

COFFEE PEEL WASTE UTILIZATION PLANNING IN WEST JAVA: A CAUSAL LOOP ANALYSIS

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Abstrak

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Peningkatan produksi biji kopi di Bandung telah secara signifikan membentuk karakter kopi di kota tersebut, Bandung menghasilkan lebih dari 30% dari total produksi kopi di Jawa Barat. Namun, pertumbuhan ini memunculkan tantangan mendesak: pengelolaan limbah yang dihasilkan selama pemrosesan biji kopi, terutama limbah dari proses pulping. Penelitian ini mengeksplorasi cara mengolah limbah kulit kopi menjadi produk yang menguntungkan di Bandung melalui Analisis Causal Loop. Data primer dan sekunder digunakan untuk menyusun model konseptual limbah kulit kopi menggunakan perangkat lunak STELLA. Model yang dikembangkan mencakup model dasar, model pupuk dan model bio pelet. Analisis ini menyoroti potensi pengurangan biaya pengelolaan limbah dan manfaat lingkungan dari konversi limbah organik menjadi dua produk: pupuk dan bio pellet. Pupuk dipilih karena kemudahan implementasi dan biaya produksi yang rendah, sementara bio pellet diunggulkan karena memiliki karakteristik energi yang superior dan kandungan senyawa kimia bernilai tinggi. Studi ini juga meneliti mekanisme pembagian pendapatan di antara para pemangku kepentingan, dengan menyarankan model distribusi pendapatan yang adil untuk memastikan manfaat ekonomi yang merata di seluruh rantai pasokan, termasuk petani dan industri.

Kata kunci: analisis lingkaran kausal, limbah kulit kopi, pupuk, bio pelet, pembagian pendapatan

Abstract

The rise of green bean coffee production in Bandung has significantly shaped the city's coffee landscape, with Bandung producing more than 30% of West Java's total coffee production. However, this growth brings a pressing challenge: managing the waste generated during green bean coffee processing, particularly remnants from pulping. This research explores ways to utilize coffee peel waste into profitable products in Bandung through a Causal Loop Analysis. Primary and secondary data are used to compile the conceptual model of coffee peel waste using STELLA Software. The model includes a basic model, a fertilizer model, and a bio pellet model. The analysis highlights potential reductions in waste management costs and the environmental benefits of converting organic waste into fertilizer and bio pellets. Fertilizer is chosen for its ease of implementation and low production costs, while bio pellets are valued for their superior energy characteristics and high-value chemical compounds. The study also examines revenue sharing mechanisms among stakeholders, suggesting equitable distribution models to ensure fair

economic benefits across the supply chain, including farmers and industry.

Keywords: *causal loop analysis, coffee peel waste, fertilizer, bio pellets, revenue sharing*

1. INTRODUCTION

Bandung stands out in the coffee industry as a hub of creativity and innovation. This city offers many unique and diverse coffee shops that have been gaining popularity in recent years. Coffee shops in Bandung have evolved beyond their traditional role as social gathering spaces to become productive workspaces (Sudono, 2019). The rise of green bean coffee production in Bandung has been a significant factor in shaping the city's coffee landscape. From 2019 to 2020, as shown in Table 1, Bandung has produced more than 30% of the total coffee production in West Java. This contribution has established it as the leading coffee producer in the region with an average production level of 7140.40 tons. Therefore, the consistent increase in production highlights Bandung's robust potential (BPS, 2023).

Table 1. Coffee Producer in West Java Province in 2019-2021 (Tons)

Regency/City	Production		
	2019	2020	2021
Bandung	6.798,21	6.798,00	7.825,00
Bogor	3.854,37	3.854,00	4.632,00
Garut	2.949,00	2.949,00	3.036,00
Tasikmalaya	1.498,91	1.499,00	1.487,00
Kuningan	1.286,31	852,00	490,00
West Bandung Regency	990,10	990,00	1.349,00
Ciamis	963,95	964,00	964,00
Sumedang	955,58	899,00	825,00
Subang	545,00	545,00	547,00
Cianjur	384,20	384,00	541,00
Pangandaran	268,60	269,00	273,00
Majalengka	230,33	230,00	241,00
Karawang	207,20	218,00	354,00
Purwakarta	189,22	189,00	189,00
Sukabumi	166,64	182,00	321,00
Banjar City	6,15	6,00	6,00
Tasikmalaya City	4,55	5,00	7,00
Bekasi	0,04	0,00	0,00
Total in West Java Province	21.298,37	20.833,00	23.087,00

However, along with this growth comes a pressing challenge related to the management of waste generated during the green bean coffee processing, particularly the remnants from pulping processes. Around 60% of the pulp is produced during this stage. There are approximately 4.695 tons of coffee peel waste in Bandung in 2021 calculated from Table 1, Leaving behind a substantial amount of coffee peel that requires careful attention and sustainable disposal methods (Novita and Irfani, 2023).

The structure of the coffee peel contains both the exocarp and the mesocarp. The exocarp, which is the durable, leathery outer layer, under that there is the soft layer of mesocarp, which constitutes the soft, pulp layer, together envelop the seed (Klinger et al, 2020). Coffee peel is separated from the beans in pulping stage by squeezing the coffee cherry into a small clearance (Bizimungu et al, 2023). Coffee peel contains 45-89% carbohydrates, 4-12% protein, 1-9% pectin and tannins, 1-2% lipids, as well as 0,12-0,26% of caffeine. Additionally, coffee peel contains phenolic acids and minerals (Carmen et al, 2020) (Hasanah et al, 2019) (Oliveira and Franca, 2015) (Rios et al, 2014). The composition of coffee peel has high potential to be turned into profitable byproducts and applied in various fields. Several studies have been conducted to process coffee peel into innovative byproducts such as ethanol, biogas, dyes, bioactive compounds, dietary fiber, particle board, fuels, and substrate for bioprocesses (Murthy and Naidu, 2012).

Despite the evident potential for repurposing coffee peel into a range of valuable products, there seems to be a notable lack of traction in Bandung. While many opt to sell the coffee peel to farmers as a mixture for livestock feed or use it as a natural fertilizer, there remains an unexplored opportunity for industrial and agricultural sectors to explore creative approaches for utilizing this excess waste from green bean production

(Carmen et al, 2020). The untapped potential of transforming coffee peel into alternative products highlights the need for further exploration and innovation to harness its benefits in a responsible and eco-conscious manner.

To thoroughly address the challenge at hand, a systematic approach known as system dynamics is strategically employed to break down and deconstruct the problem. System dynamics is a method used to enhance the understanding of a studied problem, enabling interventions in the system to make better decisions and solve complex issues. System dynamics integrates information feedback, human decision-making, and computer simulation in its approach (Martinez-Moyano, 2023) (Richardson. 1996). This paper proposes a conceptual model aimed at designing a simulation for the utilization of coffee peel waste from green coffee bean production in Bandung. Causal loop diagrams are used to interpret the cause-and-effect relationships among variables from farmers to industry. Causal loops are closed connections that create circular relationships between variables. These loops are shown with single-headed arrows that start at the "cause" and point to the "effect." It is important to note that this relationship does not necessarily hold true when reversed. A positive ("+") sign means that both variables will move in the same direction over time, if the variable at the start of the arrow increases (or decreases), the variable at the end will also increase (or decrease). On the other hand, a negative ("-") sign means the variables will move in opposite directions; if the variable at the start of the arrow increases (or decreases), the variable at the end will decrease (or increase) (Martinez-Moyano, 2023).

Previous studies about coffee waste utilization using system dynamics approach have been conducted. Martínez-Ruiz et al. (2022) used system dynamics to evaluate the energy potential from cherry coffee pulp and analyze trends in the energy supply for different energy sources in scenarios of climatic vulnerability in Colombia. Ramos-Hernández et al. (2021) studied the potential of coffee pulp as a source of biomass and the logistical operations and key variables that enable the feasibility of biomass as a source of energy at an industrial scale using the system dynamics method in Mexico. Barbero & Fiore (2015) provided a holistic vision to make the spent coffee grounds recovery activity complex, with almost no waste in Italy, by studying how to create a system that values this waste in a real and profitable way, considering local conditions.

From several previous studies that have been conducted, there has been no research on analyzing coffee peel waste into fertilizer and bio-pellets using a system dynamics approach. The objective of this research is to provide a solution to waste abundance by converting it into profitable products, thereby creating new revenue streams. A conceptual model is used because it facilitates a comprehensive understanding of the entire system, allowing for a clear depiction of the linkages between various factors.

2. METHODS

This research was conducted using system dynamics method, utilizing causal loop diagram to analyzing and facilitating a more holistic understanding of the interconnected cause-and-effect relationships among various variables involved in coffee peel waste utilization. The tools used for this research is a computer using STELLA as the software to create the causal loop diagram. The research site was Bandung City, West Java, Indonesia. Figure 1 shows the stages of this research.

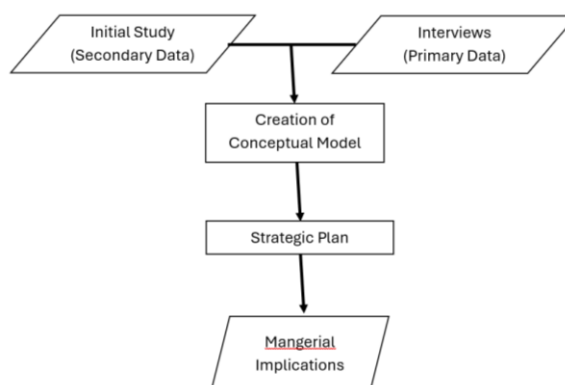


Figure 1. Research stages

2.1 Secondary Data

The research begins with an initial study to map out the problem and understand the broader context. This is achieved through a thorough literature review on system dynamics concepts, the green bean coffee production process, the green bean coffee supply chain, coffee peel byproducts, fertilizer production

processes and bio-pellet production processes. The data collected from this literature research serves multiple purposes. Firstly, it provides a solid base for later interviews, offering a solid background knowledge for discussions with the stakeholders. Additionally, the secondary data gathered from these sources is crucial in strengthening the overall conceptual analysis.

2.2 Primary Data

Interviews were conducted with farmers and industry producers, recognized as key stakeholders, to collect primary data. Individuals with extensive knowledge of green beans were selected for the interviews. Details of the experts interviewed for this research are presented in Table 2.

Table 2. Description of Secondary Data Used

Expert	Occupation	Working Experience (years)	Data Obtained
V	Farmers	5	End-to-end coffee cherry harvesting process, overall costs and income, encountered issues, and needs
W	Farmers	7	End-to-end coffee cherry harvesting process, overall costs and income, encountered issues, and needs
X	Owner of green bean processing company	5	End-to-end green bean production process, overall costs and income, encountered issues, and needs
Y	Owner of green bean processing company	10	End-to-end green bean production process, overall costs and income, encountered issues, and needs
Z	Director of green bean processing company	10	End-to-end green bean production process, overall costs and income, encountered issues, and needs

These experts provided valuable insights and firsthand information for the development of the causal loop diagram, as it incorporated real-world perspectives and experiences from key industry participants. The interview data not only supported the development of the CLD but also enhanced the overall understanding of the green bean coffee production and distribution ecosystem.

2.3 Creation of Conceptual Model

The creation of the conceptual model starts with the identification of variables influencing the green bean production process, the current state of the supply chain, and the utilization of coffee peels. This was conducted by interviewing key stakeholders. The variables within the green bean coffee production process, the green bean coffee supply chain, and coffee peel utilization were defined, followed by determining the relationships among these variables using a causal loop diagram. The result of this process is the basic model, which will be further explored and expanded into another conceptual model as a strategic plan for utilizing coffee peel waste.

2.4 Strategic Plan

The strategic plan for coffee peel utilization was crafted based on the basic model. This plan was divided into two models, each representing a different scenario for coffee peel utilization. The first model involves converting coffee peel waste into fertilizer, a practice already adopted by some farmers. The second model explores the use of coffee peel waste for producing bio pellets, a method that has not yet been widely implemented by either farmers or the industry.

2.5 Managerial Implications

The managerial implications of this research are the outcomes of strategic planning, providing practical insights. Academic studies should result in practical applications (Salminen et al., 2014). This research provides managerial implications, contributing to the utilization of coffee peel waste and the implementation of fertilizer and bio-pellet conceptual models in response to the challenges faced by farmers and industry.

3 RESULTS AND DISCUSSION

3.1 Green Bean Production

Green bean coffee production in Bandung City still relies on traditional methods. For example, producers often use sunlight to reduce the water content in green bean coffee. The production process is divided into two main methods which are dry processing and wet processing (Ameca et al, 2018). The dry processing method, also known as the natural process, involves drying the coffee cherries without the use of water. After the sorting process, the cherries are spread out in the sun and left to dry naturally. Once the coffee has lost 10-12% of its moisture content, the cherries are pulped (Rahmah et al, 2023). During this period, the cherries are turned regularly to ensure even drying and to prevent mold. This method results in a fruitier, winey, and slightly vinegar-like flavor profile due to the prolonged contact between the fruit and the bean. Natural method is more time consuming since it last for about 7-21 days. It is simpler and more traditional compared to wet processing. The natural method is typically used for specialty coffee, which refers to high-grade coffee beans, and is particularly suitable for medium roast profiles. Coffee produced by this method often commands a higher price point because of the extended processing time and the complex flavor profile.

On the other hand, wet processing involves fermentation with water, resulting in cleaner and brighter flavors. This method is often used for fine commercial coffees due to its ability to produce a more consistent and refined taste profile. Wet processing includes several steps: sorting, pulping, fermenting, washing, and drying the beans. Within wet processing, there are two distinct types: semi-wash and full-wash.

Semi wash method involves an extensive process where fermentation with water occurs over a total of 4-7 days. The process includes two drying stages. Initially, the beans are pulped to remove the outer cherry skin, and the mucilage-covered beans are then left to ferment in water. The first drying stage follows, which reduces the water content to 40%. After the first drying, the beans are washed to remove the remaining mucilage and then subjected to a second drying stage, which further reduces the water content to 12.5%. This method produces fine commercial coffee characterized by nutty, chocolate, and fruity flavors. It is recommended for medium roast and tends to fall into a slightly higher price range.

Full-wash processing also involves fermentation with water but has a shorter processing time of only 2-3 days. The process starts similarly with sorting and pulping, followed by fermentation. This quicker process results in beans that have a cleaner flavor profile with notable nutty and chocolate notes. Full-wash processed coffee is suitable for both medium and dark roasts and is generally more affordable than semi-wash processed coffee due to the shorter processing time.

Despite the advantages of wet processing, natural processing remains the most requested method by customers. This preference is largely due to the unique flavor profiles that natural processing can produce. The natural method, which involves drying the entire cherry in the sun, allows for extended contact between the bean and the cherry, leading to fruitier, winey, and slightly vinegar-like flavors. As a result, the coffee industry in Bandung typically processes coffee using the natural method, while semi-wash and full-wash methods are reserved for specific requests. Figure 2 shows the three green bean coffee production process method.

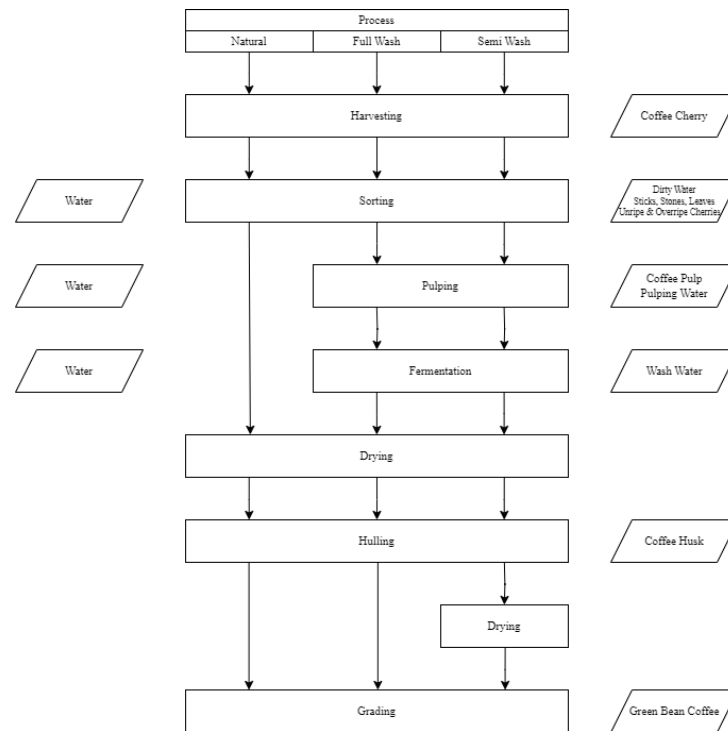


Figure 2. Green Bean Coffee Production Process

3.2 Green Bean Supply Chain

Supply chain is the end-to-end process of a product cycle, starting from raw materials as the input to the end product that is ready to sell as the output. This comprehensive process involves multiple stages and actors, each contributing to the conversion and movement of the product. The supply chain includes sourcing and procuring raw materials, manufacturing and production, quality control or grading, packaging, and warehousing. Overall, supply chain consists the entire step-by-step process of production and distribution activities, ensuring that products are efficiently created, moved, and made available to consumers. Each link in the supply chain is crucial for maintaining the flow of goods and services and meeting market demands effectively (Prathita et al, 2023).

The green bean supply chain in Bandung is relatively straightforward, involving farmers as the primary suppliers of raw materials and industry producers who process and distribute the green beans. The supply chain studied in this research has a horizontal network structure, which is presented in Figure 3. These cherries are delivered to industry producers, companies that specialize in converting the cherries into green beans through full wash, semi wash, or natural processes. After processing, the producers distribute the green beans to local coffee shops, roasters, exporters, and specialty coffee buyers.

Although farmers and industry are interconnected in the green bean supply chain, there is a significant profit disparity between the two actors, with farmers receiving lower profits than the industry. The price of coffee cherries ranges from IDR 10,000 to 15,000, while the price of green bean coffee ranges from IDR 98,000 to 150,000. Even though green bean coffee production costs more than coffee cherry harvesting, the profit margins still do not align. This discrepancy highlights the unequal distribution of profits within the supply chain, where the added value in processing and distribution by the industry results in significantly higher earnings compared to the initial cultivation and harvesting by farmers.

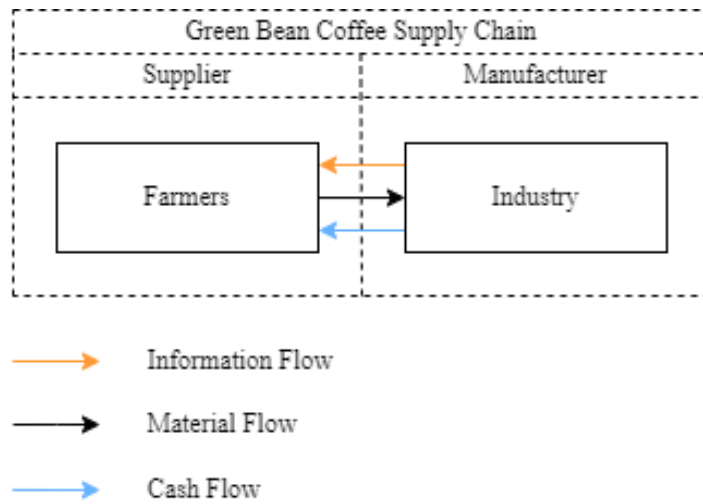


Figure 3. Green Bean Coffee Supply Chain in Bandung

3.3 Conceptual Model

The conceptual model constructed in this research is divided into three models. The basic model examines the current state of the problem, while the other two are strategic plans to improve the conditions faced by the actors in the green bean supply chain, addressing issues such as excessive coffee peel waste and unequal profit distribution. Figure 4 shows the basic model of green bean coffee production.

The basic model shows the variables that hold key positions in the green bean production process, highlighting the intricate relationships between different stages and factors involved. It starts with the farmers who harvest the coffee cherries, which are the main supply for green bean products. The production of coffee cherries directly affects the farmers' profits. However, the price of coffee cherries is highly susceptible to fluctuations due to several factors: climate change and weather conditions that affect the yield and quality of the coffee cherries, demand influenced by both local and global market conditions, and imported coffee from other countries, which adds another layer of complexity to the pricing dynamics.

On the other hand, green bean coffee production heavily depends on the availability of coffee cherries. Since the primary raw material is coffee cherries, any variation in their production directly influences the green bean production process. Consequently, the price of green beans also fluctuates, mirroring the price of coffee cherries, since the other costs associated with green bean production, such as labor, equipment, and processing, remain relatively stable over time. The production process of green bean coffee generates a substantial amount of waste, particularly coffee peels resulting from the pulping process. This waste, if not managed properly, can pose environmental challenges. Unfortunately, most industries in Bandung do not fully utilize the potential of the waste generated from green bean coffee production.

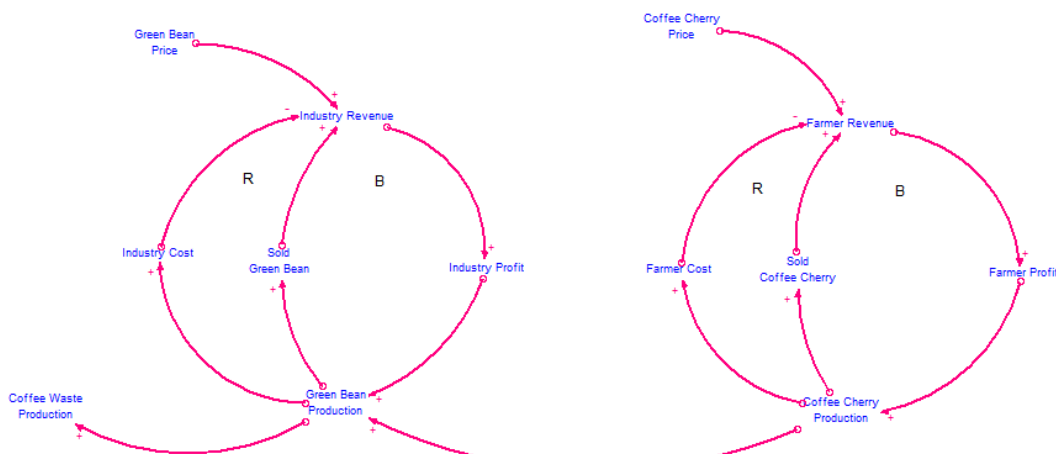


Figure 4. Basic Model

3.4 Strategic Plan

Based on the basic model, this research proposes two conceptual model that utilizes the coffee peel waste generated from the green bean process to address two critical objectives: waste reduction and profit

enhancement for both farmers and the industry. The proposed model identifies innovative ways to repurpose coffee peel waste by transforming it into valuable products that can generate additional revenue streams. Each of the proposed models focuses on different types of products, offering a range of profitability options. Ultimately, this model aims to create a more sustainable and profitable green bean supply chain by turning waste into wealth.

1) Fertilizer Conceptual Model

The fertilizer model utilizes coffee peel waste as the raw material to produce organic fertilizer. Coffee peel waste contains a high concentration of organic compounds that can decompose naturally (Bimantara et al, 2021). Composting is often chosen as a waste recycling technology because it is considered easy to implement and has low production costs. Since the process does not require expensive machinery or substantial additional materials, it can be implemented with minimal financial investment. Additionally, the use of organic fertilizer can reduce dependence on chemical fertilizers, promoting more sustainable agricultural practices and develops a green circular economy in coffee production (Rahmah et al, 2023). Figure 4 shows the fertilizer conceptual model.

Some of the green bean stakeholders in Bandung have already been practicing this method to reduce coffee peel waste. The fertilizer production process is conducted using the composting method. The composting starts with shredding the coffee peel waste into a smaller size to facilitates the decomposition process. Then the shredded coffee peel waste mixed with manure then moved into a tightly covered bucket to allow the fermentation process (Fatmawati et al, 2022). The application of coffee peel waste as a fertilizer has demonstrated promising outcomes, including enhanced soil fertility and quality, which subsequently have a positive impact on plant growth and productivity (Carmen et al, 2020) (Pagán-Roig et al, 2016) (Senthilkumar et al, 2015) (Wasilkowski et al, 2017). Revenue-sharing models can further reduce the cost of purchasing fertilizer for farmers, making organic fertilizer more accessible and affordable.

However, there are also some drawbacks. Despite the low production cost, the price of organic fertilizer is relatively low, resulting in low profit margins. The composting process can be time-consuming, taking several months to produce usable fertilizer, which can delay profit generation and may not be suitable for all farmers. The adoption of organic fertilizer can also depend on market acceptance and awareness, with potential resistance from farmers accustomed to using chemical fertilizers.

To implement the fertilizer model, an education and training program should be established to teach farmers and industry stakeholders about the composting process and the benefits of using organic fertilizer. The feasibility of this model depends on several factors, including the availability of coffee peel waste, the willingness of farmers to adopt new practices, and the initial investment required for setting up composting facilities. The impact of this model can be measured in terms of waste reduction, cost savings for farmers, and improvements in soil health and crop yields.

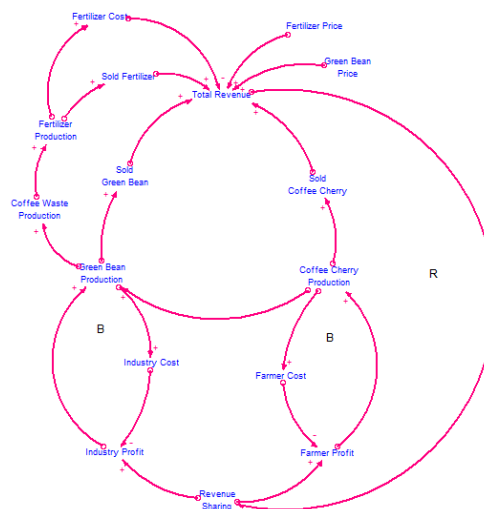


Figure 5. Fertilizer Model

2) Bio Pellet Conceptual Model

Bio pellet model explores the utilization of coffee peel waste into a type of biofuel made from compressed organic matter. Coffee peel waste have substantial energy potential and are generated in large

quantities, indicating a significant capacity for generating energy from this waste, similar to bio briquette. The main difference lies in their production methods and physical characteristics. Briquettes are typically larger and produced through roll press or piston-cylinder densification, while pellets are smaller and made using pelleting machines (Kaliyan et al, 2009). Figure 6 shows the model of coffee peel utilization into bio pellets.

Bio pellet production process start with pre-treatment, the drying process, to evaporate excess water from the coffee peel waste. The drying process plays a critical role in bio-pellet production process since it reduces the moisture level to enhance the thermochemical conversion process (Silva et al, 2023). The drying process can use three different methods, which are air drying, solar drying, or drying in a hot air chamber. After drying, the materials are filtered before milling to remove unwanted materials such as stone (Jagtap and Kalbande, 2023). Then the coffee peel waste is milled and compacted to increase the density (Cubero-Abarca et al, 2014). The milled coffee peel waste consistency similar to breadcrumbs and should not bigger than the pellet diameter. The next step are conditioning and pelletizing, most of the pelletizing machines have a built-in steam to soften and make the materials less abrasive. Pellets are created by pressing the materials through a holes in the die, reshaping the materials into pellet form. The last step is cooling process, this process helps the lignin to solidify and strengthen affecting the pellet's durability (Jagtap and Kalbande, 2023) (Peksa et al, 2007). This process is essential as it ensures that the pellets are robust and can withstand handling and transportation without breaking apart.

Bio pellet are chosen because the products obtained in this process have better energy characteristics and a greater amount of chemical compounds with high added value (Silva et al, 2023) (Setter et al, 2020). While both pellets and briquettes share similarities, pellets are generally preferred for their ease of handling. This preference stems from their smaller size, safer storage attributes due to their biologically inactive nature, and the heat treatment they undergo during production (Ahmed and Trubaev, 2024). This model offers an alternative energy source, reducing dependence on conventional fuels, while also reducing coffee peel waste and promoting sustainable waste management.

The primary challenge is the high moisture content of the raw material, which is approximately 82.4% (Perazzini and Perazzini, 2022). This high moisture content necessitates a drying process, which can increase the production cost and energy consumption. Other than that, the production of pellets typically requires more sophisticated machinery compared to briquettes (Sonkhaskar et al, 2020). The initial setup cost can be significant, covering expenses for advanced equipment, infrastructure modifications, technological integration, and training. However, these investments are crucial for achieving the desired outcome and ensuring the feasibility of the project. The process offers a much better return on investment compared to traditional fertilizer, making it a financially viable option in the long run.

Moreover, the bio briquette model can create new economic opportunities for farmers and industries involved in the revenue sharing. With the revenue sharing implemented from this model, the profit for both farmers and industry can be greatly enhanced. Revenue sharing determines the distribution of revenue generated from a transaction between supply chain stakeholders. This scheme ensures that each supply chain stakeholders is compensated for their efforts, encouraging them to increase the efficiencies in mutually beneficial way (Avinadav et al, 2015) (Bart et al, 2019). Revenue sharing in the coffee industry involves the distribution among stakeholders which are farmers and industry. This could potentially lead to increased productivity and efficiency, as all actors are motivated by the prospect of equitable profit sharing. To implement this model, training and capacity building for staff to operate and maintain the new technology will be essential. By transforming coffee peel waste into bio pellet, this model not only provides an alternative energy source but also addresses waste management issues, contributing to environmental sustainability.

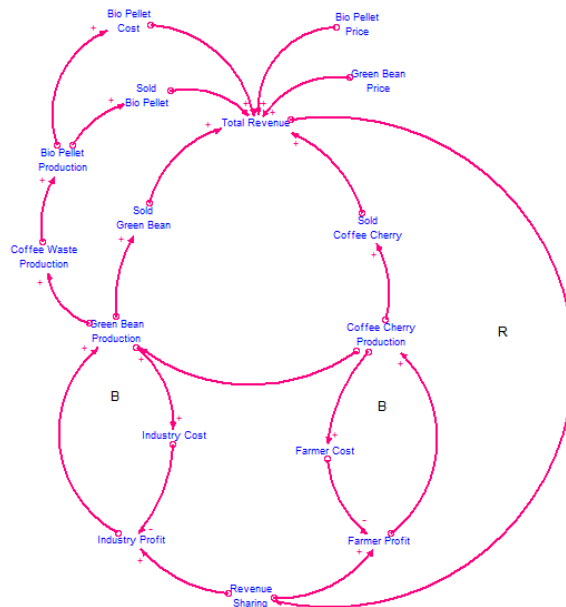


Figure 6. Bio Pellet Model

3.5 Managerial Implications

The recommendations from this research focus on utilizing coffee peel waste to produce profitable products, such as fertilizer and bio pellets, through a structured approach involving revenue sharing among stakeholders. These recommendations emphasize practical, implementable steps that address both environmental sustainability and economic disparity in the green bean coffee supply chain.

However, several considerations must be taken into account for both farmers and industry. The farmers should emphasize the quality control to meet market standards. Industry stakeholders should support waste conversion initiatives by investing in infrastructure and technology to facilitate efficient waste conversion and promote the development of fertilizer and bio pellet production. Participating in training programs will help farmers and industry understand market opportunities and improve production techniques, increasing their motivation and ability to produce high-quality outputs to meet market demands. These efforts will enhance stakeholders' ability to compete in broader markets. Additionally, farmers should engage in equitable revenue sharing mechanisms with industry stakeholders to ensure fair distribution of profits from the sale of byproducts.

Joint efforts between farmers and industry should focus on sustainability initiatives, such as reducing waste management costs and environmental impacts, and advocating for supportive government policies and infrastructure improvements to facilitate smoother export processes and market access.

4 CONCLUSION

The green bean coffee peel waste utilization model in Bandung City is developed based on three models: the basic model, fertilizer model, and the bio pellet model. By finding innovative ways to repurpose this waste, both farmers and industry stakeholders can benefit from additional revenue streams. The proposed models leverage revenue sharing to optimize profits, addressing the current disparity where farmers' profits are significantly lower compared to those of the industry. By suggesting two products derived from coffee peel waste, the models aim to create value-added opportunities that can boost the overall profitability of the supply chain. This approach not only helps in managing waste more sustainably but also ensures a more equitable distribution of profits between the two stakeholders in the green bean supply chain in Bandung City.

This study only discusses two methods to utilize coffee peel waste. Future research should explore additional methods beyond fertilizer and bio pellets, such as investigating other potential byproducts like biodegradable packaging, bioethanol, or even cosmetics. Furthermore, a detailed economic impact analysis could provide deeper insights into the long-term financial benefits for each stakeholder. Additionally, this paper lacks recommendations for policy enhancements that can facilitate the adoption of sustainable waste management practices in the coffee industry. Future research should include recommendations for such policy enhancements.

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