International Journal of Environmental Impacts
Vol. 8, No. 1, February, 2025, pp. 63-70
Journal homepage: http://iieta.org/journals/ijei

Development of Eco-Industrial Design Through Production Process Efficiency and Waste Utilization at Coffee Processing Industry

Erliza Noor[1], Muhammad Hilmi Uwais Qarani[1], Reza Ramadhani[1], Febriani[1], Muchamad Yusron[2*]

[1] Department of Agro-industrial Technology, Faculty of Agricultural Engineering and Technology, IPB University, Bogor 16680, Indonesia
[2] Research Organization for Agriculture and Food, National Research and Innovation Agency, Bogor 16911, Indonesia

Corresponding Author Email: yusron1061@gmail.com

https://doi.org/10.18280/ijei.080107

Received: 25 September 2024
Revised: 7 December 2024
Accepted: 5 January 2025
Available online: 28 February 2025

Keywords:
eco-industrial, efficiency, waste, utilization, coffee, processing

ABSTRACT

Coffee production has steadily increased each year, leading to rapid growth in the coffee industry. However, this growth has also brought challenges, particularly concerning managing generated waste in processing. The coffee processor faces significant waste management issues associated with green bean processing. To address these challenges, this study focuses on implementing the eco-industry concept, emphasizing process efficiency and waste minimization. Production efficiency is enhanced through the standardization of operations, achieved by developing standard operating procedure (SOP) documents for green bean production. Simultaneously, waste reduction strategies are employed by repurposing wet coffee pulp waste as feed for Black Soldier Fly (BSF) larvae and utilizing dry coffee pulp waste to produce briquette products. The trials of SOP implementation have demonstrated an increase in yield, reaching 15.10% for the natural process and 14.72% for the washed process, indicating improved production efficiency. Using coffee pulp waste as maggot feed has proven effective, degrading approximately 9.9kg of waste per g of maggot egg. Similarly, converting dry coffee pulp waste into briquettes has yielded products meeting quality standards, boasting a calorific value of around 6000cal/g. These initiatives not only enhance product value but also significantly reduce waste output, contributing to sustainable practices within the coffee industry.

1. INTRODUCTION

Coffee is an agricultural commodity with increasing demand and a significant market in Indonesia. This annual growth has accelerated the development of the coffee industry. However, the rapid industry growth has not been accompanied by an adequate understanding of the waste generated [1]. The substantial waste from green bean processing is a major issue for the processing coffee industry, primarily due to inefficient processes and a lack of waste management. Addressing this requires developing an industrial ecology concept aimed at preventing, reducing, and eliminating waste or pollutants at the source [2]. Implementing Industrial Ecology involves saving (efficiency) in raw material, energy, and water use, minimizing work accidents, and reducing waste [3].

Industrial ecology focuses on transforming industrial processes from linear (open-loop) systems, where resources and capital are ultimately discarded as waste, to closed-loop systems, where waste is repurposed as input for new processes [4]. Industrial ecology provides structure and consistency to emerging corporate environmental convictions. As a framework for environmental strategy, it uniquely offers a coordinating vision for effective management planning and technical implementation in tomorrow's green corporations. Industrial ecology promises to equip industries with the ability to anticipate risks and opportunities, offer genuine environmental leadership, and develop lasting solutions to pressing technical and social issues.

In industrial ecology, economic systems are part of the surrounding systems [5]. When applied to industrial operations, it requires a system view that seeks to optimize the entire industrial materials cycle from virgin material to finished material, to component, to product, to waste product, and ultimately to disposal. Factors to be optimized include resources, energy, and capital.

The concept of industrial ecology can be applied in the coffee processing industry to improve production efficiency. Achieving production efficiency involves maximizing the output from the inputs during production [6]. By optimizing resource allocation, companies can maximize output and minimize waste, leading to higher profitability and enhanced competitiveness [7]. Production output is often measured as a percent yield, comparing the product produced (output) to the raw materials used (input) [8]. Inefficient processes can result in more waste due to wasted raw materials and reduced product yield [9], often caused by incorrect procedures and failure to meet standards.

Industrial ecology can also minimize waste by repurposing it as raw material for products with added value. Green bean production generates unavoidable waste, including coffee pulp.

Coffee fruit waste, primarily pulps, can constitute up to 48% of the fruit, with 42% being fruit pulp and 6% being seed skin [10]. If not managed properly, this waste can cause foul odors.

To address these issues, an eco-industry design has been developed for coffee processors. This involves implementing efficient processes and repurposing waste from green bean production into products with added value.

2. MATERIALS AND METHODS

This project was implemented at a coffee processing facility in West Java, Indonesia. Coffee processing in this region primarily employs two methods: washed and natural. These methods are generally carried out using basic techniques with low efficiency. The coffee processing involves a batch process conducted in barrels, each with a capacity of 100kg per batch. During the process, key parameters such as pH and fermentation temperature were monitored. Additionally, the waste generated during processing is not utilized, contributing to environmental pollution. Despite these limitations, the coffee processing operates on an economic scale, with products marketed nationally and even exported. Production, however, primarily relies on small-scale, home-based industrial equipment.

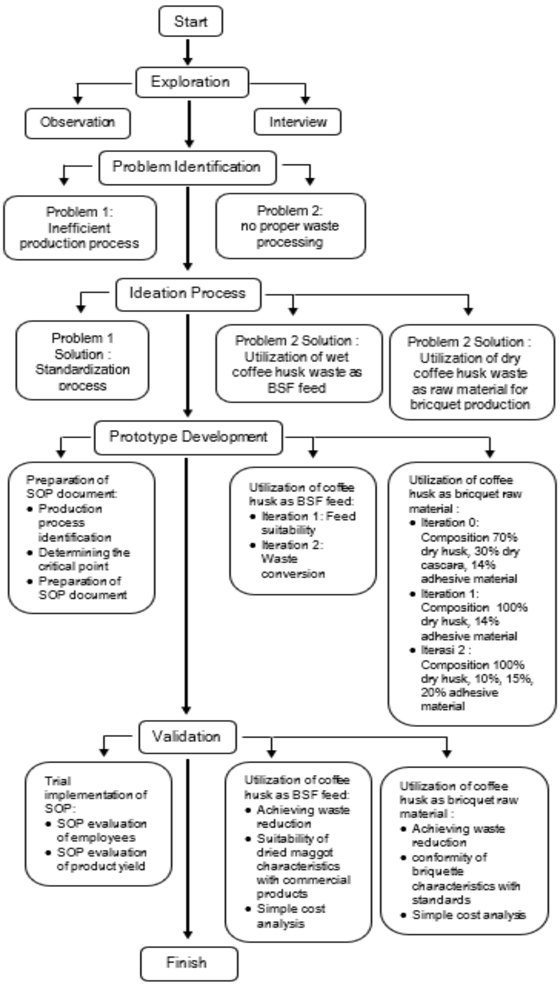


Figure 1. Stages of the main agro-industry design

Data sources were gathered through observations, interviews with partners, questionnaires, and laboratory research. The data was analysed through literature studies, brainstorming sessions, and partner discussions.

The main agro-industry design project was conducted in several stages. It began with identifying the problems faced by the coffee processor, followed by a problem-solving process. This process involved defining the problem in detail, designing a solution concept (ideation), developing a prototype, and validating the solution.

The design project begins with the exploration stage, aimed at understanding existing coffee processing methods and identifying the challenges coffee processors face. The ideation stage follows, focusing on generating and selecting solutions to address these challenges. Next is the prototype development stage, where an appropriate method for problem-solving is created through collaboration with partners. Finally, in the validation stage, the proposed method is applied and tested to ensure that the materials, procedures, processes, activities, systems, equipment, and mechanisms function as intended. Figure 1 illustrates the stages of the main agro-industry design project.

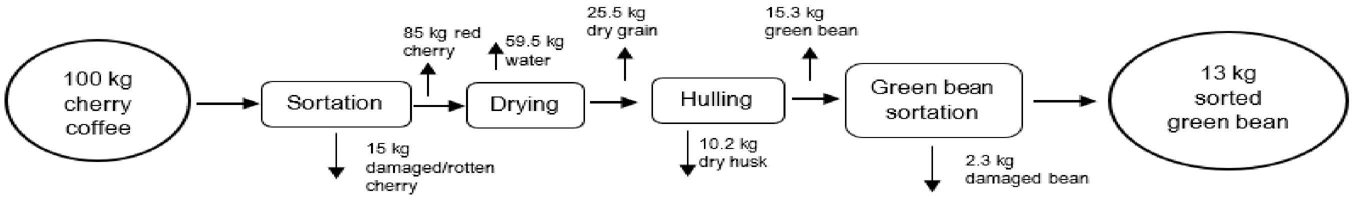
3. RESULTS AND DISCUSSIONS

3.1 Problem exploration

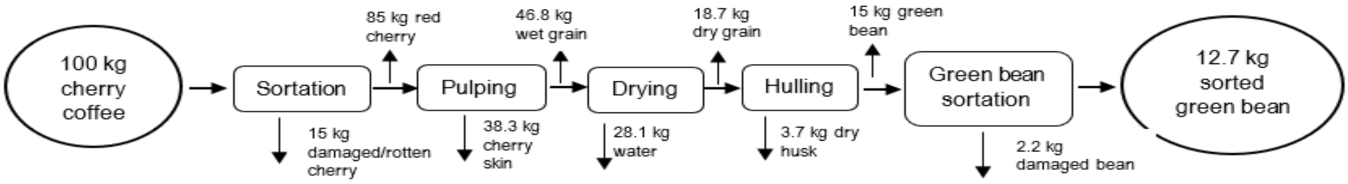
The coffee processor specializes in post-harvest coffee processing, focusing on specialty coffee in West Java, Indonesia. Their primary goal is to export coffee to several countries. The processor can process 20 tons of coffee cherries per month, with a maximum daily production of around 1-2 tons. They employ three green bean processing methods: Washed, Honey, and Natural. The differences between dry and wet processing methods result in varying amounts of green bean products. This variation is evident in the mass balance of each type of coffee processing. There are differences in yields for the natural and washed methods, namely 13% and 12.7%, respectively (Figure 2).

The mass balance of the processing process also reveals the amount of coffee pulp waste, which consists of two types: wet coffee pulp waste, produced during the pulping process in washed processing, amounting to 38.2%, and dry coffee pulp waste, produced during the pulping process, amounting to 10.2% in natural processing and 3.7% in washed processing. Based on mass balance calculations, the yield for the natural processing method is around 13%, while the washed method yields 12.7% (Figure 2). In comparison, research by Wibowo and Palupi [11] reported yields of 19.3%-20.5% for natural processing and 15.2%-17.3% for washed processing. The significant difference in yield suggests inefficiencies in this process. Inconsistent processing leads to errors, resulting in wasted materials. Discarded materials contribute to waste, further reducing the overall yield.

The production processes generate large amounts of waste, with no measures in place for its management. These problems lead to the accumulation of coffee pulp waste, causing unpleasant odors and environmental pollution (Figure 3). The coffee process faces several issues: inconsistent production processes, frequent errors during production, and inefficient processes characterized by significant raw material wastage and a large amount of coffee pulp waste resulting from inadequate management. Accumulated coffee pulp waste quickly fosters spoilage microbes, disturbing the surrounding environment and potentially polluting the air if present in large quantities [12, 13].



(a)



(b)

Figure 2. Mass balance calculation of coffee processing of (a) natural and (b) washed methods

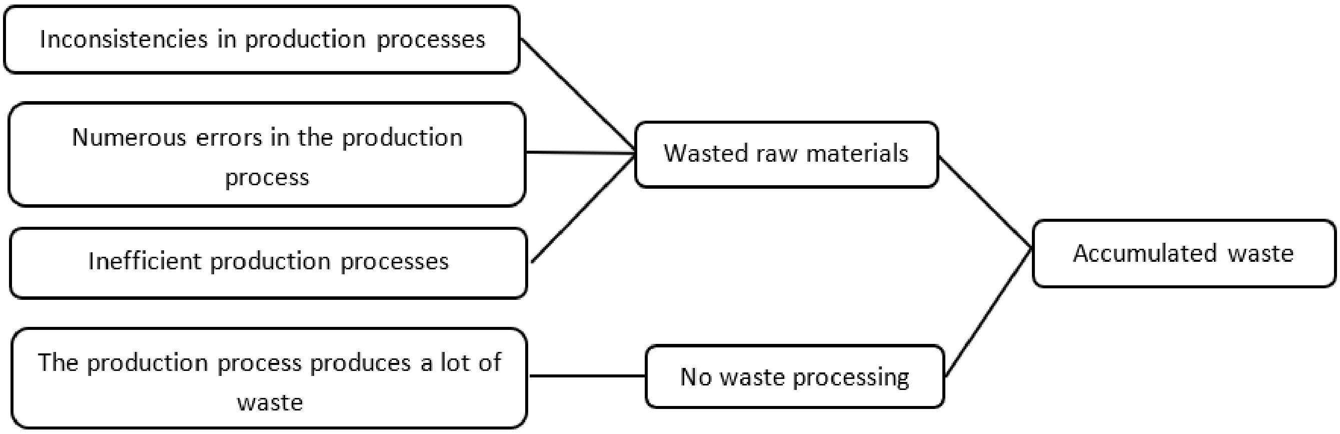


Figure 3. Problems faced in the coffee processing

3.2 Development of engineering solution design

The development of engineering solution designs was executed through the creation of prototypes. Figure 4 illustrates the prototype development for each solution.

The underlying concept for this main agro-industry design project is the development of an eco-industry or industrial ecology. This concept addresses the waste problem by increasing efficiency in using raw materials and minimizing waste during processing. In various case studies, the implementation of eco-industry has been shown to reduce waste and enhance production efficiency [14, 15]. This eco-industry development aims to increase production efficiency, as evidenced by higher production yields and reduced waste, thereby adding value through waste utilization and increasing partner income.

A specific approach was selected to address the existing problems from several alternative solutions. The chosen solution to enhance production efficiency is standardizing the green bean production process. Process standardization ensures consistent operations and minimizes errors by preparing standard operating procedure (SOP) documents [16]. This solution was chosen because the processor previously lacked production process guidelines, and the frequent turnover of human resources necessitated clear documentation for employees.

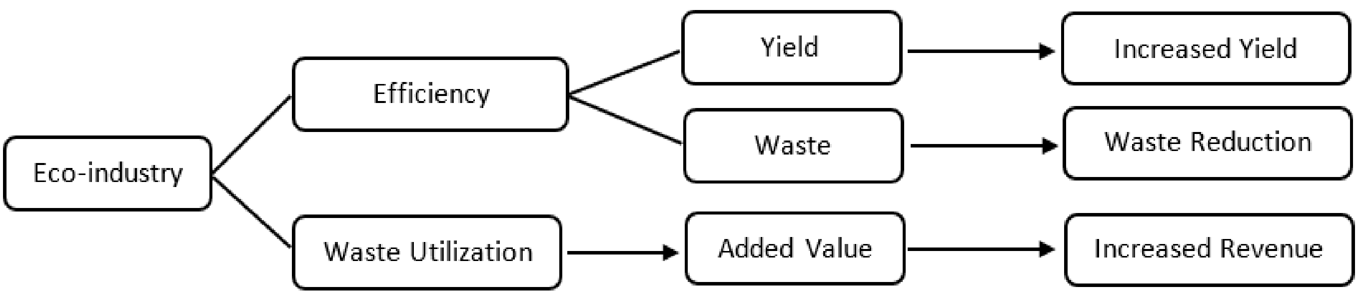


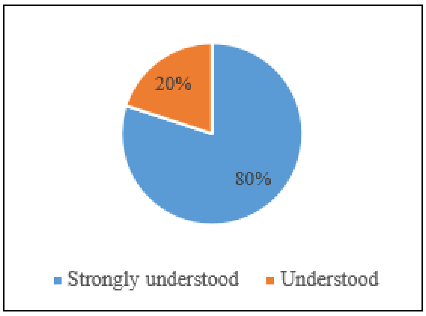
Figure 4. Development of solution prototype

For waste utilization, the selected solution involves wet coffee pulp waste as feed for Black Soldier Fly (BSF) maggots or larvae. These maggots can serve as an alternative feed due to their high protein content; BSF prepupa contains 40% protein and 30% fat, making them a suitable alternative animal feed ingredient [17, 18]. Additionally, dried coffee pulp waste can be used to develop briquette products. Coffee pulps from the pulping process have a high calorific value range of 3000 - 5000Kcal/kg, low moisture content, and low sulfur content, making them an efficient source for briquettes [19, 20].

3.3 Implementation of standard operating procedures

The standard operating procedures (SOP) document was socialized to all employees to ensure they are aware of and adhere to the system standards in the production process. The validation process for the SOP documents involves evaluating employee understanding and product yields. Employee understanding is assessed by distributing survey questions related to the SOP documents. This aims to measure employees' perceived understanding of SOPs. The questionnaire was distributed to four respondents, using a Likert scale [21] ranging from strongly disagree to agree strongly.

Standard operating procedures (SOPs) are guidelines an organization uses to ensure that work stages are conducted efficiently, consistently, and according to required standards and systematics [22]. Preparing an SOP begins with identifying the entire production process through interviews and observations. The SOP is then documented based on the standards and process specifications applied in the production section. This documentation is carried out at each production stage. Once created, the SOP document is socialized and tested for effectiveness. Socialization involves informing every production-related employee about the SOP document through written procedures distributed to them. A trial of the SOP is then conducted, and the results are used for evaluation.



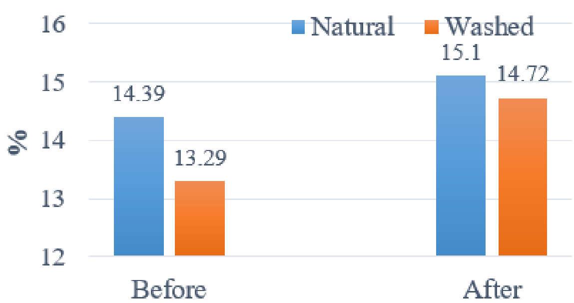


Figure 5. Level of employee understanding of SOP (above) and comparison of production yields before and after SOP socialization (below)

The SOP preparation process begins with standardizing the production process, which includes identifying critical points in each process. Critical points are determined to identify the most important parts that influence the quality and quantity of the process. Some critical points are inaccurate sorting of coffee cherries, imperfect fermentation processes, and uneven water content during drying processes.

Standardization is implemented immediately after identifying the critical points. Standardization ensures that the processes are consistently carried out, producing high-quality and sufficient quantities of green beans. SOP documents are prepared based on established standards and include clear and concise descriptions of procedures. These procedures cover each process stage, including weighing, browsing, sorting, fermentation, pulping, washing, drying, hulling, grading, and storage.

Figure 5 shows that 80% of respondents understood the SOP document, and 20% firmly understood it. Product yield evaluation is conducted by analysing the green beans produced. Percent yield serves as a reference for production process efficiency. A higher percent yield indicates a more efficient production process [23]. The image compares percent yields before and after the implementation of the SOP. Based on the graph, there was an increase in yield after implementing the SOP. Before the SOP, the yield for the natural process was 14.39%, which increased to 15.10% after the SOP. For the washed process, the yield was 13.29% before the SOP and 14.72% after the SOP. The type of processing affects the yield obtained. Although the increase in yield is still small and has not yet matched the yields reported by Wibowo and Palupi [11], the improvement indicates that the production process has become more efficient.

3.4 Utilization of wet coffee pulp waste into dried maggots

The wet coffee pulp waste produced during the pulping process constitutes 38.2% of the coffee cherries processed. This significant percentage indicates that the production process generates a substantial amount of waste. To address this issue, a solution is proposed to utilize wet coffee pulp waste as feed for maggots.

Black Soldier Fly (BSF) larvae, or maggots, are the second phase of the development process from egg to adult fly. These larvae can decompose organic waste without being vectors of disease. Maggots have cellulolytic activity due to the presence of bacteria in their intestines. The bacteria in BSF larvae intestines aid in converting organic waste [24]. Symbiotic bacteria such as *Bacillus* sp. act as agents for controlling plant pathogens. During this phase, the larvae release several antibacterial compounds into the compost biomass, resulting in cleaner compost free from harmful microbes [25]. Maggots can be used as alternative animal feed due to their high protein and fat content, which range from 30.31-60.19% and 9.13-13.13%, respectively. This is supported by their beneficial enzyme content [26].

3.4.1 Feed suitability

A proximate analysis was conducted to determine the contents of the wet coffee pulp, including water, ash, protein, fat, and carbohydrate content. The nutritional content significantly influences maggot growth. According to Dortman et al. [27] and Nur'aini and Prawanto [28], the water content in feed must be sufficiently moist, and ingredients rich in protein and carbohydrates promote good maggot growth.

The proximate analysis of coffee pulps shows results similar to those found in research by Manasa et al. [29]. Variations in water, ash, protein, fat, and carbohydrate content can be attributed to different environmental conditions where the coffee is grown, such as soil, climate, and plant growth conditions. Additionally, the seed varieties used can influence the coffee pulp content. The water content of fresh coffee pulps is 73.51%, sufficiently moist for maggot feed. According to Dortman et al. [27], organic material with a water content of 60% to 90% is readily digestible by maggots. BSF larvae can degrade organic waste, reducing its wet weight by up to 80%.

3.4.2 Dry maggots

Dry maggots are obtained through roasting using quartz sand, which requires prior washing. Quartz sand is used to roast 500 grams of fresh maggots in one batch (totaling 1.25kg), which takes approximately 15-20 minutes. This process results in 100g of dry maggots, representing an 80% reduction in weight loss percentage, which is consistent with findings from research conducted by Erwanto et al. [30], where the weight loss between wet maggots and dry maggots fed with vegetable/fruit waste was reported at 73.79%. Table 1 shows a proximate analysis of dry maggots.

Table 1. Proximate analysis of dry maggot

Characteristic	This Study	Sari et al. [31]	Commercial Product
Water content (%)	5.87±0.29	2.34	2.66
Ash content (%)	14.56±1.02	12.18	17.41
Protein content (%)	34.3±3.09	44.63	34.53
Fat content (%)	27.3±0.27	24.69	29.31
Carbohydrate content (%)	17.97±1.97	16.16	16.09

The nutritional analysis of the dried maggots in this study aligns closely with findings from Sari et al. [31] and other commercial products. The dried maggots retain high nutritional value, particularly in protein content. The growth and development of larvae heavily depend on environmental conditions, and high waste reduction does not always ensure optimal growth for BSF larvae. Dried maggots are commonly used as alternative feed for livestock such as chickens, ornamental birds, and ornamental fish. Dried maggots are a valuable nutritional supplement in livestock feeding with their high protein content.

3.4.3 Maggot waste

In addition to obtaining dried maggot products, the residual waste from organic degradation by BSF larvae, commonly known as maggot waste, can be utilized as fertilizer. Maggot waste is the residue from organic waste reduction activities by BSF larvae, which serves as a nutrient-rich fertilizer. According to Sari et al. [31], maggot waste has chemical characteristics with nutrient levels and microbiological properties that exceed standard quality criteria. Maggot residue is usually used as fertilizer and is widely used in gardening, vegetable plots, and other agricultural applications.

3.5 Utilization of dried coffee pulp waste as raw material for briquettes

Dry coffee pulp waste is produced during the hulling process in green bean production. Mass balance calculations indicate that dry coffee pulp waste accounts for 10.2% of total production in natural processing and 3.7% in washed processing. This waste can be effectively used as raw material for briquette production. Considering all the test parameters, the optimal briquette formulation is a ratio of 0.3:0.7 for dry cascara to dry coffee pulp. This formulation outperforms others in most test parameters, including the crucial parameter of calorific value. The test results for briquette composition are detailed in Table 2.

Table 2 indicates that the calorific value of the coffee pulp waste briquettes was 6043.07±598.26cal/g. This value surpasses that of wood briquettes [32] and rubber seed shell biomass waste briquettes [33] while being comparable to Alban wood charcoal and coal ash briquettes [33].

Table 2. Chemical composition of the briquette formulation

Parameter	Value
Water content (%)	2.63±0.29
Ash content (%)	10.93±1.20
Density (g/cm^3)	0.76±0.08
Burning rate (%)	0.00243±0.0003
Caloritic value (cal/g)	6043.07±598.26

This research concludes that increasing the proportion of dry coffee pulps enhances the quality of the briquettes. Briquettes were produced using 100% dry coffee pulps while maintaining the adhesive concentration at 14%. Qualitative tests assessed parameters such as hardness level, duration, burning power, and aroma [34]. However, the challenge of achieving consistent ash content levels in the briquettes remains unresolved, underscoring the need for further tests focused explicitly on optimizing adhesive concentration. According to Anis et al. [35], the concentration of starch adhesive significantly influences the ash content produced in briquettes.

Transforming dried coffee pulp waste into briquettes involves several stages to convert raw materials into usable briquettes. The production flow begins with the carbonization or charring process, where the raw material is converted into charcoal through controlled burning in a limited oxygen environment. Conventional carbonization for dry coffee pulp waste is conducted by stacking and burning in the open air. According to Yaashikaa et al. [36], carbonization is converting organic substances into carbon or carbon-rich residues through destructive pyrolysis or distillation. The yield of charcoal produced from this conventional carbonization process is approximately 43% of the initial raw material used.

Subsequently, the charcoal flour undergoes a mixing process to ensure homogeneity. Adhesive was added and thoroughly mixed to bind the charcoal flour, which inherently lacks cohesive properties. Binders are crucial in the briquetting stage, particularly when the biomass used has specific characteristics such as low bulk density, lignin content, and water-soluble carbohydrates [37].

The briquette molding process follows, where the mixture is compacted under a pressure of at least 100kg/cm². The compaction pressure directly influences the density of the briquettes, impacting their energy content per volume. Drying is essential to reduce the moisture content in the briquettes, as highlighted by Zhuo et al. [38], as it affects the initial ignition process. Additionally, drying activates the adhesive to solidify the briquette structure. Solar drying and a dehydrator equipped with a blower are employed, with the latter drying the briquettes at 70°C for 24 hours to accelerate the process.

3.6 Business model

The business model involves platforms that connect resources and processes and provide resulting services to ensure long-term profitability for the company. A business model outlines how a company can generate profit. The business can operate with greater focus by defining the products offered and identifying the target market. A business model can be broken down into three parts: the type of product produced and the resources available for its creation, the marketing and distribution strategies, and the pricing strategy for the sales process. Figure 6 illustrates the changes in the business model of the industrial ecology of the coffee processing industry.

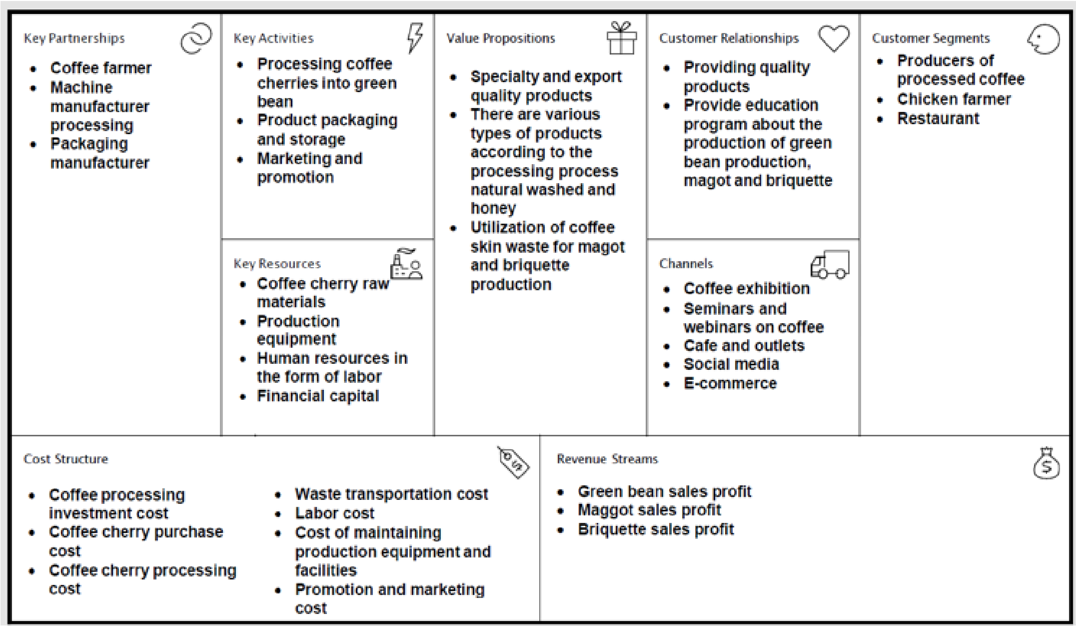


Figure 6. Business model of industrial ecology of coffee processing industry

Figure 6 illustrates the revised business model, adapted to the eco-industry approach of the coffee processor. This renewal is driven by the introduction of new products within the overall production process. In the customer segments section, additions include new segments such as chicken farmers and ornamental fish owners for dried maggot products and BBQ restaurants for briquette products. In customer relations, there are changes to the education program with a greater emphasis on the zero-waste concept due to the reduction and utilization of waste in green bean production. The channels section remains unchanged from the previous business model.

Additional points in the value propositions section include products derived from waste processing, such as maggots and briquettes. Key activities of the business model have expanded from solely producing green beans to also cultivating maggots and producing briquettes. In the key resources section, there are new resources, such as coffee husk charcoal. The key partners section remains unchanged from the previous business model.

Changes in the business model are also evident in the cost structure section, with new cost structures, including investment costs for waste processing, purchasing maggot eggs, and purchasing coffee charcoal. These changes in the cost structure lead to additional income and an increase in the revenue stream from the sales of dried maggots and briquettes.

The results of this study offer both social and economic benefits. From a social perspective, utilizing coffee waste helps reduce environmental pollution and mitigates negative social impacts on the surrounding community. Economically, the utilization of coffee waste generates products such as dried maggots and briquettes, which have market value and provide additional income opportunities for coffee processors.

3.7 Challenges and limitations of implementing the eco-industrial system

Industrial ecology is deeply interconnected with utilizing natural resources, production technologies, and management practices. It has become an essential component of ecological policy, serving as a critical foundation for environmental management and economic competitiveness. By fostering the adoption of sustainable production processes, industrial ecology facilitates the transition from traditional to modern manufacturing methods, providing companies with a competitive edge [39]. Integrating industrial ecology into economic practices involves developing and implementing innovative products, services, or processes, as well as new marketing and organizational strategies that enhance workplace efficiency and environmental relationships.

The primary objective of industrial ecology is to deliver environmental benefits, which can arise directly from production processes or through the use of products and services by consumers. These benefits include:

- Reduced material consumption per unit of product,
- Lower emissions detrimental to the environment and company operations,
- Use of less polluting and more environmentally friendly resources,
- Mitigation of soil, water, and air pollution.

Despite its advantages, adopting industrial ecology can face various challenges at different stages of development and implementation. These challenges often mirror those encountered by other types of innovation but are amplified by market failures in environmental protection [40]. Key obstacles include:

- Economic: Limited internal financial resources, insufficient external funding, high interest rates on innovation loans, financial risks due to uncertainty in return on investment, and doubts about achieving economic benefits.
- Legal: Frequent legislative changes create market uncertainty and unclear or inconsistent environmental protection regulations.
- Marketing: Poor identification of market needs and uncertainties around the demand for innovative products.
- Technological: Insufficient research and development infrastructure, lack of information about available technologies, limited technology accessibility, and inadequate support from research centers.
- Staffing: Inadequate managerial competencies, lack of skilled personnel to manage ecological innovation processes, insufficient training and experience, lack of confidence, and reluctance to take risks in eco-innovation.

Addressing these challenges requires coordinated efforts across economic, legal, technological, and human resource domains to ensure the successful implementation of industrial ecology and its long-term benefits.

4. CONCLUSIONS

Implementing eco-industrial design can improve production efficiency and waste utilization in the coffee processing industry. Efficiency is enhanced through standardized operations, achieved by developing standard operating procedures (SOPs) for green bean production. Simultaneously, waste reduction strategies are applied by repurposing wet coffee pulp waste as feed for Black Soldier Fly (BSF) larvae and converting dry coffee pulp waste into briquette products. This approach promotes sustainable practices and enhances coffee production's economic viability by creating value-added products from waste streams.

ACKNOWLEDGMENTS

This work is supported by the Ministry of Research, Technology and Higher Education of the Republic of Indonesia (Grant No.: 15834/IT3.D10/PT.01.02/P/T/2023).

REFERENCES

[1] Purnomo, M., Yuliati, Y., Shinta, A., Riana, F.D. (2021). Developing coffee culture among Indonesia's middle-class: A case study in a coffee-producing country. Cogent Social Sciences, 7(1): 1949808. https://doi.org/10.1080/23311886.2021.1949808

[2] Shah, A., Che Mat, C.R., Ibrahim, A., Zhang, Y., Muzammil, S. (2024). Introduction to industrial ecology. In: Industrial Ecology. Industrial Ecology. Springer, Singapore. https://doi.org/10.1007/978-981-97-3619-5_1

[3] Li, C., Ahmad, S.F., Ayassrah, A.Y.B.A., Irshad, M., Telba, A.A., Awwad, E.M., Majid, M.I. (2023). Green production and green technology for sustainability: The mediating role of waste reduction and energy use. Heliyon, 9(12): e22496, https://doi.org/10.1016/j.heliyon.2023.e22496

[4] Shah, A., Che Mat, C.R., Ibrahim, A., Zhang, Y., Muzammil, S. (2024). Current practices in industrial ecology. In: Industrial Ecology. Industrial Ecology. Springer, Singapore. https://doi.org/10.1007/978-981-97-3619-5_2

[5] Fet, A.M., Deshpande, P.C. (2023). Closing the loop: industrial ecology, circular economy and material flow analysis. In Business Transitions: A Path to Sustainability: The CapSEM Model. Cham: Springer International Publishing, pp. 113-125. https://doi.org/10.1007/978-3-031-22245-0_11

[6] Suh, D.H., Moss, C.B. (2021). Examining the input and output linkages in agricultural production systems. Agriculture, 11(1): 54. https://doi.org/10.3390/agriculture11010054

[7] Teresa, E. (2023). Industrial management: Enhancing efficiency and productivity. Industrial Engineering & Management, 12: 2. https://www.hilarispublisher.com/open-access/industrial-management-enhancing-efficiency-and-productivity.pdf.

[8] Ray, S.C. (2022). Choice of inputs and outputs for production analysis. In Handbook of Production Economics. Singapore: Springer Nature Singapore, pp. 1083-1116. https://doi.org/10.1007/978-981-10-3455-8_20

[9] Utsev, J.T., Imoni, S., Onuzulike, C., Akande, E.O., Orseer, A.M., Tiza, M.T. (2024). Strategies for sustainable construction waste minimization in the modern era. Bincang Sains dan Teknologi, 3(1): 1-10. https://doi.org/10.56741/bst.v3i01.506

[10] Pérez Calvo, A., Paz Ruiz, N., Delgado Espinoza, Z. (2023). Coffee pulp: A sustainable and affordable source for developing functional foods. Processes, 11(6): 1693. https://doi.org/10.3390/pr11061693

[11] Wibowo, Y., Palupi, C.B. (2022). Analisis nilai tambah pengolahan biji kopi arabika (studi kasus: Rumah kopi banjarsengon, Jember). Jurnal Agroteknologi, 16(1): 37-48.

[12] Snyder, A.B., Martin, N., Wiedmann, M. (2024). Microbial food spoilage: Impact, causative agents and control strategies. Nature Reviews Microbiology, 22: 528-542. https://doi.org/10.1038/s41579-024-01037-x

[13] Taormina, P.J. (2021). Microbial growth and spoilage. In: Taormina, P.J., Hardin, M.D. (eds) Food safety and quality-based shelf life of perishable foods. Food Microbiology and Food Safety. Springer, Cham, pp. 41-69. https://doi.org/10.1007/978-3-030-54375-4_3

[14] Muhardi, M., Cintyawati, C., Adwiyah, R., Hami, N., Hashim, R., Omar, S., Shafie, S.M. (2020). The implementation of sustainable manufacturing practice in textile industry: An Indonesian perspective. The Journal of Asian Finance, Economics and Business, 7(11): 1041-1047. https://doi.org/10.13106/jafeb.2020.vol7.no11.1041

[15] Sarkar, B.D., Sharma, I., Gupta, S. (2023). Waste minimization in agri-food supply chain: Perspective for sustainable development. Environment, Development and Sustainability, 1-25. https://doi.org/10.1007/s10668-023-04130-y

[16] Nissinboim, N., Naveh, E. (2018). Process standardization and error reduction: A revisit from a choice approach. Safety Science, 103: 43-50. https://doi.org/10.1016/j.ssci. 2017.11.015
[17] Supriyatna, A., Kurrahman, O.T., Cahyanto, T., Yuliawati, A., Kulsum, Y. (2018). The potency of black soldier larvae (Hermetia illucens L.) as a source of protein for livestock feed. Biosaintifika: Journal of Biology & Biology Education, 10(2): 448-454. https://doi.org/10.15294/biosaintifika.v10i2.14422
[18] Ewald, N., Vidakovic, A., Langeland, M., Kiessling, A., Sampels, S., Lalander, C. (2020). Fatty acid composition of black soldier fly larvae (Hermetia illucens)-Possibilities and limitations for modification through diet. Waste Management, 102: 40-47. https://doi.org/10.1016/j.wasman.2019.10.014
[19] Demisu, D.G., Muluye, A.B. (2024). Factors affecting the quality and performance of bio-briquette produced from biomasses via thermo-physical processes: Synthesis. International Journal of Energy and Water Resources, 8(3): 371-384. https://doi.org/10.1007/s42108-023-00268-7
[20] Tamilselvan, K., Sundarajan, S., Ramakrishna, S., Amirul, A.A.A., Vigneswari, S. (2024). Sustainable valorisation of coffee husk into value added product in the context of circular bioeconomy: Exploring potential biomass-based value webs. Food and Bioproducts Processing, 145: 187-202. https://doi.org/10.1016/j.fbp.2024.03.008
[21] Joshi, A., Kale, S., Chandel, S., Pal, D.K. (2015). Likert scale: Explored and explained. British Journal of Applied Science & Technology, 7(4): 396-403. https://doi.org/10.9734/BJAST/2015/14975
[22] Bhattacharya, J. (2015). Guidance for preparing standard operating procedures (SOPs). IOSR Journal of Pharmacy, 5(1): 29-36. http://iosrphr.org/papers/v5i1/Version-2/E0512029036.pdf.
[23] Hegab, H., Shaban, I., Jamil, M., Khanna, N. (2023). Toward sustainable future: Strategies, indicators, and challenges for implementing sustainable production systems. Sustainable Materials and Technologies, 36: e00617. https://doi.org/10.1016/j.susmat.2023.e00617
[24] Li, X., Zhou, S., Zhang, J., Zhou, Z., Xiong, Q. (2021). Directional changes in the intestinal bacterial community in black soldier fly (Hermetia illucens) larvae. Animals, 11(12): 3475. https://doi.org/10.3390/ani11123475
[25] Zabulionė, A., Šalaševičienė, A., Makštutienė, N., Šarkinas, A. (2023). Exploring the antimicrobial potential and stability of black soldier fly (Hermentia illucens) larvae fat for enhanced food shelf-life. Gels, 9(10): 793. https://doi.org/10.3390/gels9100793
[26] Makinde, O.J., Makinde, J. (2015). Maggot meal: A sustainable protein source for livestock production-A review. Advances in Life Science and Technology, 31: 35-42.
[27] Dortman, B., Diener, S., Verstappen, B., Zurbrugg, C. (2017). Black Soldier Fly Biowaste Processing: A Step-By-Step-Guide. Dübendorf, Switzerland.
[28] Nur'aini, N., Prawanto, A. (2022). The effectiveness of maggot (Hermetia Illucens) growth in various growing media. Indonesian Journal of Agricultural Research, 4(3): 219-226. https://doi.org/10.32734/injar.v4i3.7155
[29] Manasa, V., Padmanabhan, A., Anu Appaiah, K.A. (2021). Utilization of coffee pulp waste for rapid recovery of pectin and polyphenols for sustainable material recycle. Waste Management, 120: 762-771. https://doi.org/10.1016/j.wasman.2020.10.045
[30] Erwanto, E., Fathul, F., Sutrisna, R. (2024). Effect of growth media differences on maggot weight, fresh production and dry matter black soldier fly (BSF). In AIP Conference Proceedings. 2970(1): 050041. https://doi.org/10.1063/5.0209840
[31] Sari, G.L., Sefrina, L.R., Hanifi, R., Rizki, S., Samad, A.S. (2024). Analysis of maggot nutrition in various farming periods and organic wastes as a growth medium. In E3S Web of Conferences. EDP Sciences, 500: 02005. https://doi.org/10.1051/e3sconf/202450002005
[32] Kumar, J.A., Kumar, K.V., Petchimuthu, M., Iyahraja, S., Kumar, D.V. (2021). Comparative analysis of briquettes obtained from biomass and charcoal. Materials Today: Proceedings, 45(2): 857-861. https://doi.org/10.1016/j.matpr.2020.02.918
[33] Haryanti, N.H., Wardhana, H., Husain, S., Noor, R., Anggraini, Y., Sofi, N., Aprilia, D. (2021). Briquettes from biomass waste. In Journal of Physics: Conference Series. 2104(1): 012003. https://doi.org/10.1088/1742-6596/2104/1/012003
[34] Yunusa, S.U., Mensah, E., Preko, K., Narra, S., Saleh, A., Sanfo, S. (2024). A comprehensive review on the technical aspects of biomass briquetting. Biomass Conversion and Biorefinery, 14(18): 21619-21644. https://doi.org/10.1007/s13399-023-04387-3
[35] Anis, S., Fitriyana, D.F., Bahatmaka, A., Anwar, M.C., Ramadhan, A.Z., Anam, F.C., Permana, F.A., Hakim, A.Z., Da Silva Guterres, N.F., Da Silva, M.S. (2024). Effect of adhesive type on the quality of coconut shell charcoal briquettes prepared by the screw extruder machine, Journal of Renewable Materials, 12(2): 381-396. https://doi.org/10.32604/jrm.2023.047128
[36] Yaashikaa, P.R., Kumar, P.S., Varjani, S., Saravanan, A.J.B.R. (2020). A critical review on the biochar production techniques, characterization, stability and applications for circular bioeconomy. Biotechnology Reports, 28: e00570. https://doi.org/10.1016/j.btre.2020.e00570
[37] Kpalo, S.Y., Zainuddin, M.F., Manaf, L.A., Roslan, A.M. (2020). Production and characterization of hybrid briquettes from corncobs and oil palm trunk bark under a low pressure densification technique. Sustainability, 12(6): 2468. https://doi.org/10.3390/su12062468
[38] Zhuo, Y., Xie, Z., Shen, Y. (2021). Model study of carbonisation of low rank coal briquettes: Effect of briquettes shape. Powder Technology, 385: 120-130. https://doi.org/10.1016/j.powtec.2021.02.071
[39] Shah, A., Che Mat, C.R., Ibrahim, A., Zhang, Y., Muzammil, S. (2024). Challenges of industrial ecology in the manufacturing sector. In Industrial Ecology: A Fusion of Material and Energy in Green Supply Chain Context. Singapore: Springer Nature Singapore, pp. 283-323. https://doi.org/10.1007/978-981-97-3619-5_14
[40] Hegab, H., Shaban, I., Jamil, M., Khanna, N. (2023). Toward sustainable future: Strategies, indicators, and challenges for implementing sustainable production systems. Sustainable Materials and Technologies, 36: e00617. https://doi.org/10.1016/j.susmat.2023.e00617