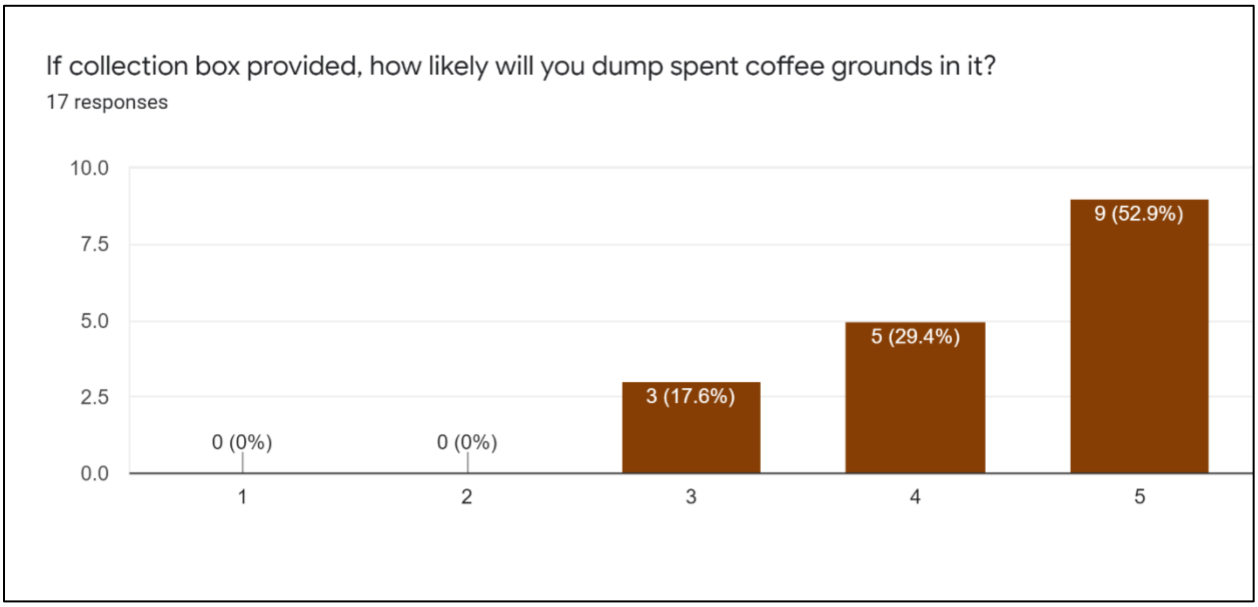

Are you willing to give away the spent coffee grounds (i.e. coffee waste) for free?
17 responses
35.3%
58.8%
Yes
No
Maybe

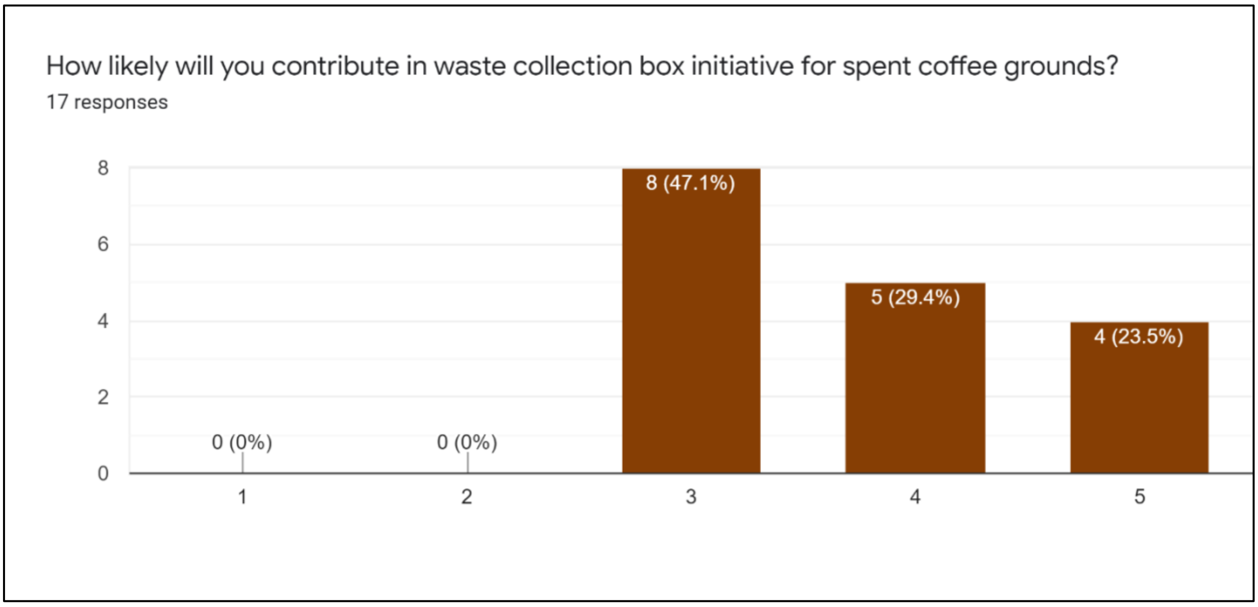

What is the average coffee waste generated per day (in kilogram) ?
15 responses
3
2
1
0
3 (20%)
2 (13.3%)
2 (13.3%)
1 (6.7%)
0,75 kg
0.5
1
1.5
2
2-4kg
2kg
4
4L
5
8-10

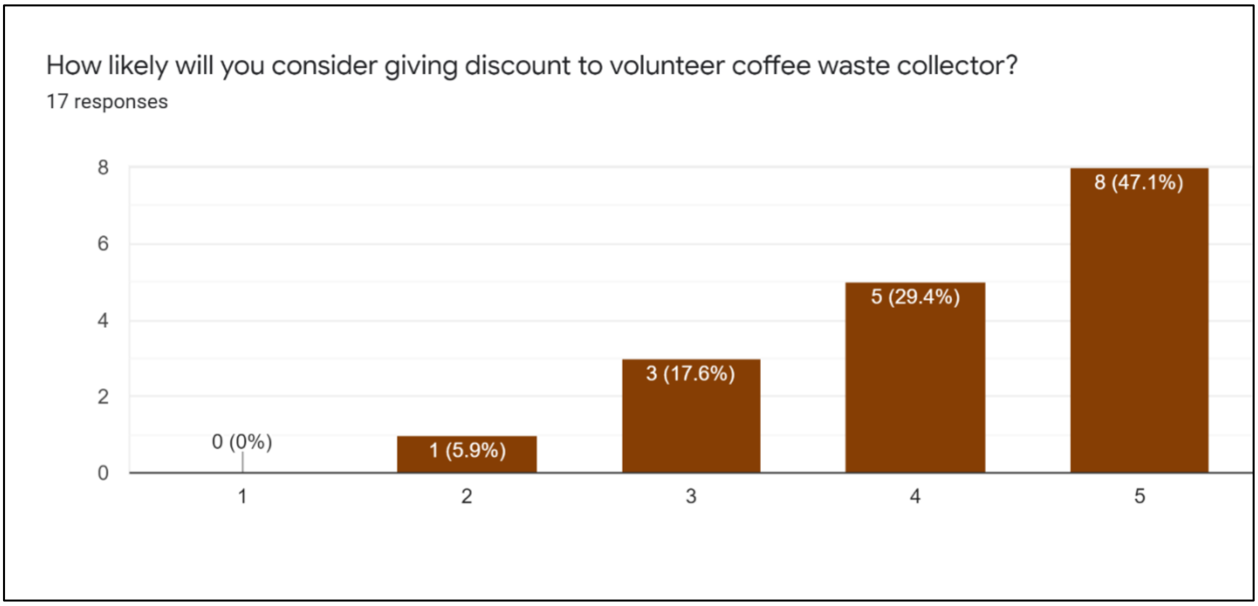

What is the average number of coffee consumption (no. of cups) per day?
16 responses
2
1
0
2 (12.5%)
1 (6.3%)
6
20
25
50
70
80
90
100
200
250
400


How aware are you about the harmful effect of the spent coffee grounds waste?
16 responses
10.0
7.5
5.0
2.5
0.0
9 (56.3%)
1 (6.3%)
2 (12.5%)
3 (18.8%)
1 (6.3%)
1
2
3
4
5


How likely will you support recycling of spent coffee grounds?
17 responses
10.0
7.5
5.0
2.5
0.0
0 (0%)
2 (11.8%)
4 (23.5%)
2 (11.8%)
9 (52.9%)
1
2
3
4
5


If collection box provided, how likely will you dump spent coffee grounds in it?
17 responses
10.0
7.5
5.0
2.5
0.0
0 (0%)
0 (0%)
3 (17.6%)
5 (29.4%)
9 (52.9%)
1
2
3
4
5


How likely will you contribute in waste collection box initiative for spent coffee grounds?
17 responses
8
6
4
2
0
0 (0%)
0 (0%)
8 (47.1%)
5 (29.4%)
4 (23.5%)
1
2
3
4
5


How likely will you consider giving discount to volunteer coffee waste collector?
17 responses
8
6
4
2
0
0 (0%)
1 (5.9%)
3 (17.6%)
5 (29.4%)
8 (47.1%)
1
2
3
4
5