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# HANDBOOK ON CIRCULAR ECONOMY MODELS IN COFFEE PRODUCTION

ISPAE

INSTITUTE OF STRATEGY AND POLICY ON AGRICULTURE AND ENVIRONMENT

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# CIRCULAR ECONOMY MODELS IN COFFEE PRODUCTION

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# ACRONYMS

| | |
|---|---|
| AGREINFOS | Centre for Information and Services in Agriculture and Environment |
| ARP | Agricultural Restructuring Plan |
| BOD | biological oxygen demand |
| CE | circular economy |
| CF | carbon footprint |
| CGIAR | Consultative Group on International Agricultural Research |
| CIRAD | French Agricultural Research Centre for International Development |
| COD | chemical oxygen demand |
| CPTPP | Comprehensive and Progressive Agreement for Trans-Pacific Partnership |
| DARD | Department of Agriculture and Rural Development |
| EUDR | EU Deforestation Regulation |
| EVFTA | EU–Viet Nam Free Trade Agreement |
| FDI | foreign direct investment |
| GBE | Green Bean Equivalent |
| GDP | gross domestic product |
| GHG | greenhouse gas |
| GWP | global warming potential |
| HRT | hydraulic retention time |
| IPSAE | Institute of Strategy and Policy for Agriculture and Environment |
| IRR | internal rate of return |
| LPG | liquefied petroleum gas |
| MAE | Ministry of Agriculture and Environment |
| MARD | Ministry of Agriculture and Rural Development |
| NDC | Nationally Determined Contributions |
| NPK | nitrogen, phosphorus, and potassium |
| NPV | net present value |
| TSS | total suspended solids |
| UKVFTA | UK–Viet Nam Free Trade Agreement |
| UNDP | United Nations Development Programme |
| VAC | vườn-ao-chuồng (garden-pond-livestock] |

# GLOSSARY

**Carbon footprint**
A carbon footprint in agriculture refers to the total emissions over the life cycle of production, including emissions from chemical manufacturing, energy, machinery, equipment, etc. It is measured in the same units as GHG emissions and calculated per product unit (kgCO2e/kg of product).

**Coffee intercropping and agroforestry**
Coffee intercropping and agroforestry refer to cropping systems in which coffee is cultivated alongside other crops and/or trees to enhance productivity, biodiversity, and resource use efficiency. These systems involve selecting complementary crops/species that do not compete with coffee for essential resources and/or provide ecological functions. Common components include fruit trees, leguminous species, and shade trees, which contribute to soil fertility, influence microclimate, and have the potential to provide other ecosystem services (e.g. pests and diseases' regulation), thereby improving overall system sustainability and resilience.

**Dry (Natural) processing method**
Dry processing is one of the oldest and most basic coffee processing procedures in history, commonly used to process Robustarobusta coffee. This procedure aims to reduce the moisture content of the coffee to 10–12 per cent through sun-drying or using a mechanical drying machine.

**Greenhouse gas (GHG) emissions**
GHG emissions are usually measured in tons of carbon dioxide equivalent (tCO2e). They are calculated according to the global warming potential (GWP) of methane and nitrogen oxide emissions per unit of area (ha) or ton of product.

**Pulped natural (Honey) processing method**
Pulped natural processing involves removing the outer fruit layer of the coffee cherry (depulping) before drying the beans. It is also called "honey" depending on the amount of mucilage kept around the beans before drying. However, careful drying after depulping remains essential to ensure quality and avoid fungal contamination.

**Wet (Washed) processing method**
Wet processing is a coffee processing method in which coffee cherries are first depulped, before removing the remaining mucilage through a fermentation step carried out in water-filled tanks. As a result, this method requires a substantial amount of water, which should be properly treated before being released to avoid environmental pollution. However, this method is commonly preferred for arabica coffee in regions where water is readily available, as it lowers the risk of contamination and defects, leading to a more consistent flavour profile.

## Acknowledgements

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This work is supported by the Building Circularity into Nationally Determined Contributions (NDCs) - A Practical Toolbox (CE-NDC Toolbox), co-developed by UNDP, UNEP's One Planet Network, and the UNFCCC secretariat. Viet Nam is one of seven countries that are currently implementing the CE-NDC Toolbox around the world. This Handbook relates primarily to Stage 2 of the CE-NDC Toolbox, which aims to help identify and select circular interventions and assess their potential mitigation impact to inform the NDC 3.0. process.


## Objectives and Target Audience of the Handbook

The objectives of this Handbook are to present evidence on good circular practices and to provide actionable recommendations contributing to the transformation of the coffee sector and alignment with national climate goals and international sustainability commitments, thereby supporting Viet Nam's agricultural sector climate ambitions. It outlines the application of circular economy (CE) principles across the coffee production landscape, helping to address existing gaps by offering practical guidance and evidence-based recommendations for implementing and scaling circular practices that reduce waste, optimize resource use, and minimize environmental impacts in the coffee sector.

Targeted for use by coffee producers, processors, exporters, business associations, Farmers' Unions, coffee cooperatives, Non Governmental Organizations (NGOs), academia, agricultural extension centres, and community organizations, as well as policymakers and other coffee industry stakeholders engaged in sustainable agricultural practices and environmental conservation. The Handbook will also serve as a valuable resource for agricultural researchers, industry experts, and organizations working to promote the adoption of CE models across agricultural supply chains. It is also designed to assist the Ministry of Agriculture and Environment (MAE), local authorities, and other policymakers working to integrate CE into agriculture strategies.

## About *Building Circularity into NDCs: A Practical Toolbox*

As of 2023, only 28 per cent of NDCs explicitly mention CE as part of their mitigation measures. However, CE approaches can contribute to the reduction of GHG emissions in several NDC sub-sectors, representing key opportunities to advance climate ambition.

The CE-NDC Toolbox aims to support countries in identifying, prioritizing, implementing, and tracking CE interventions in their NDCs to raise ambition and accelerate implementation as part of a just and inclusive transition. The toolbox is organized in four stages to leverage a country's policy cycle, from assessing the GHG emissions associated with material use and prioritising sectors/sub-sectors for the NDC to defining CE policy responses, identifying policy instruments, and tracking and reporting progress in national Biennial Transparency Reports (BTRs) as part of the NDC process. Each stage includes a set of steps and key questions to consider, as well as tried-and-tested tools, case studies, and checklists. Examples of how to use the toolbox in two high-impact sectors (construction and food waste) are also provided in the User Guide.

# EXECUTIVE SUMMARY - KEY RESULTS FOR NDC 3.0

Coffee production is central to Viet Nam's socio-economic development, employing over 600,000 farmers directly and supporting more than 2.6 million jobs. It is also, however, highly resource- and emission-intensive, contributing significantly to the agriculture sector's GHG emissions.

In 2024, the total plantation area for coffee in Viet Nam was 718,000 hectares, producing more than 1.95 million tons annually (MAE, 2025). Given that most Vietnamese coffee production uses dry processing, and assuming that each kilogram of green beans generates a nearly equivalent weight of dry husks, an estimated 1.6 million tons of dry husks are produced annually, representing a valuable resource for high-quality fertilizer.

CE models in the coffee sector can simultaneously reduce emissions, recycle waste, improve soil health, and enhance climate resilience, as illustrated in the Central Highlands and Northern provinces. Examples and best practices exist and must be scaled up.

This Handbook, therefore, presents four high-impact CE models for coffee production, validated with expert interviews and field visits: intercropping with avocado, durian, persimmon, pepper, and macadamia; producing organic fertilizer from coffee husks; improving small-scale wastewater treatment; and improving large-scale biogas wastewater treatment. The handbook presents technical guidance and detailed steps and photos to guide farmers and cooperatives in applying these practices.

Adopting these models can reduce the carbon footprint of coffee production and minimise pollution from waste and wastewater, directly supporting Viet Nam's climate commitments. Further, these models can enhance farm profitability by lowering chemical fertilizer use, boosting yields, and diversifying income sources, with additional social and environmental co-benefits, including stronger community engagement in resource stewardship and more resilient farming systems.

All the models present proven economic and environmental benefits, such as:

- **Intercropping coffee with avocado, durian, pepper, persimmon, and macadamia:** Diversifies income, increases carbon sequestration, and raises net present value (NPV) by 57% over monocropping.
- **Producing organic fertilizer from coffee husks:** Turns 45% of dry cherry waste into nutrient-rich compost, reducing chemical fertilizer dependence and costs.
- **Improving Small-scale wastewater treatment:** Low-cost biological systems cut pollution from arabica wet-processing.
- **Improving Large-scale biogas wastewater treatment:** Profitable at processing plants, with an internal rate of return of (IRR) of 28 - 34% and NPV up to VND 983 million VND over 15 years.

Recent assessments identify three major emission hotspots in Viet Nam's green coffee production: nitrogen fertilizer use on soils (driving $N_2O$ emissions), industrial fertilizer production, and fossil fuel energy use in cultivation, processing, and transport.

Therefore, mitigation priorities in coffee production should include:

- Optimizing fertilizer use through improved formulations and calibrated application to cut $N_2O$ emissions;
- Improving energy efficiency across the supply chain, from mechanization to processing and logistics, to reduce $CO_2$ emissions; and
- Promoting sustainable production models, including agroforestry, renewable energy, and low-impact processing technologies.

To mitigate the environmental impact of coffee wastewater, the Handbook also highlights three practical solutions for small- and large-scale facilities:

- Anaerobic treatment to capture methane and convert it into biogas for energy use;
- Biological treatments using microorganisms or enzymes to lower biological oxygen demand (BOD) and chemical oxygen demand (COD), thereby reducing methane emissions; and
- Water recycling systems to cut wastewater volumes, decrease organic loads, and enhance processing efficiency.

Together, these measures reduce pollution, limit GHG emissions, and improve resource efficiency in coffee processing.

Adopting these measures would increase farm profitability through better resource efficiency, lower input and operational costs in processing and distribution, enhance investment attractiveness and scalability of climate-smart coffee, and contribute to resilient, low-carbon agriculture aligned with Viet Nam’s NDC and global climate commitments.

By combining environmental gains with economic and social advantages, CE models in the coffee sector offer a practical pathway to advance Viet Nam’s sustainable agriculture and NDC ambitions while aligning with trade and market drivers. In addition, circular practices in coffee production in agriculture directly support Viet Nam’s NDC target of 15.8% unconditional and 43.5% conditional emission reductions by 2030. The Handbook also contributes to achieving the objectives of the Prime Minister Decision 540/QD-TTg dated 19 June 2024 approved the Development Programme of Science and Technology Application and Transfer to promote a circular economy in agriculture; and is compatible with European Union (EU) Deforestation Regulation (EUDR) requirements.

Chapter 1

# BACKGROUND

## 1.1 Context and Coffee Production in Viet Nam

Agricultural development plays a crucial role in ensuring a consistent food supply for a growing global population, eradicating extreme poverty, and promoting shared prosperity. Agriculture accounts for approximately 4 per cent of global gross domestic product (GDP), with some of the least developed countries relying on it for over 25 per cent of their GDP (World Bank, 2020). As of 2024, Viet Nam's agriculture, forestry, and fishing sector contributed approximately 11.9 per cent to the country's GDP (World Bank, 2024). However, the agriculture sector is the second-largest contributor of GHG emissions in Viet Nam, at about 19 per cent of total emissions in 2020 (World Bank, 2022).

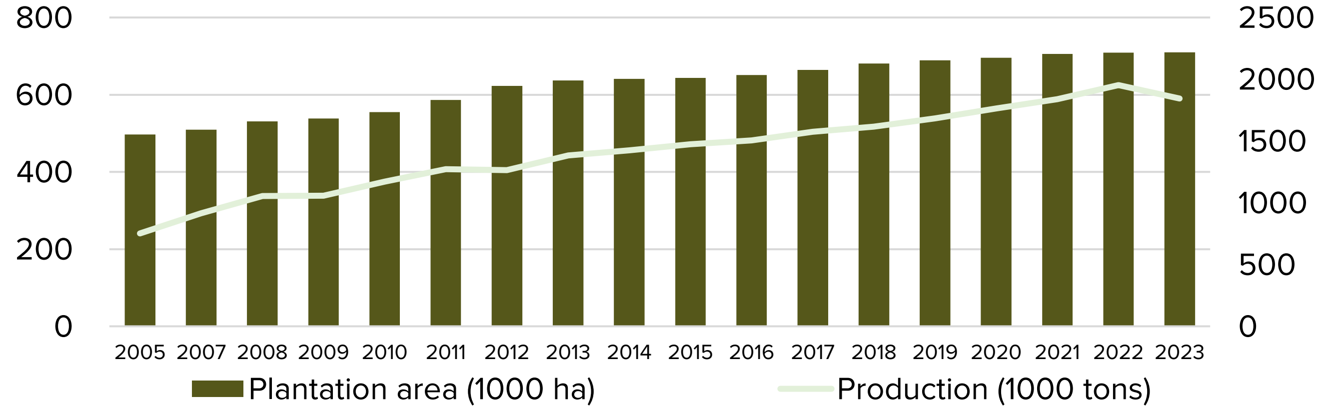
Viet Nam's most recent NDC outlines a commitment to reducing total GHG emissions by 15.8 per cent unconditionally and up to 43.5 per cent with international support by 2030, compared to the business-as-usual (BAU) scenario (Socialist Republic of Viet Nam, 2022). Given its substantial share of national emissions, the agriculture sector is integral to achieving these targets. Implementing circular economy practices (such as optimizing biomass use, recycling agricultural waste, and adopting sustainable farming techniques) can play a pivotal role in mitigating emissions while enhancing the sector's resilience to climate impacts.

A subset of Viet Nam's agricultural sector, the coffee industry employs 600,000 - 700,000 direct employees (Duc et al., 2021) and roughly 2 million labour jobs in coffee processing and support services, significantly and increasingly contributing to the country's socio-economic development and global coffee value chains. While the sector is critical for livelihoods and exports, it is also associated with high fertiliser use, water-intensive practices, deforestation risk, and large volumes of organic waste and wastewater, all of which lead to soil degradation, water pollution, and GHG emissions.

Viet Nam is the world's second-largest coffee producer and its top exporter of robusta coffee, accounting for 17 per cent of global production (USDA, 2025). Just in the 2023 - 2024 crop year, Viet Nam alone produced approximately 1.95 million tons of coffee (roughly 32.6 million bags), with export earnings exceeding USD 5 billion, the highest ever recorded (VNS, 2024). Vietnamese coffee has been exported to over 80 countries and territories, bringing in USD 4.18 billion in 2023 (MAE, 2024). The EU is Viet Nam's largest coffee export market, accounting for about 41 per cent of total export value, followed by Japan (7.5 per cent), USA (about 7 per cent), the UK (2.7 per cent) and South Korea (2.2 per cent) (Viet Nam Customs Office, 2024). In coffee production in Viet Nam, 90 per cent of coffee beans are robusta and only 10 per cent are arabica (MAE, 2024).

The Central Highlands are the largest robusta coffee-producing region in Viet Nam, accounting for more than 95 per cent of coffee production. In the North, the total area for coffee production in Son La province in 2023 was 18.8 thousand hectares, accounting for only 2.8 per cent of the total coffee area but about 50.3 per cent of the total arabica area (MAE, 2024).

**Figure 1. Coffee plantation area and production in Viet Nam (2005 - 2023)**




*Source: GSO and MAE, 2024*

Overall, Viet Nam's coffee value chain, including stakeholders such as farmers, collectors, processors and exporters, is characterized by small-scale producers, buying agents, and local traders playing an important role in connecting farmers and enterprises, and medium technology. These aspects are expanded on below.

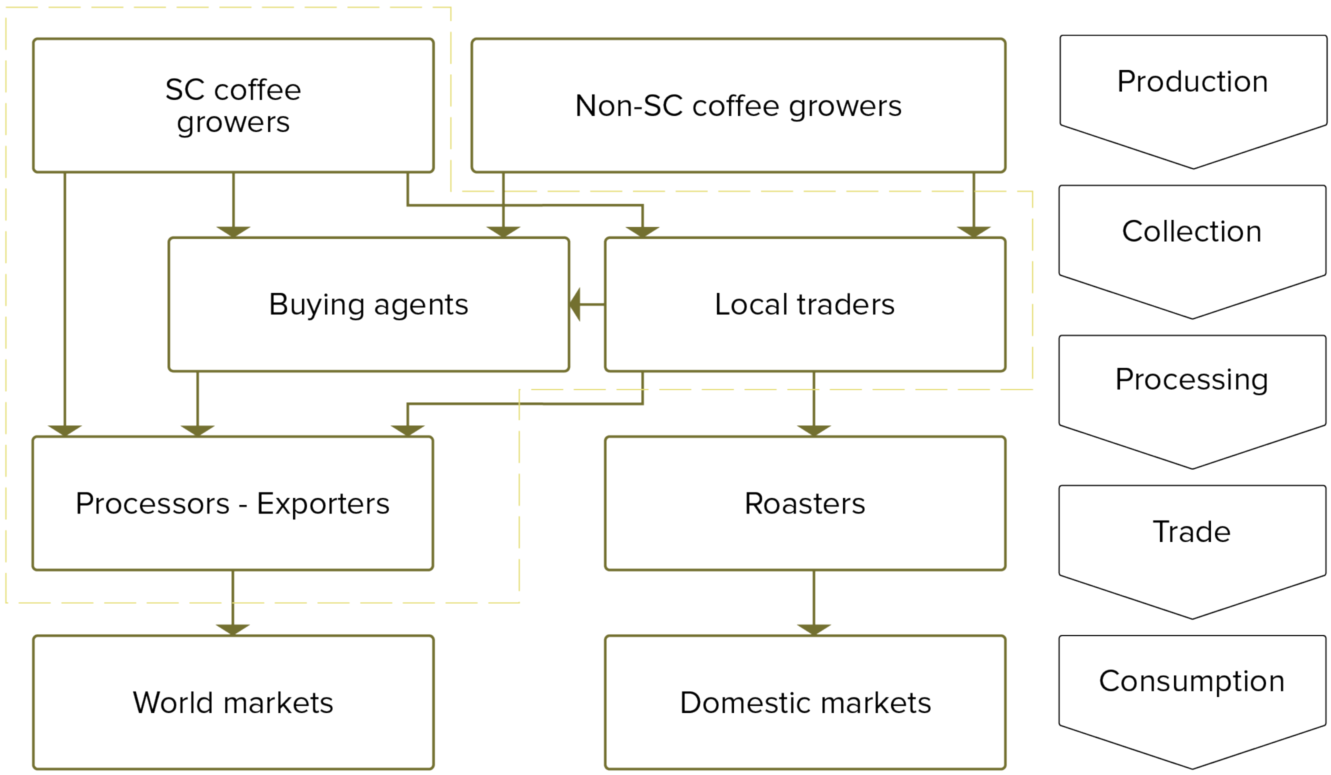
### 1.1.1 Farmers are mainly small-scale producers

The Vietnamese coffee sector primarily consists of small-scale farmers who grow coffee on farms ranging from 0.5 - 3.5 hectares (IDH, 2021). Most farmer households dry coffee after harvesting in the open air and then sell it to collectors. The level of mechanization in households is very low: few farmers can dry coffee by machine, because machinery and equipment for processing in small processing establishments and within households are often unreliable and uncommon, so harvested coffee is mainly dried in the yard. However, the area for drying yards is often inadequate, which leads to the coffee drying too thickly or being piled up, jeopardizing the drying and preliminary processing of coffee within the first 24 hours after harvest. In addition, processing workers often lack the experience to develop beyond a low skill level, which greatly affects final coffee quality (Hung Anh & Bokelmann, 2019; IPSARD, 2020).

### 1.1.2 Buying agents and local traders play an important role in connecting farmers and enterprises

Buying agents and local traders transport coffee, including fresh and dry cherries and beans, from coffee growers to coffee processing and exporting enterprises. Some private purchasers are also involved in processing, but only in the form of simple dry processing such as cleaning, drying, and husking/polishing. Collectors often sign contracts with processing and exporting enterprises to purchase coffee beans, but very few collectors sign contracts with coffee farmers (except those participating in sustainable coffee programmes). As a result, farmers can choose to sell to agents who offer higher prices and sometimes provide materials and fertilizers to them (IPSARD, 2020).

**Figure 2. Coffee value chain in Viet Nam**




*Note: SC coffee: Sustainable Certified Coffee*
*Source: Hung Anh & Bokelmann (2019)*

### 1.1.3 Processors and exporters mainly apply medium technology

Processing and exporting enterprises mainly buy coffee cherries and beans from collectors to process and sell to large roasters. Processing enterprises mainly follow the dry processing method. They often invest in drying systems, mills, and screening machines to classify beans into sizes, separate stones, screen impurities, and polish the beans. In recent years, enterprises have begun cooperating with agents and farmers to produce and purchase coffee according to 4C, UTZ, and Rainforest Alliance standards (expanded on in Table 1). These enterprises organize training courses for farmers with the support of large companies such as Nestlé and Olam Group.

Currently, Viet Nam has about 113 coffee processing and exporting enterprises, including 13 foreign direct investment (FDI) enterprises. Only one third of enterprises have factories processing green coffee for export, while the rest still have to buy coffee through a system of collectors and agents. Medium technology is used by about 21 small-scale enterprises, and medium-advanced technology accounts for 54 per cent, equivalent to 34 enterprises, which are mainly state-owned and limited liability companies. Advanced technology processing is used by about 12.7 per cent, equivalent to 8 enterprises. A few enterprises have also invested in the deep processing industry such, as Vinacafe, Trung Nguyen, and Nescafé (Nhung, 2022).

**Table 1. Common sustainable coffee certification standards**

| Standard | Origin | Requirements for Certification |
|---|---|---|
| 4C (Common Code for the Coffee Community) | 4C Services GmbH (4C) | Compliance with the 4C "Code of Conduct", including economic, social, and environmental dimensions aiming to advance labour rights and sustainable practices. |
| UTZ (UTZ Certified) | UTZ Foundation | Compliance with UTZ "Code of Conduct" covering labour rights, environmental protection, and quality management. |
| Rainforest Alliance | Rainforest Alliance and the Sustainable Action Network (SAN) | Must meet standards for protecting wildlife, water and ecosystem conservation, soil and integrated pest management, and fair treatment of workers. |
| Fair Trade | Fair Trade Foundation | Confirmation of a fair price for smallholder coffee producers and their cooperatives, including human rights and environmental protection standards to minimize pollution and ensure worker safety. |

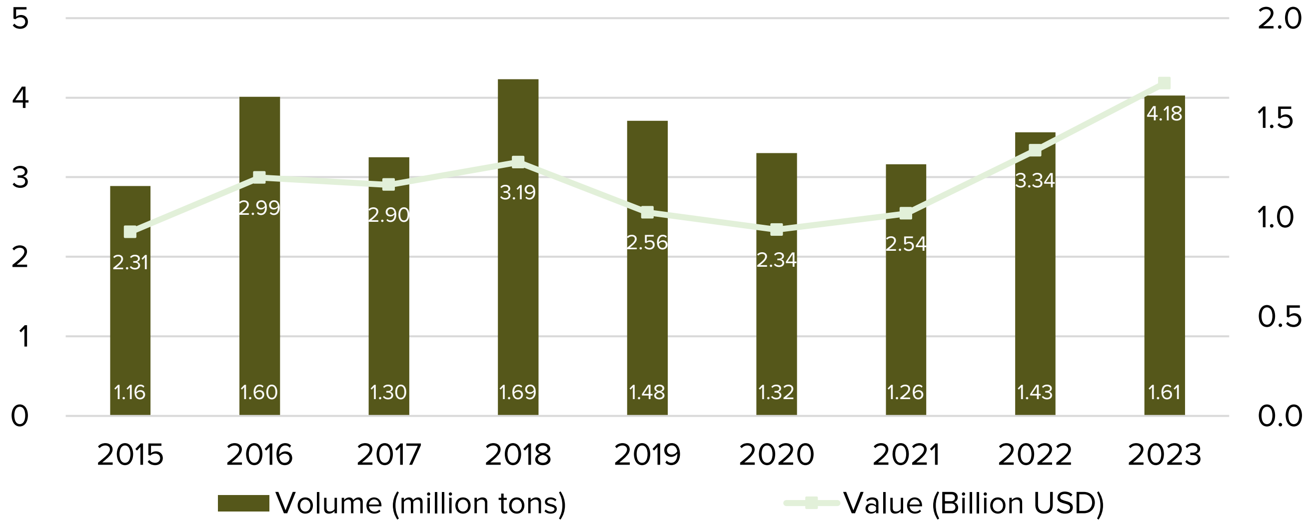
*Source: Lazaro et al., (2008); 4C Services GmbH (2020); Fair Trade International (2025)*

The most popular channel for the coffee value chain in Viet Nam goes from farmers to buying agents and local traders, then to processing and exporting enterprises, accounting for about 60 per cent of total coffee production. Direct connections between farmers and enterprises are still limited. With the advantages of proximity to production areas, available resources, and being able to pay farmers in cash or in advance, collectors buy most of their coffee beans from farmers. Additionally, these buying agents help to organize training sessions on coffee production and monitoring and provide technical support to assist producers in following sustainable standards. As a result, many coffee farmers sell their beans through buying agents. Only a small percentage of households sell directly to enterprises: typically, those with large production volumes, consistent coffee quality, and compliance with required safety and technical standards.

### 1.1.4 Trade as a driver of green and circular practices

As the coffee trade grows, there is increasing pressure to adopt sustainable and environmentally friendly practices, especially given the impacts of climate change and the need for sustainable agriculture development (MAE, 2023). In recent years, green circular practices, which focus on reducing waste, reusing resources, and minimizing environmental impact, have emerged as key drivers for sustainable agricultural development in Viet Nam's coffee sector.

**Figure 3. Coffee export volume and value in Viet Nam (2015 - 2023)**




*Source: MAE and Viet Nam Customs Office, 2024*

### 1.1.5 Increasing demand for certified sustainable coffee products

With growing awareness of food safety importance and environmental degradation, there is increasing global demand for sustainably produced coffee. International coffee buyers, roasters, and consumers are becoming more concerned with the sustainability of the supply chain. Certifications such as 4C, Fair Trade, UTZ, Rainforest Alliance, and organic certifications have pushed Vietnamese coffee producers to adopt greener practices to meet market demands. International and domestic consumers, willing to pay a premium for coffee products that are certifiably produced through sustainable methods, are creating an incentive for producers to adopt green circular practices and influencing the uptake of sustainable agriculture in Viet Nam.

### 1.1.6 CE in Trade Agreements

CE has become a vital pathway for developing agriculture-based economies and balancing economic growth with environmental sustainability, and its relevance is increasingly reflected in global trade policies. Many modern trade agreements include commitments to sustainable development, environmental protection, and climate change adaptation, which are core principles that align with CE practices. For Viet Nam's coffee sector, the 2019 EU - Viet Nam Free Trade Agreement (EVFTA) is particularly significant. While offering preferential market access, the EVFTA also obliges Viet Nam to meet higher environmental and sustainability standards. These requirements present both a challenge and an opportunity for Vietnamese coffee producers to adopt CE models (such as waste recycling, sustainable packaging, and renewable energy use) to maintain market competitiveness. Beyond the EVFTA, other trade frameworks such as the 2016 Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) and the 2019 UK - Viet Nam Free Trade Agreement (UKVFTA) further underscore the shift toward sustainability in international trade.

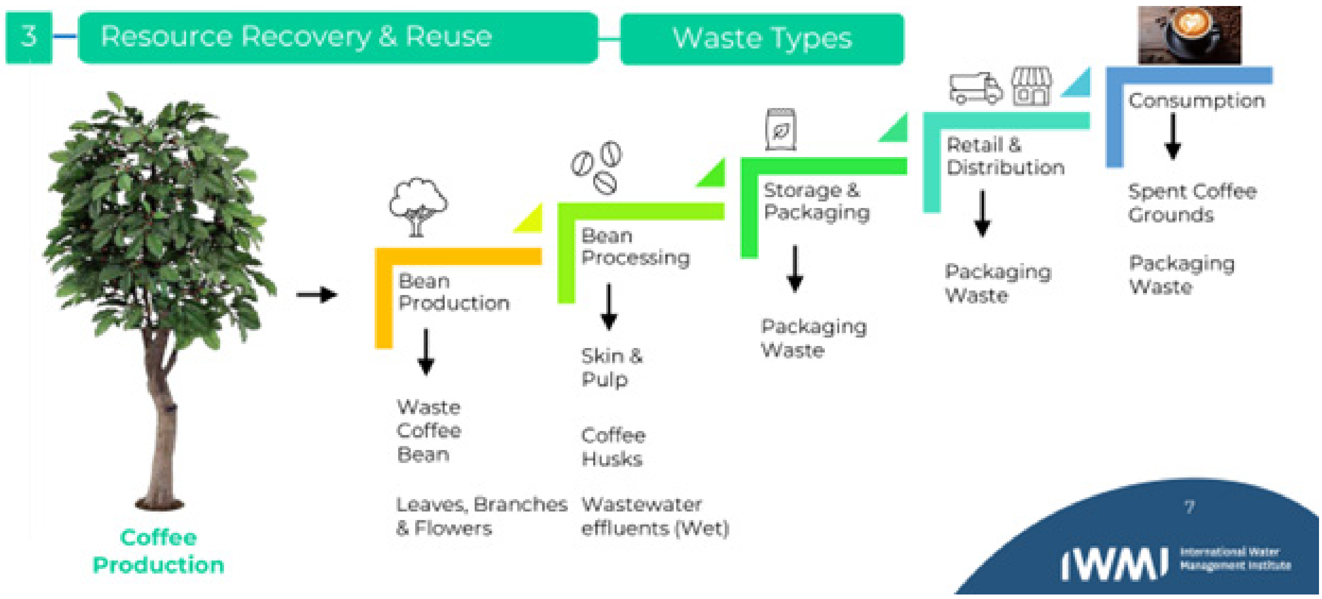
These agreements contain provisions that encourage environmental cooperation, promote sustainable agriculture, and discourage harmful practices such as deforestation and excessive chemical use. As major buyers increasingly value transparency, traceability, and environmental accountability, embedding CE principles across the coffee value chain is becoming not only a policy initiative but also a market-driven necessity.

In 2023, the EU, the largest market for Vietnamese coffee, issued the EUDR, which aims to curb global deforestation. The EUDR prohibits the placing of certain commodities, including coffee, on the EU market unless these products' production does not contribute to deforestation or forest degradation (e.g., products and their inputs must not have been produced on land that was deforested since 2020) (European Commission, 2025). While the EUDR does not explicitly mandate CE practices, its emphasis on traceability and sustainable sourcing practices is closely aligned with the objectives of a CE. To best access this market, coffee producers in Viet Nam will need to improve their environmental impact, focusing on preventing deforestation, enhancing input use efficiency and biodiversity, and improving land management..

## 1.2 Environmental and Climate Challenges in Coffee Production

Coffee production in Viet Nam currently leads to severe environmental harm, including soil degradation, water scarcity, deforestation, and biodiversity loss. In many coffee plantations, the overuse of chemical fertilizers and pesticides has led to the loss of soil fertility and increased soil erosion, as well as soil and water pollution (Hong, 2024). In addition, intensive production methods and climate change have worsened water shortages in major coffee-producing regions such as the Central Highlands and some provinces in the Northwest, which has a direct negative effect on coffee productivity and increases production costs. Further, the expansion of coffee plantation areas in Viet Nam is contributing to habitat destruction and loss of biodiversity.

**Figure 4. Coffee production stages and waste**




*Source: Somorin, 2023*

### 1.2.1 Waste generation

In Viet Nam, the processing of coffee cherries to obtain the beans creates a significant volume of byproducts, mainly in the form of coffee husks, which account for 45 per cent of the dry cherry weight (dry process), equating to 0.9 tons of husks per ton of dry beans. Conversely, wet processing (mainly used for arabica), can generate up to 2.5 - 3.5 tons of fresh pulp and mucilage, as well as 40 - 45 $m^3$ of wastewater for each ton of dry coffee beans (Gil-Gómez et al., 2024; Santos et al., 2021; Serna-Jiménez et al., 2022). Coffee production on farms also generates a significant amount of waste, including leaves and pruned twigs and branches (Gil-Gómez et al., 2024; Mendoza Martinez et al., 2019).

Coffee producers' and processing facilities' awareness of environmental protection is still limited, so they often discharge waste directly into the environment, polluting water and other natural sources in the process (Hong Minh et al., 2021). However, this waste can be considered underutilized biomass. It is estimated that one ton of fresh coffee cherry yields around 200 and 220 kg of green beans for arabica and robusta respectively (Wintgens, 2004). Coffee processing generates over 40 million tonnes of biomass each year (C4CEC, 2023), representing a significant untapped resource for CE solutions. These byproducts, rich in lignocellulosic materials and bioactive compounds, present significant opportunities for CE initiatives, including composting, and the creation of value-added products, such as biofuel, biochar, and cascara (Hoseini et al., 2021; Heeger et al., 2017).

Despite their potential, much of this biomass remains underutilized, highlighting the need for improved waste management and valorisation strategies in Viet Nam's coffee sector.

### 1.2.2 Soil degradation

Intensive coffee farming over many years, especially in the Central Highlands, has led to soil degradation. Farmers often rely heavily on chemical fertilizers and pesticides, which damage soil quality over time and reduce its health through acidification and increased incidence of pests and diseases (Nguyen, 2017; Wiryadiputra & Tran, 2008). Soil erosion is also a concern, especially in hilly areas where coffee is grown, as the removal of vegetation for farming and poor land management practices lead to the loss of topsoil. Further, growing coffee as a monoculture (only one crop in a field) can also deplete soil nutrients, leading to reduced soil fertility. Overall, reduced soil fertility and loss of topsoil can lead to reduced agricultural productivity, increased water pollution from sediment runoff, increased risk of landslides and floods, and, over time, desertification, making soil degradation a significant environmental concern for coffee production (Somorin, 2023).

### 1.2.3 Water overuse and water pollution

The increase in coffee-growing areas hurts water conservation due to high water use in both coffee producing and processing. Coffee plants need between 300 - 400 litres of water per tree/irrigation round (about 600 - 1,200 $m^3$/ha). Many coffee farmers drill wells to access water for coffee irrigation, but this causes steady water flow in the wells and depletes groundwater due to overexploitation (D'haeze, 2020, 2019; Riddell, 2019). Coffee processing also requires a lot of water, especially for wet processing, which is fairly expensive and usually only used for high-quality arabica beans. In the harvesting season, coffee processing causes water source pollution both in surface and groundwater (Duc et al., 2021).

### 1.2.4 Biodiversity losses

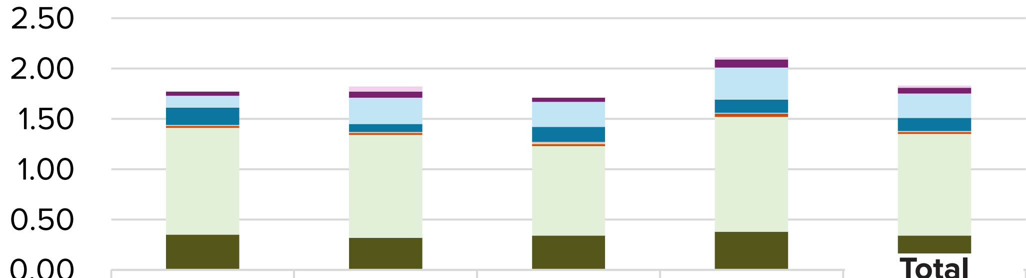
As demand for coffee grows, there is pressure to expand coffee plantations, which leads to deforestation, particularly in the Central Highlands where most coffee farms are located. Before 2010, one of the primary reasons for forest decline in Viet Nam was the reclaiming of land for industrial crops such as coffee (Nguyen T.H.M et al., 2021). This not only reduces biodiversity but also contributes to climate change by releasing carbon stored in trees. Moreover, the shift to coffee farming often replaces diverse ecosystems with single-species crops (i.e., monocultures), reducing regional biodiversity and increasing vulnerability to pests and diseases, which can further threaten the health of coffee plants. According to the Department of Agriculture and Rural Development (DARD) (now the Department of Agriculture and Environment) of Lam Dong province, in recent years deforestation for coffee plantations in the Central Highlands has rarely occurred, but the replaced coffee area in the past has not been recovered into forest.

### 1.2.5 Carbon emissions

Growing and producing coffee can also harm the environment by emitting large amounts of GHGs, such as methane, carbon dioxide, and chlorofluorocarbons. This process occurs in all stages of coffee production and processing. According to a 2019 survey by the Sustainable Trade Initiative (IDH), the total emissions of farm-level robusta coffee production in Lam Dong and Dak Lak provinces were approximately 1.39 $tCO_2e$ per metric ton of dried coffee beans (after subtracting carbon sequestration). In more recent studies, carbon emissions (without subtracting carbon sequestration) are estimated at 1.83 $tCO_2e$ per tons Green Beans Equivalent (GBE) in the former, and at 3.85, 2.65, and 2.58 $tCO_2e$ per t GBE for monocrop, medium-diversified, and highly diversified systems, respectively, in the latter (Enveritas, 2023; Kuit et al., 2020).

In Viet Nam's coffee production, fertilizers are by far the most significant contributors to carbon emissions, followed by energy use. On average, 73 - 83 per cent of total emissions are from fertilizer use, 8 - 27 per cent from energy use, and 13 per cent from residue management (Enveritas, 2023; Kuit et al., 2020; IDH, 2025). Fertilizer application levels are fairly stable from one year to the next, but energy use varies with rainfall levels during the coffee flowering period. When rainfall is lower than usual, energy usage goes up as farmers increase the volume of irrigation water they apply. Other sources of emissions, such as pesticides, are negligible, contributing around 2 kg $CO_2e$ per metric ton of coffee. The carbon footprint of coffee production varies significantly between conventional and sustainable practices, which is described in further detail in Section 4.2.

**Figure 5. Carbon footprint per province, split by emission source, Central Highlands (kg $CO_2e$/kg GBE)**




| | Gia Lai | Lâm Đồng | Đắk Lắk | Đắk Nông | Total |
|---|---|---|---|---|---|
| Land use change | 0.00 | 0.05 | 0.00 | 0.02 | **0.02** (1%) |
| Transport | 0.04 | 0.06 | 0.04 | 0.08 | **0.06** (3%) |
| Waste water | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** (<1%) |
| Residue management | 0.12 | 0.26 | 0.25 | 0.32 | **0.24** (13%) |
| Crop protection | 0.00 | 0.00 | 0.00 | 0.00 | **0.00** (<1%) |
| Energy use (irrigation) | 0.17 | 0.08 | 0.15 | 0.13 | **0.13** (7%) |
| Energy use (processing) | 0.01 | 0.01 | 0.02 | 0.01 | **0.01** (<1%) |
| Energy use (field) | 0.02 | 0.02 | 0.02 | 0.03 | **0.02** (1%) |
| Fertilizer use and soil | 1.06 | 1.02 | 0.89 | 1.14 | **1.01** (55%) |
| Fertilizer production | 0.35 | 0.32 | 0.34 | 0.38 | **0.34** (19%) |

*Source: Enveritas, 2023*

## 1.3 Circular Economy in Viet Nam's Coffee Production

The concept of CE was first officially introduced by Pearce and Turner in 1990, who criticized the linear economic model for treating the environment as a mere waste repository. They proposed a closed-loop system that views the Earth as an interconnected system where material flows should be cyclical, supporting both economic growth and environmental sustainability. Building on this foundation, in 2013 the Ellen MacArthur Foundation further defined CE as "an industrial system that is restorative or regenerative by intention and design". This approach replaces the traditional "end-of-life" concept with "restoration," emphasizes renewable energy and seeks to eliminate toxic inputs while minimizing waste through smarter design of materials, products, systems, and business models. CE encompasses the concept of the 9Rs (from reduce by design, to refuse and reduce, all the way donw to recycle as the options with the lowest co benefits) by transforming waste into valuable resources, opposing the linear 'take-produce-consume-discard' model and promoting a production system that returns waste as inputs for further use. Ongoing technological advancements have accelerated the adoption of CE practices and expanded their relevance across economic and social sectors.

In recent years, numerous circular models and practices have been adopted within the coffee sector globally, including landscape approaches and agroforestry models that integrate coffee cultivation with other crops or trees (e.g., fruit or timber trees); organic farming and composting models that avoid/reduce the use synthetic fertilizers and pesticides while recycling organic waste; water recycling and wastewater management systems in coffee processing; bioenergy production from coffee byproducts such as husks and pulp; and renewable energy use in processing and roasting, including solar, wind, and other renewable sources. Compiling and disseminating these good practices is essential for raising awareness, building capacity, and scaling up CE models throughout Viet Nam.

### 1.3.1 Policy Support

While CE has gained prominence in recent decades, it is worth noting that circularity in agriculture is not a new concept in Viet Nam. A long-standing example is the vườn - ao - chuồng (VAC) or garden - pond - livestock model: an integrated farming system that embodies circular principles by linking crop cultivation, aquaculture, and animal husbandry in a closed-loop cycle. Organic waste from one component serves as inputs for another, thereby enhancing resource efficiency, reducing environmental pollution, and promoting sustainable livelihoods. The VAC model reflects Viet Nam's traditional knowledge and offers valuable insights into how CE principles were already being practised locally long before being formally conceptualized in global discourse.

Today in Viet Nam, the concept of CE is formally defined in Article 142 of the Revised Law on Environmental Protection (LEP) No. 72/2020/QH14. According to this article, a CE is an economic model that "encompasses the design, production, consumption, and service activities aimed at reducing raw materials, extending product life, reducing waste generation, and minimizing adverse impacts on the environment" (Art. 142.1).

In Viet Nam, circular practices are being promoted by the Government of Viet Nam as one mechanism to drive the transition toward sustainable agriculture, as illustrated by the recent updates in the policy frameworks. For example:

- To formalize the transition toward CE, the Prime Minister issued Decision No. 687/QĐ-TTg (June 7, 2022), approving the Scheme on Development of Circular Economy in Viet Nam. MAE, formerly the Ministry of Agriculture and Rural Development (MARD), was tasked with developing supportive legal and institutional frameworks to implement CE models in agriculture and rural development, which are increasingly embedded in national socio-economic development strategies, sectoral policies, and local action plans.

- The Strategy for Sustainable Agriculture and Rural Development for the 2021 - 2030 period, with a vision to 2050 (Decision 150/QD-TTg) identifies CE as a key solution to enhance added value and sustainability in agriculture. This strategy integrates economic, environmental, and social goals while promoting resilience to climate change.
- Decision No. 540/QĐ-TTg (June 19, 2024) approved the Scheme on Science Development, Technology Application, and Transfer to Promote Circular Economy in Agriculture by 2030, focusing on enhancing recycling and reuse of agricultural byproducts, boosting innovation, and enabling scalable CE practices across the sector. This evolving policy environment provides a solid foundation and mandate for the integration of CE guidelines in the coffee sector, establishing both practical relevance and institutional backing for implementation.

Importantly, CE practices in Viet Nam's coffee sector are closely aligned with the country's NDC, particularly the targets on reducing GHG emissions and promoting climate-resilient, low-carbon agriculture. Integrating circular agriculture models such as waste recycling, agroforestry, and renewable energy use into coffee value chains not only contributes directly to emissions reduction but also enhances adaptation capacity in climate-vulnerable regions like the Central Highlands. These practices, if scaled up, can be systematically tracked and reported through the national measurement, reporting, and verification (MRV) system which underpins Viet Nam's NDC implementation.

Nevertheless, critical gaps remain for scaling proven models, enabling farmer access to finance and technology, and linking local initiatives with national reporting frameworks. This Handbook contributes to addressing these gaps by providing evidence on circular practices and offering actionable recommendations for aligning coffee sector transformation with national climate goals and international sustainability commitments.

### 1.3.2 The uptake of circular practices

In Viet Nam, key waste materials include coffee husks (dry fruit and parchment, i.e., the outer shell of dried beans) from dry processing, as well as pulp, mucilage, and wastewater from wet processing. These byproducts can be converted into compost or organic fertilizers, biochar, biogas, and biofuel, while wastewater, if properly treated, can be reused for irrigation or biogas generation.

Implementing circular models within Viet Nam's coffee value chain could substantially reduce GHG emissions and prevent environmental degradation while restoring ecosystems, minimizing waste, and enabling the reuse of byproducts generated throughout the value chain.

Some farmers and companies are adopting green circular practices to increase resilience to climate change, improve soil health, and ensure long-term sustainable coffee production, but the adoption of circular models is still limited. However, practices like agroforestry, intercropping, organic farming, and integrated soil fertility/pest management are becoming more common.

To improve coffee sustainability, added value, and quality, in recent years MAE, local authorities, and the private sector have supported coffee producers to engage in certification schemes such as 4C, UTZ, Rainforest Alliance, and other organic certifications that foster sustainable practices. In 2022, the certified coffee area (including VietGAP, 4C, Rainforest, and UTZ) was about 185,800 hectares, accounting for approximately 26 per cent of the total coffee area (Anh, 2023). Certified coffee areas are mainly in large-scale, specialized coffee production areas such as Lam Dong (about 76,000 ha), Dak Lak (about 45,600 ha), Dak Nong (23,500 ha), and other provinces in the Central Highlands region. The Central Highlands region, where most coffee is grown, has seen some growth in sustainable certifications, though it still remains a small portion of total production.

Large-scale enterprises in processing and exporting coffee are proactive in supporting and guiding farmers to apply sustainable farming methods that meet the requirements of export markets. For example, Nestlé Viet Nam is helping to guide farmers in how to meet 4C criteria through their Nescafé Plan, while IDH and its partners are implementing the Initiative for Sustainable Landscapes (ISLA) for coffee production.

- **Nescafé Plan**: After 12 years of implementing the Nescafé Plan in the Central Highlands provinces, Nestlé Viet Nam has trained over 330,000 households to produce sustainable coffee according to 4C standards and distributed more than 73.5 million disease-resistant and high-yield seedlings for replanting purposes. By participating in the project, farmers have reduced the amount of irrigation water by 40 - 60 per cent, reduced the amount of pesticides and chemical fertilizers by 20 per cent, and intercropped coffee with black pepper, helping to increase land use efficiency, improve ecological diversity, and reduce emissions (Nescafé, 2025).
- **ISLA:** Since 2014, the ISLA has been introduced and implemented in Viet Nam by the IDH, government agencies, and private companies (e.g., LDC, JDE, Olam, and others). From 2016 to 2018, the programme supported over 11,000 farmers in 65 communes across 15 districts to produce coffee sustainably. To tackle complex sustainability challenges that cannot be addressed by a single supply chain or individual party, since 2019, IDH has also convened multi-stakeholder coalitions to implement the Production-Protection-Inclusion approach in 4 districts (or compacts) —the Cu M'gar and Krong Nang districts in Dak Lak, and the Di Linh and Lac Duong districts in Lam Dong—laying the groundwork for sustainable landscape governance.

The adoption of intercropping techniques among farmers has increased significantly since the programme began, rising from 15 per cent in 2015 to 96 per cent by 2020. Water consumption in coffee cultivation was reduced by 20 per cent, the use of chemical fertilizers was lowered by 14 per cent, and banned pesticides were completely phased out. Carbon emissions from coffee production also fell by 60 per cent during the 2019 - 2020 period compared to 2015 - 2016, primarily due to the implementation of agroforestry practices and reduced input usage.

Economically, farmers participating in the programme achieved incomes 20 per cent higher than their non-participating counterparts across more than 10,000 hectares of coffee and intercropped farmland. In addition, farmers diversified their income streams through activities such as fruit tree cultivation, beekeeping, and handicraft production (IDH, 2025). According to IDH's 2022 ISLA Annual Report, 2,064 trainers and 30,205 farmers, 32 per cent of whom were women, received training between 2021 and 2022. The training sessions covered a wide range of topics including forest protection, soil and water conservation, intercropping and agroforestry practices, agro-input management, workplace safety, and techniques for harvesting and post-harvest handling.

To enhance green cover within farmlands, 6,343 farmers increased crop diversity, with 55 per cent receiving direct assistance from the programme that distributed approximately 200,000 intercropping seedlings. Furthermore, the programme facilitated the development of a farm and forest mapping system to strengthen traceability efforts, supporting compliance with the EUDR and connecting the region to SourceUp, a platform linking sustainable, low-carbon coffee producers with international buyers (KIT, 2023).

In coffee value chains, successful circular agriculture models have been implemented in various localities, including reusing coffee waste and adopting agroforestry and intercropping practices. Such models have the potential to both increase economic efficiency and add value to coffee production.

Below is a brief overview of common CE practices in coffee production in Viet Nam.

**Agroforestry and intercropping**, where coffee trees are planted alongside other crops and trees, is a key component of circular agriculture. This model helps create a more diverse, resilient farming system that benefits both the environment and farmers' livelihoods.

- **Coffee with shade trees**: Integrating shade trees into coffee plantations can provide various benefits, such as improving coffee quality and productivity, conserving biodiversity, enhancing soil fertility, saving and conserving water, and preventing soil erosion. Shade trees help regulate temperature and humidity around coffee plants, reducing heat and water stress, which leads to better bean development and flavor consistency. Their leaf litter enriches soil organic matter and nutrient cycling, while their roots stabilize the soil and improve water retention. Additionally, shade trees can provide farmers with secondary products such as timber, fruit, or fuelwood, diversifying income sources.
- **Intercropping coffee with other crops**: Currently, in Central Highlands provinces such as Lam Dong, Dak Nong, and Dak Lak, coffee trees are planted with other crops such as avocado, black pepper, durian, macadamia, and persimmon, providing farmers with multiple streams of income.

These practices have the potential to improve soil fertility, reduce pest pressure, and increase income, enhancing overall farm economic and environmental resilience by diversifying cropping systems.

**Recycling coffee waste**: In coffee production and processing, large amounts of organic waste (such as leaves, branches, husks, pulp, and coffee grounds) and wastewater are generated. Using organic waste from coffee to produce valuable products such as compost, biogas, or biochar and reusing wastewater are innovative approaches to reducing environmental pollution.

- **Composting**: Coffee husks and pulp can be composted to enrich the soil, reducing the need for chemical fertilizers, improving soil health, and lowering carbon emissions.
- **Biogas**: Coffee waste, especially pulp and mucilage, can be used in biogas digesters to produce methane, which can then be used as an energy source for coffee processing or other farm operations. This reduces reliance on fossil fuels and minimizes the environmental impact of waste.
- **Biochar:** Biochar, a form of charcoal made from organic material like coffee waste, can be used to improve soil health, enhance soil carbon sequestration, and reduce GHG emissions.
- **Wastewater reuse**: Wastewater from coffee processing can be transformed into irrigation water using a low-cost, scalable water filtration system. This simple yet effective solution involves just two storage tanks, a microbial culture medium, and molasses, effectively treating the wastewater while fostering both crop growth and water conservation.

Chapter 2

# METHODOLOGY

To compile and prioritize the CE practices presented in this Handbook, the authors conducted a desk study, expert consultations, and a field survey, using selection criteria based on feasibility, scalability, and relevance. This approach enabled the researchers to contextualize CE practices within Viet Nam's current policy environment, drawing on existing studies and local expert knowledge while generating new insights through practical testing. The combination of fieldwork and desk research has resulted in a robust set of guidelines that are both data-informed and practically applicable for farmers and coffee value chain stakeholders. The proposed models were subsequently discussed and validated with key experts during a hybrid workshop co-hosted by UNDP.

## Desk study

The desk study used the value chain approach presented under Stage 2 of the CE-NDC Toolbox involved a thorough review of relevant documents, reports, and research on CE practices and agricultural byproduct management, with a focus on existing legal frameworks, government efforts to reduce GHG emissions, and challenges within the coffee sector, such as climate change and carbon footprints. This phase also incorporated insights from previous studies in the coffee value chain at national and international levels.

## Expert consultation

Experts were consulted to support the selection of typical models, gain insight into bottlenecks, and share experiences on solutions to promote CE practices in coffee production. CE experts representing different organizations were consulted, including the Department of Crop Production under MAE, IDH, the Viet Nam National University of Agriculture, research institutes, and UNDP experts, among others. They provided feedback on key findings and recommendations for scaling up sustainable practices during direct semi-structured interviews and a hybrid workshop, co-hosted by UNDP, to discuss and validate the selection of circular models with key experts.

**Table 2. List of key experts consulted**

| No | Name | Organization |
|---|---|---|
| 1 | Dr. Tran Dai Nghia | Former Department Head, Department of Natural Resources and Environment Economics at the Institute of Policy and Strategy for Agriculture and Rural Development (IPSARD) |
| 2 | Prof. Pham Thi My Dung | Director, Science Institute of Rural Development (SIRD) |
| 3 | Mr. Bui Duc Hao | Coordinator, Viet Nam Coffee and Landscape Programme at IDH |
| 4 | Mr. Hoang Van Thang | Director, Silviculture Research Institute |
| 5 | Mr. Le Van Duc | Former Vice Director, Crop Department at MAE |
| 6 | Mr. Nguyen Quang Trung | Deputy Director, Northern Mountainous Agriculture and Forestry Science Institute (NOMAFSI) |
| 7 | Assoc. Prof. PhD Mai Van Trinh | Director, Institute for Agricultural Environment (IAE) |
| 8 | Mr. Nguyen Ngoc Son | Agriculture Specialist, GIZ Viet Nam |
| 9 | Ms. Nguyen Cam Thuy | Coordinator, Partnership for Sustainable Agriculture in Vietnam (PSAV) at Grow Asia |
| 10 | Ms. Giang Do | French Agricultural Research Centre for International Development (CIRAD) |
| 11 | Ms. Phan Thi Thu Lan | Project Officer, GIZ |

## 2.1 Selection of the circular models for the Handbook

Various CE methods can be applied in coffee production, including:

- Implementing smart irrigation techniques to reduce water consumption;
- Switching to renewable energy in coffee processing plants to lower GHG emissions;
- Reusing coffee tree prunings (branches and twigs) to produce biochar for soil improvement and carbon sequestration;
- Implementing regenerative agriculture practices such as cover cropping and intercropping to improve soil health and carbon sequestration; and
- Implementing numerous uses for dried coffee husks and coffee pulp (e.g., compost additives, animal feed, cascara tea for human consumption, and more) to reduce reliance on synthetic fertilizers and create value-added products (ICO, 2023).

However, following expert consultations, field visits, and interviews, the researchers prioritized three CE models for in-depth investigation based on three criteria: relevance and adoption potential, feasibility and practicality, and lastly, scalability and replicability.

The three circular models that have been selected are:

**1. Intercropping in coffee cultivation:** Intercropping and agroforestry systems, where coffee is grown alongside fruit/spice or timber trees such as black pepper (itself often grown on cassia), avocado, durian, and persimmon, is a means of improving biodiversity, soil health, and economic resilience;

**2. Producing organic fertilizer from coffee husks:** The production of organic fertilizer from coffee husks utilizes composting techniques to transform agricultural waste into a nutrient-rich soil amendment; and

**3. Improving wastewater treatment in coffee processing:** Wastewater treatment models using low-cost, physio-biological methods are being adopted to manage pollution from wet coffee processing. This category is subdivided into two models with different requirements:

A. **Small** coffee processing facilities and

B. **Large** coffee processing facilities.

These models were prioritised because they demonstrate practical solutions for sustainability and circularity as well as have a strong potential for GHG emissions reduction, directly addressing the most pressing environmental, economic, and social challenges specific to Viet Nam's coffee production system (Table 3).

**Table 3. Criteria for CE model selection**

| Model | Relevance & Adoption Potential | Feasibility & Practicality | Scalability & Replicability |
|---|---|---|---|
| 1. Intercropping in coffee cultivation | Improves soil quality, reduces dependency on single crops and increasing biodiversity, and supports certification such as 4C, Rain Forest Alliance, which are compulsory for exporting coffee to main markets such as the USA, EU, Japan, etc. | Builds on current practices in the Central Highlands; minimal technical barriers. | Widely practised; popular combinations include coffee with avocado, durian, black pepper, or persimmon. |

| Model | Relevance & Adoption Potential | Feasibility & Practicality | Scalability & Replicability |
|---|---|---|---|
| 2. Organic fertilizer from coffee husks | Addresses major waste issue (45% of dry cherry weight), reduces GHGs, and improves soil health. | Low-cost composting methods; accessible to smallholders; has potential to be applied in cooperatives and larger coffee processing facilities (both wet and dry processing). | Piloted in Lam Dong; already proven to be cost-saving and environmentally friendly. |
| 3A. Wastewater treatment in small coffee-processing facilities | Reduces water pollution and water use; addresses key environmental and regulatory concerns. | Offers simple bio-physiological methods applicable at the household/coop levels. | Demonstrated success at the smallholder level; has strong potential to expand, especially in wet-processing areas. |
| 3B. Wastewater treatment in large coffee-processing facilities | | | |

## 2.2 Field survey and Validation

Field trips were conducted in the two provinces of Son La and Lam Dong, which are key production zones for coffee in Viet Nam. Lam Dong is one of the country's leading robusta coffee production areas in the Central Highlands, while Son La is a major centre for arabica cultivation in the Northern mountainous region. These provinces were selected to represent both ecological and value chain diversity within Viet Nam's coffee sector. Field surveys were conducted to test and examine the three CE models selected. The surveys focused on circular practices and technical steps during cultivation and on-farm processing, which are the production stages responsible for the majority of the coffee sector's carbon footprint (Chéron-Bessou et al., 2024).

The research identified the key actors involved in coffee production in the provinces, while interviews and consultations explored technical processes, economic viability, and barriers to adoption. A set of checklists/questionnaires for key stakeholders for each CE model was developed to explore specific information and details on CE practices and information on GHG emissions reduction as a result of CE practices. This Handbook also provides concrete data on GHG emissions reduction associated with these practices.

Chapter 3

# TECHNICAL GUIDELINES FOR IMPLEMENTING CIRCULAR MODELS IN THE COFFEE PRODUCTION

This Handbook maps the technical processes for each model in detail, providing step-by-step guidance along with visual examples and photographs to support replication by farmers. The cost-benefit analysis that is included highlights the multiple advantages of CE models and presents clear guideline for scaling up CE models in Viet Nam's coffee sector, demonstrating both the environmental urgency and practical feasibility of integrating circular practices into everyday farming and processing operations.

## 3.1 Model 1 - Intercropping in coffee cultivation

### 3.1.1 Overview

Prior to the 1990s, the remaining robusta coffee plantations planted by the French always had Senna siamea (muồng đen) trees intercropped within the coffee gardens to serve as windbreaks and provide shade. Between 1983 and 1990, 70 - 80 per cent of coffee-growing areas in the Central Highlands incorporated shade trees (WASI, 2021).

From 1994 to 1995, the global coffee market experienced a significant price surge, with prices more than doubling compared to previous years (Dubois, 2006). In pursuit of higher yields, farmers cut down all shade/windbreak trees in their coffee gardens, focusing instead on applying fertilizers and using large amounts of water to achieve maximum productivity. However, according to many farmers, after the shade and windbreak trees were removed their coffee gardens' initial very high yields subsided within only a few years, subsequently beginning to show signs of exhaustion due to overexploitation and the emergence of pests and diseases. Furthermore, the intense sunlight and winds of the Central Highlands during the dry season caused coffee plants to deteriorate rapidly without the protection previously offered by shade trees. Smallholder farmers, who are the majority of Viet Nam's coffee producers, struggled with these issues for years, prompting a shift towards diversified farming systems with the support of scientific and agricultural agencies (e.g., the DARD, agricultural extension services, etc.) and international organizations. This transition was guided by national policies such as the Viet Nam Sustainable Coffee Plan to 2020 and Vision to 2030, the Agricultural Restructuring Plan, and Resolution 120/NQ-CP on Sustainable Development of the Mekong Delta.

In 2022, the coffee cultivation area in Viet Nam's Central Highlands was approximately 614,000 hectares. Of this, 163,100 hectares were intercropped with other plants, accounting for 25.1 per cent of the total coffee-growing area. The provinces with significant intercropping areas included Dak Lak with 81,400 ha (38.1 per cent of the province's total coffee area); Dak Nong with 51,200 ha (38 per cent), Lam Dong with 23,000 ha (13.1 per cent), Kon Tum with 5,900 ha (20.5 per cent).

Intercropping in coffee gardens involved a variety of plants, but the most common are fruit trees with a total of 58,600 ha, including 28,500 ha of durian, 28,100 ha of avocado, 1,400 ha of persimmon, and 600 ha of other fruit trees. Additionally, industrial crops were intercropped on 71,900 ha, including 49,800 ha of black pepper, 7,300 ha of cashew, 5,000 ha of macadamia, 600 ha of mulberry, and 9,200 ha of other industrial crops.

Table 4 offers a comparison of some of their relative agricultural requirements in relation to arabica and robusta coffee.

## Table 4. Comparison of crops for intercropping with coffee

| Criteria | Coffee Arabica | Coffee Robusta | Black Pepper | Avocado | Macadamia | Persimmon | Durian |
|---|---|---|---|---|---|---|---|
| Climate Requirements | Cool, tropical (18 - 24°C) | Warm, tropical (22 - 30°C) | Warm, humid (25 - 30°C) | Warm to moderate (15 - 28°C) | Moderate (16 - 25°C) | Cool (15 - 22°C) | Warm, humid (24 - 30°C) |
| Rainfall (mm/year) | 1,200 - 2,200 | 1,500 - 2,500 | 1,500 - 2,500 | 1,200 - 2,000 | 1,200 - 2,500 | 1,000 - 1,500 | 1,500 - 2,500 |
| Humidity | Moderate (60 - 80%) | High (70 - 90%) | High (>75%) | Moderate (60 - 70%) | Moderate (60 - 80%) | Moderate | High (75 - 85%) |
| Soil pH Range | 5.5 - 6.5 | 5.0 - 6.0 | 5.5 - 6.5 | 5.5 - 7.0 | 5.0 - 6.5 | 5.5 - 6.5 | 5.5 - 6.5 |
| Elevation (m) | 800 - 2,000 | 200 - 800 | 200 - 700 | 400 - 1,500 | 300 - 1,200 | > 800 | < 1,000 |
| Sunlight Requirements | Partial shade | Moderate to full sunlight (optional light shade) | Light to moderate shade | Broad canopy, light shade | Light shade | Direct sunlight, mild | Moderate to full sunlight |
| Water Management | Supplemen-tal in dry season | Essential irrigation | Essential irrigation during dry season | Regular irrigation required | Supplemen-tal irrigation needed indry season | Consistent soil moisture required | Requires high wate availability; irrigation needed in dry season |
| Spacing | 2 - 2.5 m between rows | 2 - 2.5 m between rows | 2.5 - 3 m between plants | 8 - 10 m between trees | 10 - 12 m between trees | 8 - 10 m between trees | 10 - 12 m between trees |
| Pest/Disease Risks | Moderate (leaf rust) | High (borers, nematodes) | High (Phytophthora, root rot, mealybugs) | Moderate (root rot, thrips) | Low (stem borers) | Moderate (scale insects) | High (Phytophthora, fruit borers) |
| Economic Returns | Moderate to high | Moderate | High (short term) | High (medium term) | Very high (long term) | Moderate (medium term) | Very high (medium to long term) |
| Time to Harvest | 4 - 5 years | 3 years | 2 - 3 years | 3 - 4 years | 5 - 7 years | 3 - 5 years | 5 - 7 years |
| Environmental Benefits | Shade crop, carbon storage, biodiversity improvement | Carbon storage, biodiversity improvement | Soil erosion control, biodiversity improvement | Shade for coffee, organic matter enrichment | Shade crop, carbon sequestration, soil stabilization | Organic matter enrichment, moderate shade | Shade for coffee, biodiversity, and organic matter contribution |
| Circular Benefits | Coffee husks/pulp and leaf litter are composted or used as organic mulch; agroforestry systems recycle organic matter and improve soil water retention; shade trees improve microclimate and reduce erosion | Coffee husks/pulp and leaf litter are composted or used as organic mulch; agroforestry systems recycle organic matter and improve soil water retention; shade trees improve microclimate and reduce erosion | Black pepper vines shed biomass used as mulch; pepper husks composted or reused; N-fixing living poles can increase soil organic matter and improve nutrient cycling | Avocado waste (peel/seed) composted; shade trees support water conservation | Shells used as biomass fuel or compost; leaf litter enriches soil | Fruit and leaf waste composted; supports integration with seasonal crops | Thick biomass and fruit waste composted; leaf litter maintains soil organic carbon |

*Source: Data compiled from ICO (2021), FAO Ecocrop (2021), CIRAD (2020), VAAS (2022), DARD Lam Dong (2022), Australian Macadamia Society (2021), Rainforest Alliance (2020), World Coffee Research (2021), and IDH (2022)*

**Table 5. Common coffee intercropping species**

| Species | Common Varieties | Notes |
|---|---|---|
| Persimmon (*Diospyros kaki*) | Hong Da Lat, Hong Gion | Cool-climate, popular in Lam Dong |
| Avocado (*Persea americana*) | Booth 7, Hass, 034 Avocado | Strong market demand, suitable for Dak Lak and Gia Lai |
| Durian (*Durio zibethinus*) | Ri6, Monthong (Mong Thong) | High value but needs high water supply |
| Macadamia (*Macadamia integrifolia*) | 246, 344, A4, A268 | Adapted to coffee zones |
| Black pepper (*Piper nigrum*) | Vinh Linh, Loc Ninh, Vuon Sim | Traditional intercrop, requires careful pest control |
| Cashew (*Anacardium occidentale*) | PN1, BH6, KS05, AB0508 | Suited to drier edges of Central Highlands |
| Shade trees (some also used as black pepper living poles) | Cassia siamea, Erythrina subumbrans, Gliricidia sepium, Leucaena leucocephala | Approved for shade regulation in agroforestry |

*Source: Western Highlands Agriculture and Forestry Science Institute (WASI), Ministry of Agriculture and Rural Development (MAE) and Sustainable Pepper Development Project by IDH and Rainforest Alliance (2022 - 2023)*

**Table 6. Criteria for intercropping species selection**

| Category | Key evaluation points |
|---|---|
| Ecological compatibility | Climate (temperature, rainfall), elevation range, soil pH, and drainage needs |
| Morphology | Tree height and canopy width; deep vs. shallow root system compatibility |
| Water requirements | Match crop water needs with irrigation capacity; avoid high competition |
| Shade tolerance | Tolerates partial shade or provides moderate shade without suppressing coffee |
| Pest and disease risk | Avoid species prone to pests/diseases transmissible to coffee |
| Economic potential | Market demand, price stability, and profitability vs. cost of care |
| Harvest timing compatibility | Staggered harvest seasons minimize labour and ensure continuous income |
| Legal recognition | Species/varieties approved by MAE or local authorities |
| Environmental contribution | Leaf litter, carbon sequestration, and biodiversity improvement |
| Management compatibility | Ease of pruning, irrigation integration, and pest management |

*Source: FAO (2013), ICRAF (2017), CIRAD (2020), IDH & Rainforest Alliance (2022), MAE, 2021*

### 3.1.2 Benefits

- **Economic benefits:** Intercropping in coffee plantations can increase farmers' incomes by enhancing land-use efficiency, diversifying harvests, and providing additional revenue streams, mitigating the risks associated with price and crop yield fluctuations. It also reduces input costs by enhancing natural soil fertility and lowering the need for synthetic fertilizers and pesticides. This integrated method helps build economic and climate resilience while increasing overall farm productivity.

- **CE and environmental benefits:** Intercropping supports CE principles by recycling nutrients, reducing agricultural byproducts, and optimizing resource use. Environmentally, it enhances biodiversity, improves soil structure, and reduces erosion, contributing to more climate-resilient and regenerative coffee production systems.
- **Social benefits:** Intercropping also provides social benefits by improving food security and sovereignty for farming households through diversified crop production, which also reduces dependency on a single income source. It encourages knowledge sharing and community-based farming practices, strengthening social cohesion and resilience among rural communities. Additionally, it can create more year-round labour opportunities and reduce labour peaks (for the harvest), while supporting livelihoods and potentially reducing rural unemployment.

In this Handbook, we will consider 2 models: (i) arabica coffee intercropping with persimmon, and (ii) robusta coffee intercropping with avocado. The selection of the two intercropping models was based on a combination of agronomic, economic, and environmental considerations and validation with the  key experts mentioned previously.

### a. Intercropping Arabica coffee with persimmon

Arabica coffee and persimmon are both highly suited to the cooler highland climates found in the northern and central provinces of Viet Nam, particularly in Son La and Lam Dong. Persimmon thrives in ecological conditions that match perfectly with arabica's environmental needs: cool temperatures (15 - 22°C), high elevations (>800 m), and fertile, well-drained soils.

Persimmon trees have a moderate canopy structure and deep root systems that do not directly compete with the shallower-rooted arabica coffee plants. Their deciduous nature (shedding leaves in winter) allows for increased light penetration to coffee during critical dry-season growth periods, balancing shade benefits without year-round light obstruction.

Persimmon is a high-value crop with a growing domestic and export market, particularly for high-quality varieties like Hong Da Lat and Hong Gion. Integrating persimmon diversifies farmers' income streams, providing additional revenue during the September - November harvest season and helping farmers reduce their dependency on fluctuating coffee prices.

Persimmon trees enhance biodiversity, contribute significant organic matter through leaf fall, and stabilize soil with deep root systems. This supports climate resilience, helps with soil and water conservation, and aligns with the goals of Viet Nam's Agricultural Restructuring Plan and broader sustainability initiatives.

### b. Intercropping Robusta coffee with avocado

Robusta coffee and avocado are both adapted to the warmer midland and lowland climates of Viet Nam's Central Highlands, especially in provinces like Dak Lak, Gia Lai, and Dak Nong. Avocado varieties such as Booth 7 and 034 Avocado tolerate warmer conditions and fit well in these lower elevation (200 - 800 m) coffee zones.

Avocado trees have a broad canopy that provides valuable moderate shading to robusta coffee plants. Their root systems, while extensive, develop vertically and horizontally without excessively competing with coffee. Proper pruning of avocado ensures a balanced canopy that enhances the microclimate without excessive shading stress.

Avocado cultivation offers relatively high short- to medium-term economic returns, with Vietnamese avocados becoming increasingly popular in both domestic and international markets. Their harvest season (June - September) does not overlap with robusta's peak harvest (December - March), enabling farmers to optimize labour use and spread income sources throughout the year. In practice, avocado intercropping has been adopted by leading farmers across the Central Highlands. Success stories highlight increased profitability per hectare and reduced vulnerability to the volatile coffee market.

Avocado trees improve soil moisture retention through shading and organic matter contribution. Their leaf litter boosts soil fertility and reduces erosion risks, contributing to sustainable farm management, which is a key component of Viet Nam's agricultural development strategies.

### 3.1.3 Technical steps for Robusta and avocado intercropping

The following technical steps for intercropping coffee and avocado follow the guidelines of the National Agriculture Extension Centre (MAE, 2018).

#### Step 1. Planting conditions

- The robusta coffee plantation area must meet the following conditions:
  - Garden slope less than 15 degrees
  - Favourable irrigation conditions
  - Soil layer thickness over 70 cm with good drainage
  - Groundwater table deeper than 100 cm
  - Soil pH between 3.7 and 6.0
- For new plantings or replanting, the area must have less than a 5 per cent infection rate of yellow leaf disease or root rot caused by nematodes and/or soil fungi. For existing commercial coffee plantations, the infection rate must not exceed 10 per cent.
- The avocado varieties used for intercropping must be officially recognized and approved by relevant authorities.

#### Step 2. Techniques for intercropping avocado in coffee plantations

- Intercropped avocado trees are planted at a density of 55 - 69 trees per hectare, replacing some coffee planting holes.
- Recommended planting distances:
  - 12 x 12 meters (69 trees/ha), avocado planted at coffee holes. Robusta spacing: 3 x 3 meters, with a density of 1,041 trees/ha
  - 12 x 15 meters (55 trees/ha), avocado planted at coffee holes. Robusta spacing: 3 x 3 meters, with a density of 1,055 trees/ha

Note: Plant seedlings at the same level as the planting hole to avoid waterlogging.

- Plant year-round if irrigation is sufficient, otherwise plant at the beginning of the rainy season (May - August).
- Planting hole: 60 x 60 x 60 cm. Mix 10 - 15 kg decomposed manure, 0.5 kg fused phosphate fertilizer, and 0.5 kg lime with topsoil.
- Treat planting hole soil with Imidacloprid (0.5 litres/hole) or Diazinon (50g/hole) before planting.
- Avocado seedling standards: Strong, 40 - 60 cm tall; stem diameter >0.6 cm; no pests/diseases; graft union 15 - 20 cm above root ball; nursery age 3 - 4 months after grafting.

#### Step 3. Fertilization

*Organic fertilizer*

- Robusta: Apply 5 - 10 kg of decomposed manure per tree every two years. Fertilize along canopy drip line.

- Avocado: Apply 20 - 30 kg of decomposed manure per tree annually at the start of rainy season.
- If manure is unavailable, use biological organic fertilizers. Supplement with green manure or crop residues.
- Use biological products to suppress nematodes and soil-borne pathogens.

*Lime application*

- Based on soil pH (KCl):
  - › pH < 4.0: 1,000 kg/ha every 2 years
  - › pH 4.0 - 4.4: 800 kg/ha every 2 years
  - › pH 4.5 - 4.9: 600 kg/ha every 2 years
  - › pH 5.0 - 5.4: 400 kg/ha every 2 years
- Apply lime at the beginning of rainy season after first rains.
- Spread lime evenly on the soil surface.

*Chemical fertilizer*

- Apply fertilizer when soil is moist.
- Scatter fertilizer evenly around the canopy drip line, lightly till, or cover.

**Table 7. Detailed fertilizer rates and schedules for coffee and avocado**

| Year | | NPK | | Single nutrient fertilizer | | |
|---|---|---|---|---|---|---|
| | | Type | Rate | Urea | Fused phosphat fertilizer | Potassium chloride (KCl) |
| New plantation | Coffee (kg/ha/year) | NPK 2:2:1 (16 - 16 - 8) | 400 | 130 | 600 | 50 |
| | Avocado (kg/tree/year) | | 0,8 - 1,0 | - | - | - |
| Year 2 | Coffee (kg/ha/year) | NPK 2:2:1 (16 - 16 - 8) | 750 - 800 | 260 | 600 | 160 |
| | Avocado (kg/tree/year) | | 1.5 - 2.0 | - | - | - |
| Year 3 | Coffee (kg/ha/year) | NPK 2:2:1 (16 - 16 - 8) | 950 - 1,000 | 330 | 600 | 220 |
| | Avocado (kg/tree/year) | | 2.2 - 2.5 | - | - | - |
| Commercial | Coffee (kg/ha/year) | NPK 2:2:1 (16 - 16 - 8) NPK 2:1:2 (16 - 8 - 16) | 1,400 - 1,600 | 480 - 550 | 600 | 330 - 420 |
| Year 4 | Avocado (kg/tree/year) | | 3.0 - 3.5 | - | - | - |
| Commercial | Coffee (kg/ha/year) | NPK 2:2:1 (16 - 16 - 8) NPK 2:1:2 (16 - 8 - 16) | 1,400 - 1,600 | 480 - 550 | 600 | 330 - 420 |
| Commercial | Avocado (kg/tree/year) | NPK | 6.0 - 7.0 | - | - | - |

**Table 8. Timing and fertilizer types for 1 ha of coffee intercropped with avocado**

| | Feb | Mar | Apr | May | June | July | Aug | Sep |
|---|---|---|---|---|---|---|---|---|
| Coffee | **Single nutrient fertilizer** | | | | | | | |
| | 1st time | | 2nd time | | 3rd time | | 4th time | |
| | 72 - 80 kg Urea | | 120 - 140 kg Urea | | 144 - 165 kg Urea | | 144 - 165 kg Urea | |
| | | | 600 kg<br>Fused phosphate fertilizer | | - | | - | |
| | | | 100 - 124 kg KCl | | 115 - 148 kg KCl | | 115 - 148 kg KCl | |
| | **Mixed fertilizer** | | | | | | | |
| | 1st time | | 2nd time | | 3rd time | | 4th time | |
| | 210 - 240 kg<br>NPK<br>4:01:01<br>(20 - 5 - 5) | | 350 - 400 kg<br>NPK<br>2:02:01<br>(16 - 16 - 8) | | 420 - 480 kg<br>NPK<br>2:1:2<br>(16 - 8 - 16) | | 420 - 480 kg<br>NPK<br>2:01:02<br>(16 - 8 - 16) | |
| Avocado | 1st time | | 2nd time | | 3rd time | | 4th time | |
| | 1.0 - 1.5 kg/tree<br>NPK<br>2:01:02<br>(16 - 8 - 16)<br>(14 - 7 - 17)<br>(16 - 6 - 19) | | 2.0 - 2.5 kg/ tree<br>NPK<br>2:01:02<br>(16 - 8 - 16)<br>(14 - 7 - 17)<br>(16 - 6 - 19) | | 2.0 - 2.5 kg/ tree<br>NPK<br>2:1:2<br>(16 - 8 - 16)<br>(14 - 7 - 17)<br>(16 - 6 - 19) | | 0.5 kg/ tree<br>Kali<br>Sulphate | |

*Foliar fertilizer*

- Use foliar fertilizers rich in sulphur (S), magnesium (Mg), zinc (Zn), boron (B), organic matter, and amino acids.
- Apply evenly to the underside of leaves during cool, dry weather.
- Spray 2 - 3 times annually from May to September.

## Step 4. Irrigation

- Use root-zone irrigation or drip irrigation systems; avoid flood irrigation.

**Table 9. Watering volume and cycles for coffee and avocado**

| Crop | Root Irrigation Volume (liters/plant/time) | Drip Irrigation Volume (liters/plant/time) | Number of Irrigations | Interval (days) |
|---|---|---|---|---|
| Coffee | 400 - 420 | 350 - 390 | 3 | 30 - 35 |
| Avocado | 200 - 250 | 200 - 220 | 1 | 30 - 35 |

*Note: Adjust irrigation schedules based on rainfall (30 mm of rain can substitute for one irrigation cycle).*

**Table 10. Irrigation schedule by month for coffee and avocado**

| Month | Nov | Dec | Jan | Feb | Mar | Apr |
|---|---|---|---|---|---|---|
| Coffee | No irrigation | | Flowering irrigation (1st) | | Fruit irrigation (2nd) | Fruit irrigation (3rd) |
| Avocado | No irrigation | | No irrigation | | No irrigation | Fruit irrigation (1st) |

### Step 5. Pruning and Canopy Management

*Coffee Pruning*

- Branch Pruning: Conduct twice annually.
  - First pruning: After harvest, remove ineffective branches (dead, diseased, weak), shorten aged secondary branches, and remove ground-touching branches.
  - Second pruning: Mid-rainy season; thin dense internal branches.
- Sucker Removal: Remove suckers regularly.
- Plant Replacement:
  - Remove weak plants and replant with vigorous seedlings.
  - For trees with poor yield or rust disease, top-cut and graft with elite varieties.

*Avocado Pruning*

- Conduct pruning immediately after harvest (October - November).
- Remove diseased, dead, and ineffective branches.
- Ensure first branch starts at 0.8 - 1.0 meters above coffee canopy.
- Prune at least once a year. Remove pruned material from the field to prevent disease.

### Step 6. Weeding

- Weed 3 - 4 times per year across the entire plantation.
- On sloping land: Weed in strips; avoid full-surface weeding.
- Herbicides are not recommended.

### Step 7. Harvesting and Post-Harvest Management

*Coffee Harvesting and Storage*

- Harvesting:
  - Harvest ripe cherries in at least two passes per season.
  - Avoid picking green or unripe fruits; do not strip branches or break limbs.
- Harvest Standards:
  - 80% ripe fruits (yellow or red) in first harvest round regular harvests.
  - At least 70% ripe fruits in final harvest round.
  - Impurity rate below 0.5%.
- Storage:
  - Transport cherries promptly to processing facilities.
  - For wet processing: Process within 24 hours.
  - For dry processing: Dry on concrete floors, tarpaulins; thickness ≤ 30 cm; turn frequently.
  - Protect from rain; avoid pile thickness >30 cm.

*Avocado Harvesting and Storage*

- Harvesting:
  - Only harvest physiologically mature fruits (skin color darkens; loses sheen).
  - Use picking tools with cushioning to prevent damage.
  - Sort out overripe, pest-damaged, cracked fruits.
- Storage:
  - Transport fruits immediately to storage facilities.
  - Best storage period: Not more than two days.
  - Store in clean, cool, dry areas free of chemical contamination.

## 3.1.4 Technical steps for Arabica and persimmon intercropping

### Highlighted Technical Requirements

- Slope: <15°.
- Water Source: Reliable year-round.
- Soil Depth: >70 cm.
- Soil pH: 5.0 - 6.0.
- Legal Status: Intercropped species must be approved varieties.
- Planting Time: Early rainy season (May - August) preferred if no irrigation available.
- Tree Selection: Prefer trees with moderate root systems, compatible canopy architecture, and complementary harvesting schedules.

### Step 1. Garden Design for Intercropping

- Arabica spacing: 2.5 x 2.5 meters or 3 x 3 meters.
- Persimmon trees planted at 8 - 10 meters apart within coffee rows or between coffee rows depending on canopy size.
- East-west orientation for rows to maximize sunlight exposure.
- Maintain a height difference to ensure persimmon canopy provides seasonal shade without excessive light blockage.
- Design must prioritize efficient harvesting paths and irrigation access.

### Step 2. Soil Preparation and Fertilization

- Conduct mechanical plowing and deep tillage to 60 cm depth.
- Adjust pH to the optimal range of 5.0 - 6.0 using lime or sulfur as needed.
- Enrich soil with:
  - Organic compost (10 - 20 kg per pit)
  - Phosphate fertilizer (0.5 - 1.0 kg per pit)
  - Additional potassium for fruit crops like avocado.
- Prepare planting pits:
  - Coffee: 50 x 50 x 50 cm
  - Persimmon: 60 x 60 x 60 cm
- Fill pits 20 - 30 days before planting with amended soil.

### Step 3. Irrigation System Construction

- Moderate watering required, critical during fruiting stages.
- Lay out main and lateral irrigation lines across planting zones.
- Build drainage ditches to prevent water stagnation in rainy seasons.

### Step 4. Weed, Pest, and Disease Management

- Implement mulching using coffee husk, straw, or organic residues.
- Manual weeding during early stages; mechanical or chemical methods can supplement later.

- Targeted monitoring:
  - Arabica: Coffee leaf rust (*Hemileia vastatrix*)
  - Persimmon: Scale insects (*Coccus hesperidum*)
- Apply biological controls and integrated pest management (IPM) approaches where possible.

#### Step 5. Pruning and Canopy Management

- Arabica:
  - After harvest (December - January) and mid-rainy season (June - July).
  - Remove dead, diseased, or crossing branches.
- Persimmon:
  - Prune after harvest (October - November).
  - Shape tree to maintain 3 - 4 main branches.
  - Encourage ventilation and sunlight penetration into the canopy.

#### Step 6. Harvesting and Post-Harvest Management

- Arabica:
  - Harvest season typically from October to January.
  - Pick only fully ripe red cherries to ensure best quality.
- Persimmon:
  - Harvest season runs from September to November.
  - Pick fruits when they reach full colour and firmness; avoid mechanical damage.
  - For astringent varieties, post-harvest de-astringency treatment may be needed.
- Immediate post-harvest sorting and storage in shaded, well-ventilated areas.
- Prepare fruits for fresh market or processing according to quality standards.

### 3.1.5 Technical steps and requirements for integrating shade trees in coffee intercropping systems

#### Step 1. Selection of Shade Tree Species and Varieties

- Recommended Species:
  - *Cassia siamea (Muồng đen)*
  - *Erythrina subumbrans (Cây vông nem)*
  - *Gliricidia sepium (Muồng cưa)*
  - *Leucaena leucocephala (Keo dậu)*

#### Step 2. Site Planning and Spacing

- Plant shade trees along the coffee rows or between coffee rows based on desired shading intensity.
- Recommended spacing:
  - *Cassia siamea*: 20 x 20 meters
  - *Leucaena leucocephala*: 10 x 10 meters
  - *Erythrina subumbrans*: 8 x 8 meters
  - *Gliricidia sepium*: 6 x 8 meters or used as live fences
- Orientation of rows should follow the east-west direction to optimize morning and afternoon light penetration.

### Step 3. Nursery Preparation and Planting

- Seedling Production:
  - Use seeds or stem cuttings (for Gliricidia sepium)
  - Raise in polybags with a balanced soil-compost mixture for 45 - 60 days
- Transplanting Guidelines:
  - Ideal seedling height: 30 - 40 cm with healthy root systems
  - Plant during early rainy season (May to July)
  - Dig planting pits of 30 x 30 x 30 cm
  - Apply 3 kg of compost + 0.5 kg of NPK (5 - 10 - 3) per pit
  - Backfill with mixed topsoil and organic matter; firm gently around the seedling

### Step 4. Irrigation and Soil Moisture Management

- Water shade tree seedlings immediately after planting and 1 - 2 times per week during dry spells in the first year.
- Use mulch (coffee husk, straw, leaf litter) to retain moisture and suppress weed growth around tree bases.
- Ensure proper drainage to prevent waterlogging, especially in flat or clayey areas.

### Step 5. Pruning and Canopy Management

- Start from the second or third year after establishment
- Initial Phase:
  - Retain the strongest central stem
  - Remove lateral branches below half of total tree height
- Mature Phase:
  - Maintain a canopy clearance of 2 - 3 meters above coffee plants in year 3 - 4
  - Gradually increase to 4+ meters during coffee production phase
  - Prune 1 - 2 times per year to thin the canopy and reduce light competition
  - Remove suckers and low branches regularly

### Step 6. Integration with Coffee Management

- Combine shade tree pruning with major coffee operations (e.g., after harvest or rainy season).
- Use pruned biomass (twigs, leaves) as organic mulch or compost material.
- Avoid over-shading: monitor coffee leaf color and productivity as indicators of excessive shade.
- Complement with fruit trees (e.g., avocado, persimmon) only if resource availability allows.

## 3.2 Model 2 – Producing organic fertilizer from coffee husks

### 3.2.1 Overview

In the context of declining soil health/fertility caused by unsustainable land use and excessive reliance on chemical fertilizers and pesticides, utilizing organic fertilizers has become essential for maintaining soil health and improving crop yields. Coffee husks, a byproduct generated during coffee dry processing, account for approximately 45 per cent of the weight of dry coffee cherries and are often burned or discarded directly into the environment, causing air and soil pollution.

However, coffee husks also provide a sustainable raw material for organic fertilizer production. With high nutritional content, including 25 - 30 per cent organic matter, 1.8 - 2 per cent nitrogen, and essential micronutrients like calcium, magnesium, zinc, and boron, coffee husks hold significant potential for agricultural applications. Proper composting of coffee husks can enhance their utility while mitigating issues like nutrient wastage, environmental pollution, and the spread of pathogens.

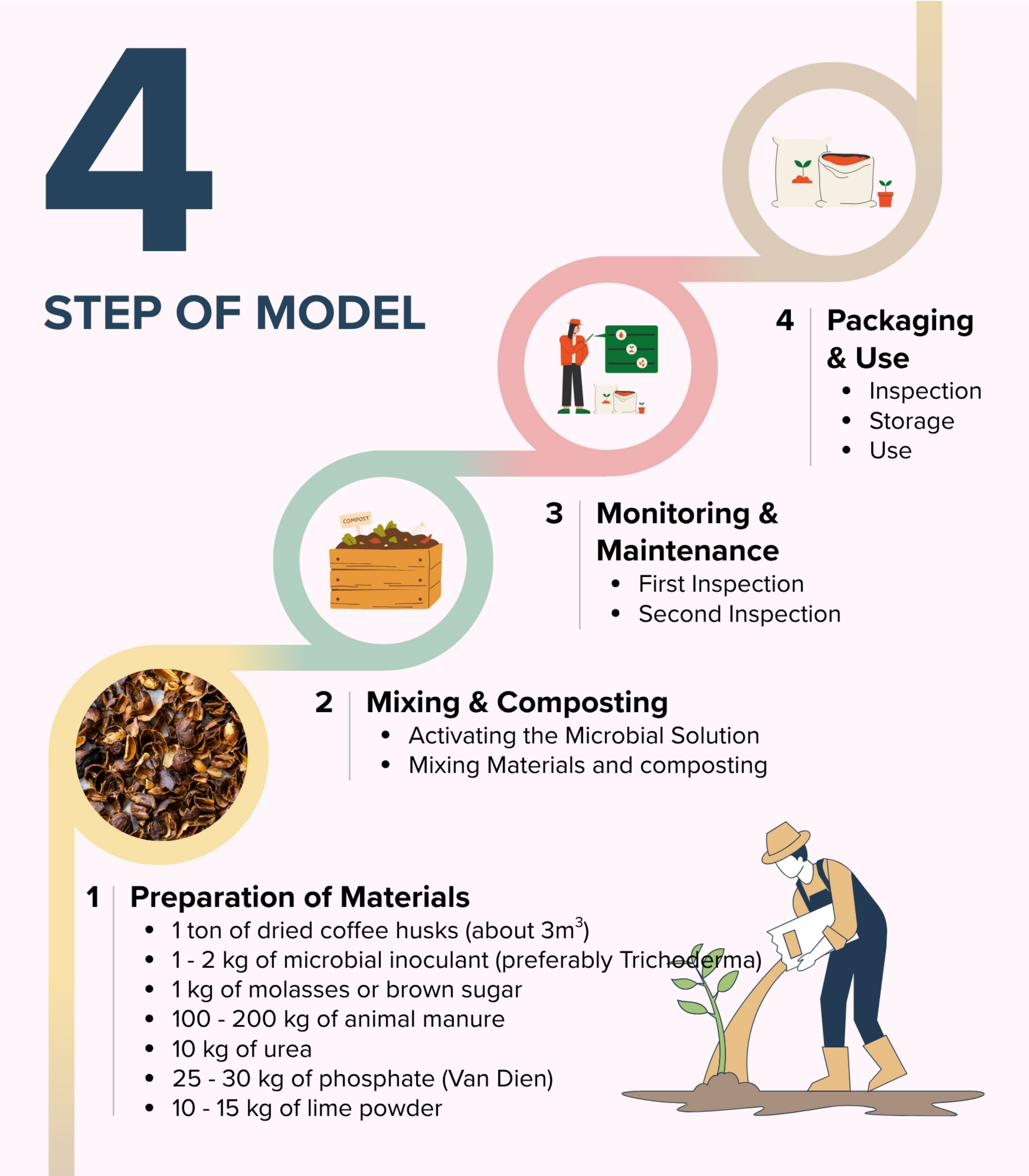
In 2024, the total plantation area for coffee in Viet Nam was 718,000 hectares, producing more than 1.95 million tons (MAE, 2025). Given that most Vietnamese coffee production uses dry processing, and assuming that each kilogram of green beans generates a nearly equivalent weight of dry husk, an estimated 1.6 million tons of dry husks are produced annually, representing a valuable resource for high-quality fertilizer.

### 3.2.2 Benefits

- **Economic Benefits**: Economically, this model reduces fertilizer costs and can increase crop yields. Using organic fertilizer made from coffee husks significantly lowers farmers' expenses on chemical fertilizers. On average, applying organic fertilizer from coffee husks could reduce fertilizer costs by VND 7 - 9 million per hectare per crop season. Further, organic fertilizers derived from coffee husks enrich the soil with essential nutrients, improving soil fertility and plant growth. Recent studies study have found that applying these fertilizers enhances the productivity of crops such as coffee and black pepper, resulting in higher yields (WASI, 2021; Nguyen et al., 2013).
- **CE and Climate Benefits**: By reducing pollution and improving soil quality, this model can also lead to a reduced need for inorganic fertilizer and other inputs. Recycling coffee husks into organic fertilizer helps decrease agricultural waste, reducing environmental pollution caused by burning or improper disposal of husks such as landfilling. Composting coffee husks also mitigates environmental contamination while raising public awareness about eco-friendly practices. Organic fertilizer derived from coffee husks also enhances soil structure by increasing aeration and water retention, contributing to better soil fertility and rehabilitation. Additionally, this practice improves the effectiveness of chemical fertilizers for coffee and other crops. Moreover, as a microbial organic fertilizer, it introduces beneficial microorganisms to the soil, enabling plants to resist soil-borne diseases and promoting overall soil health. In one study, Nguyen et al. (2013) found that after three years of applying coffee husk compost on a coffee field and only applying chemical fertilizers in the cultivation of coffee lead to reductions in pH, soil organic carbon (OC%), nitrogen (N%), phosphorus (P%), potassium (K%), and other available nutrients, increasing soil degradation. Conversely, applying 80 per cent chemical fertilizer and 2 kg of compost improved the fertility of the soil: pH, OC%, and N% had increased. The physical structure of the soil was also improved as pore space increased, which can enhance plants' absorption of nutrients and strengthen microorganism growth. Altogether, this leads to a reduced need for chemical fertilizer and maintains the fertility of the soil.
- **Social Benefits**: Producing organic fertilizer from coffee husks can generate employment opportunities, especially within cooperatives and small enterprises and foster environmental awareness. Training programs on composting coffee husks, for instance, have been widely conducted, enabling farmers to adopt this model and encouraging a broader commitment to environmental conservation. In Sơn La, Lâm Đồng, and Đắk Lắk, the provincial agricultural extension centers provide technical guidance on composting organic fertilizer from coffee husks. These programs are typically organized annually and integrated into technical training programs for early-season production.

### 3.2.3 Technical steps for producing organic fertilizers from coffee husks

**Figure 6. 4 technical steps for producing organic fertilizer from coffee husks**




#### Step 1. Preparation of Materials

Prepare the following materials in the specified proportions:

- 1 ton of dried coffee husks (approximately 3 $m^3$)
- 1 - 2 kg of microbial inoculant (preferably Trichoderma)
- 1 kg of molasses or brown sugar
- 100 - 200 kg of animal manure

- 10 kg of urea
- 25 - 30 kg of phosphate (Van Dien)
- 10 - 15 kg of lime powder

*Preparation steps*

- Pile processed coffee husks (either wet or dry).
- Mix 1 litre of Emina microbial solution with 1 litre of molasses and 100 litres of water.
- Check the moisture level of the husks: reduce moisture by sun-drying if too wet, or spray with water if too dry. The optimal moisture level is 50 - 60 per cent.
- Gather necessary tools, such as hoes, shovels, rakes, and water hoses. Prepare equipment for activating the microbial solution, including water barrels and sprinklers.
- Use tarps or similar materials to cover and secure the compost pile from wind. Natural woven material derived from waste is encouraged to use instead of plastic.

**Photo 1. Materials in coffee compost as fertilizer**

### Step 2. Mixing and Composting

#### a. Activating the Microbial Solution

- Dissolve 1 - 2 kg of microbial inoculant with 1 kg of molasses (or brown sugar) in 50 - 70 litres of clean water. Stir the mixture continuously.
- Allow the solution to activate for 2 - 3 hours before applying it to the compost pile.

**Photo 2. Dissolving microbial inoculant with clean water**

#### b. Mixing Materials and composting

- Spread a layer of coffee husks about 40 cm thick on the ground. Moisten and mix until the moisture level reaches 50 - 60 per cent (squeeze a handful of husks; water should seep through your fingers without dripping).
- Add the prepared materials (manure, urea, phosphate, lime) sequentially onto the husks. Mix thoroughly and add water to ensure uniform moisture (aim for 55 - 60 per cent). Use approximately 700 litres of water per ton of husks across this and the previous step. Avoid overwatering to prevent runoff or nutrient loss.

**Photo 3. Adding materials (manure, urea, phosphate, lime) sequentially onto the husks**

- Form the mixture into windrows approximately 20 cm high and 2 - 2.5 meters wide. The length depends on the volume of the compost. Apply the activated microbial solution evenly using a sprinkler, mixing thoroughly.
- Build the pile to the final dimensions: 0.9 - 1.2 meters high, 2.5 - 3 meters wide, and a length suited to the compost volume.
- Cover the pile with organic materials (e.g., straw, green manure, legumes) to a thickness of 10 cm. Lightly sprinkle water over the cover and secure a tarp over the pile to maintain moisture and temperature. Anchor the tarp to prevent wind displacement.

### Step 3. Monitoring and Maintenance

*First Inspection (15 days)*

- Check the pile by digging into the centre. Look for white fungal growth and measure the temperature, which should reach 60 - 80°C to decompose materials and kill pathogens.
- Add water to maintain moisture levels at 50 - 60 per cent if the pile appears dry.

*Second Inspection (3 - 4 weeks)*

- Reassess moisture levels and mix the pile thoroughly for even decomposition.
- Cover the pile again and allow it to compost for an additional 2 months. Regularly monitor and add water as needed to ensure microbial activity continues effectively.

**Photo 4. Covering compost with tarpaulin for 3-4 weeks**

### Step 4. Packaging and use

- After 3 - 4 months, inspect the pile. Fully decomposed compost will appear dark brown, soft, and crumbly with an earthy smell.
- Apply the compost directly to crops as fertilizer.
- For storage, package the compost into bags and store in a cool, dry, and covered area to preserve its nutrient content until use.

**Photo 5. Packaging the compost**


## Highlighted technical requirements

- Material quantity requirements:
  - › The amount of coffee husks required depends on the model scale. To ensure economic efficiency, a minimum quantity of several tons (up to tens of tons) is recommended for fertilizer production.
  - › Coffee husks should be mixed with supplementary materials such as animal manure, plant residues, or other organic waste to balance nutrient levels. A typical ratio is 50 per cent coffee husks, 20 per cent animal manure, and 30 per cent plant residues or other organic waste. The use of animal manure highlights the potential of crop-livestock integration, as well as cross-circularity between livestock and coffee sector.
- Material quality requirements:
  - › Coffee husks must be free of preservatives or harmful chemicals. Preference should be given to husks from organic farming to ensure safety.
  - › o The initial moisture content of the materials should range between 50 - 60 per cent to support microbial growth during composting.
  - › During the first phase of composting (2 - 4 weeks), the pile temperature should be maintained at 50 - 65°C to eliminate pathogens and accelerate decomposition.
- Technical requirements for the composting process:
  - › The composting process typically takes 60 - 90 days. To achieve high-quality fertilizer, the process should be extended to at least 2 - 3 months in natural temperature.
  - › The composting area should be covered to protect the pile from rain, allow for adequate ventilation, and be built on a hard surface (e.g., cement or bricks) to prevent soil or groundwater contamination.
  - › Turn the compost regularly (every 1 - 2 weeks) to ensure even decomposition and provide oxygen for the microorganisms breaking down the organic material.
- Quality control requirements:
  - › Regularly measure moisture levels and add water as needed to maintain the ideal range of 50 - 60 per cent.
  - › Monitor the temperature weekly to keep it within the optimal range. Adjust by adding or reducing materials if necessary.
  - › Fully decomposed organic fertilizer should have a dark brown colour (no unpleasant odour of coffee husks) and a pleasant, earthy smell.
- Time and workforce requirements
  - › The composting process and site management need to be maintained over a period of 2 - 3 months, depending on weather conditions and production scale.
  - › For small- to medium-scale operations, 1 - 2 workers are required to handle turning, monitoring, and maintaining the compost environment. For larger operations, a workforce of 5 - 10 people may be necessary.
  - › Health and safety regulations are needed.

### 3.2.4 Technical steps for applying coffee-husk fertilizer

#### When to apply organic fertilizer for coffee plants

**1. Basal fertilization before planting**

Apply organic fertilizer 2 - 3 weeks before planting. This helps loosen the soil, enhances microbial activity, and provides nutrients immediately when the plant starts to develop roots (Hoang, 2022).

**2. Supplemental fertilization**

Supplemental applications of organic fertilizer help maintain soil fertility and improve nutrient absorption for the plants.

- Fertile soil with high organic content: Apply once every 3 - 4 years.
- Normal soil: Apply once every 2 years.

**3. Regular fertilization schedule**

Organic fertilizer is typically applied three times per year as follows:

- *First application*: During the second irrigation cycle of the dry season. This strengthens the root system and increases resistance to nematodes.
- *Second application*: This is the main application, accounting for 60 per cent of the total organic fertilizer used. It is applied at the beginning or middle of the rainy season when the soil is adequately moist, the roots demand more nutrients, and soil microorganisms are actively thriving. Under these conditions, organic and microbial fertilizers perform optimally, promoting a healthy root system and improving the efficiency of chemical fertilizers.
- *Third application*: At the end of the rainy season (late August to early September). During this time, many microorganisms die, and organic matter rapidly degrades due to prolonged rain. Organic fertilizers combined with beneficial microorganisms help restore the soil's microbial system. The suitable moisture and increased soil aeration at this time make it ideal for applying organic microbial fertilizers.

#### How to apply organic fertilizer

- For young coffee plants without overlapping canopies: Dig trenches along the canopy diameter, 0.3 - 0.4 m deep, 0.3 m wide, and about 1/4 to 1/2 the length of the canopy edge.
- For mature coffee plants with overlapping canopies: Dig trenches between two coffee rows with similar dimensions as above.
  - › If trenches are dug horizontally this year, they should be dug vertically the following year.
  - › If there is a limited amount of organic fertilizer, alternate rows can be skipped. For the next application, dig trenches in the remaining rows.
- Always cover the soil after applying organic fertilizer to provide an environment conducive to microbial activity and to prevent nutrient loss through leaching.

## 3.3 Model 3A: Improving wastewater treatment in small-scale coffee processing facilities

### 3.3.1 Overview

While the processing method is not inherently tied to the coffee variety (i.e., robusta or arabica), certain trends and practical considerations often influence the choice of the processing approach for each variety. Robusta is typically processed using the dry method because it is cost-effective and suitable for the large-scale production of robusta, which is often used in blends and instant coffee. Wet processing of robusta is less common but can enhance its quality, producing cleaner and more consistent flavours and making it more competitive in premium markets.

Arabica, however, is often processed using the wet method because it enhances arabica's intrinsic qualities, such as its bright acidity, complex flavour profile, and clean cup, which are prized in specialty coffee markets. Arabica beans are also more delicate and susceptible to defects, so the controlled environment of wet processing reduces the risk of inconsistent quality.

- **Traditional wet processing**: This method is water-intensive. Conventional wet-processing may consume between 20 - 100 $m^3$ (20,000 - 100,000 L) of water per ton of green coffee, with the lower end of the range achieved only by recycling. Ecological wet milling should require under 10 $m^3$ of water per ton of green coffee, ideally under 5 $m^3$ (Brando, 2004, p. 647). With recycling practices, consumption can be reduced to between 9 - 13 $m^3$ (9,000 - 13,000 L) per ton.
- **Improved wet mills**: Implementing ecological wet mill designs has shown a reduction in water usage by up to 70 per cent, achieving an average of 0.67 L of water per kg of coffee cherries, equating to 670 L per ton. However, it also requires investment in dry de-pulping, mechanical mucilage removal equipment, and the redesign of the mill to use the least water possible.

Although wet processing technology has been improved, it still requires a significant amount of water, a pressure on natural resources that occurs in the dry season, and it generates wastewater containing nitrogen and phosphorus which can lead to environmental pollution if not properly treated.

Currently in Viet Nam, at the scale of households or cooperatives, coffee processing can adopt a combined physico-biological wastewater treatment technology which enables wastewater reuse for irrigation. This reduces environmental pollution and enhances production efficiency. It should be noted that the fresh pulp (the first step of the wet process) can be used as compost feedstock, which is also the case for the mucilage at the bottom of the first decantation tank.

Physico-biological wastewater treatment technology combines physical, chemical, and biological processes to manage and treat wastewater effectively. Coffee wastewater contains sugars, caffeine, and tannins, which cause high BOD and COD. Physico-biological methods effectively reduce these loads. Biological processes also remove nitrogen and phosphorus, preventing waterway eutrophication, which is when waterways become overly enriched with nutrients, leading to excessive plant and algal growth, reduced water quality, and is harmful to aquatic ecosystems. Treated wastewater can be reused for irrigation or non-potable purposes in coffee farms, a circular solution to environmental challenges.

### 3.3.2 Benefits

- **Economic benefits**: Treated coffee-processing wastewater contains significant amounts of nitrogen, phosphorus, and potassium, which are essential for plant growth. Application of this effluent can reduce the need for synthetic fertilizers. Studies have shown that irrigating with treated coffee-processing wastewater can lead to increased crop yields which is attributed to the added nutrients and improved soil conditions (Alemayehu et.al., 2020).
- **CE and climate benefits**: The circular model for treating and reusing coffee wastewater as irrigation water reduces the risk of groundwater and natural stream pollution. It also safeguards local ecosystems by minimizing harmful organic substances and microorganisms in wastewater and preventing negative impacts on biodiversity, thereby reducing environmental pollution and protecting ecosystems. Further, reusing treated wastewater maintains soil moisture and enhances soil structure through beneficial organic components. This improves soil aeration, nutrient content, and crop productivity while increasing resistance to erosion and degradation, ensuring long-term soil fertility for coffee cultivation. The organic content in treated coffee-processing wastewater can increase soil organic matter, improving soil structure, water retention, and microbial activity, thereby improving soil fertility.
- **Social benefits**: The circular wastewater treatment model for coffee processing generates additional job opportunities for local labour through activities such as wastewater collection, treatment, system operation, and maintenance. Furthermore, it raises public awareness about the importance of environmental protection and sustainable resource use. By adopting this model, people can gain a deeper understanding of the negative impacts of untreated waste and are encouraged to shift towards environmentally friendly production practices, fostering a positive impact on sustainable agricultural practice uptake.

### 3.3.3 Technical steps for waste-water treatment at small-scale coffee facilities

**Figure 7. 5 steps of wastewater treatment in coffee processing at small-scale coffee facilities**


#### Step 1. Clean water and preparation of secondary biological products

a. Clean water (7 - 10 days)

A clean water reservoir is constructed near the coffee processing system. Depending on the household's coffee production volume, the reservoirs vary in size (10 - 15m$^3$, noting that 1 ton of fresh pulped beans occupy 0.95 - 1.05 m$^3$ before adding water). Clean water is pumped into the reservoir 7 - 10 days prior to the coffee harvest. This area is equipped with a pumping system that transfers water to the fuel tank (coffee holding tank), de-pulping machine, fermentation and washing tanks, and other cleaning and processing units.

### b. Preparation of secondary biological products (10 days)

Approximately one week before harvest, households cultivate and propagate beneficial microorganisms by converting primary biological products (e.g., EM1) into secondary biological products through the following steps:

- Preparation: Mix 1 litre of EM1 solution, 1 litre of molasses, and 18 litres of chlorine-free water (if the water contains chlorine, let it sit in an open container for 24 hours to allow chlorine evaporation). 1 litre of EM1 solution per 1 $m^3$ of wastewater.
- Container requirements: Use a plastic container with a tightly sealed lid and a capacity of 20 - 30 litres.
- Fermentation process: Dissolve EM1 and molasses in water within the container, seal it tightly, and allow anaerobic fermentation for 5 - 7 days.
- Gas release: During fermentation, gas buildup may cause the container to expand. Open the lid briefly every 1 - 2 days to release excess gas, then reseal to prevent damage to the container.
- Result: The secondary fermented solution (EM2) is successful if a white film forms on the surface and it emits a sweet-sour aroma.

**Photo 6. Biological products (EM1)**

**Photo 7. Container requirements**

### Step 2. Mixing with secondary microbial solutions

After harvest, coffee cherries are soaked in clean water mixed with a secondary microbial solution for 6 - 8 hours in the holding tank. This process removes impurities such as soil, dust, and leaves, as well as unripe cherries, which float to the water surface. The wastewater and impurities are then directed to the primary wastewater tank through a pipeline system.

### Step 3. Wastewater recovery (~24 days)

Wastewater generated during coffee processing activities, including pulping, fermentation, washing, and cleaning, is collected and directed to a dedicated storage tank (Tank 1). This tank is designed to hold wastewater for a minimum of 24 days, allowing for the reduction of pollutant concentrations.

**Photo 8. Coffee pulping**

**Photo 9. Soaking, fermentation, and cleaning area**

### Step 4. Decanting (1 storage tank) and anaerobic decomposition/digestion (5 - 7 months)

- Wastewater from coffee processing is collected in a primary storage tank (Tank 1) and then pumped into a secondary storage tank (Tank 2). In Tank 2, wastewater is mixed with microbial agents and undergoes natural decomposition facilitated by microorganisms over 6 - 7 months.

**Photo 10. Storage tank for decomposition/digestion**

- During the decomposition process, mechanical aeration is performed once a month, and pH levels are monitored using litmus paper to ensure optimal environmental conditions.

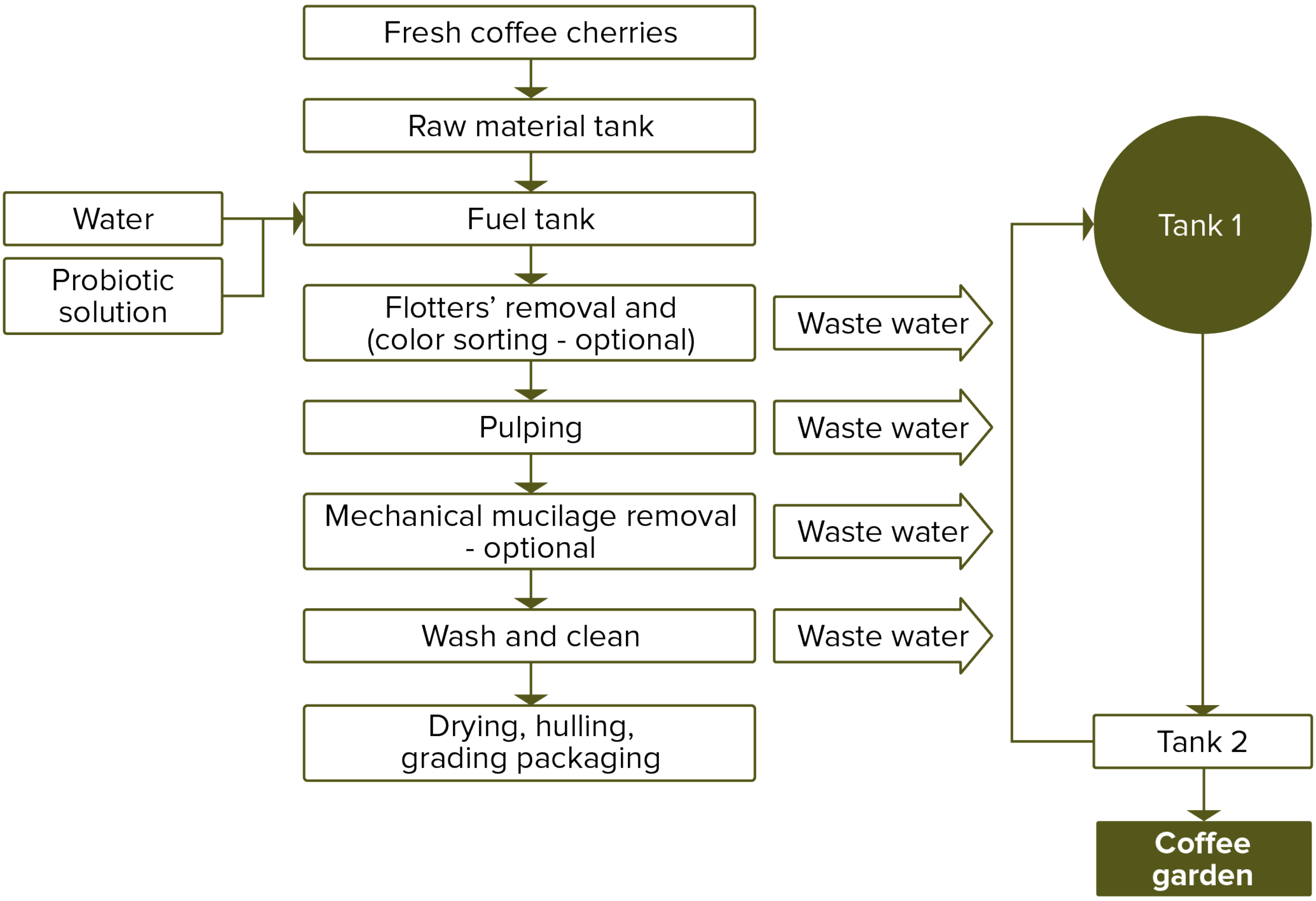
### Step 5. Use

After 6 - 7 months of natural decomposition, clear, odour-free and treated wastewater from coffee processing can be used for irrigation and fertilization of coffee plants. Coffee producers pump additional water into the secondary storage tank (Tank 2), stir it evenly, and use the mixture for irrigation. The treated wastewater not only supplies moisture and organic matter, but also provides nitrogen and phosphorus, helping to reduce production costs for farmers.

**Photo 11. Using treated wastewater for coffee plant irrigation**

Coffee processing wastewater must comply with the National Technical Regulation on Industrial Wastewater (QCVN 40:2011/BTNMT), issued by MAE. This regulation specifies permissible limits for key parameters such as pH (5.5 - 9), $BOD_5$ (≤ 50 - 100 mg/L), COD (≤ 75 - 150 mg/L), total suspended solids (≤ 50 - 100 mg/L), and microbial content, depending on the classification of the receiving environment (Column A or Column B). Compliance with QCVN 40:2011/BTNMT is mandatory for the discharge of treated coffee wastewater into natural water bodies to ensure environmental protection and sustainable resource management.

**Figure 8. Wastewater treatment in small-scale facilities**




## Highlighted technical requirements

- Knowledge of microbial cultivation and wastewater quality:
  - › Farmers must have basic knowledge of cultivating microbial agents to successfully implement the model, reduce costs, and minimize environmental impact.
  - › Treated wastewater must meet state regulations to be used for coffee plant irrigation.
- High initial investment costs:
  - › Requires significant upfront capital or access to financial support policies.
  - › Initial costs average around VND 213 million (including storage tanks, treatment systems, tarpaulin, and pipelines), posing challenges for many farmers.
- Proximity of production and treatment systems:
  - › Production areas, processing sites, and wastewater treatment systems must be located near each other to minimize costs and labour.
  - › Coffee plantations are often far from processing facilities, increasing transportation and irrigation costs significantly.

## 3.4 Model 3B: Improving wastewater treatment in large-scale coffee processing facilities

### 3.4.1 Overview

This model produces biogas through anaerobic decomposition, effectively reducing pollution and providing a renewable energy source. The biogas can be used as fuel for production activities such as drying and hulling (the mechanical removal of the final protective layers from the dried coffee bean), thermal energy production used for drying coffee, electricity production, or as fuel for biogas-powered engines, altogether helping businesses lower energy costs and optimize resources.

The high-density polyethylene-covered biogas digester technology is commonly utilized, featuring a leak-proof, simple design with low costs, simple maintenance, and high efficiency. This technology not only effectively treats wastewater but also converts waste into valuable resources, delivering economic and sustainable development benefits.

Using biogas allows businesses to meet green production standards, enhance their eco-friendly image, and demonstrate social responsibility. This approach attracts environmentally conscious customers and partners, providing a competitive edge in the coffee processing industry.

This model (Model 3B) differs from Model 3A in that it applies to large enterprises, requiring high upfront costs and more advanced technology. The benefits of its application are similar, but differ in scale.

### 3.4.2 Benefits

- **Economic benefits**: This model significantly reduces energy costs by utilizing biogas as an alternative fuel, achieving savings of 20 - 50 per cent compared to traditional energy sources (likely coal). Wastewater treatment costs are optimized through an on-site self-operating system, transforming wastewater from a financial burden into an economic resource, thereby optimizing energy costs and wastewater treatment.

  Furthermore, implementing this model enables products to achieve a “clean production” certification. Although no specific regulation directly mandates wastewater treatment for coffee in the US and EU, compliance with major sustainability certifications such as Rainforest Alliance, Fairtrade, USDA Organic, and EU Organic standards requires proper management and treatment of wastewater to meet environmental protection criteria and market access requirements. Therefore, this model brings economic benefits by enhancing brand value and expanding market reach.

- **CE and climate benefits**: This model’s wastewater treatment system reduces 90 - 95 per cent of pollutants, improves water quality, prevents eutrophication, and protects aquatic ecosystems. Treated water meets legal standards and can be reused for cleaning facilities, contributing to minimizing environmental impacts and presenting a circular solution to an environmental challenge through efficient wastewater treatment. The conversion of methane in wastewater into biogas also reduces GHG emissions, and treated sludge can be repurposed as organic fertilizer. By reducing emissions and repurposing waste, this model supports CE goals, aligns with Viet Nam’s climate ambitions, and overall advances sustainable agricultural development.

- **Social benefits**: The model can contribute to job creation through roles in technology testing, operating, and troubleshooting for local workers, and can enhance living conditions by reducing environmental pollution. It also raises community awareness about sustainable production, fostering a lifestyle aligned with environmental protection goals.

### 3.4.3 Technical steps for wastewater treatment at large-scale coffee facilities

**Figure 9. 5 steps for wastewater treatment in coffee processing**


#### Step 1. Waste collection and separation

The wastewater generated during coffee processing (from washing, soaking, fermentation, etc.) is directed to a sedimentation tank. Here, sand and large-sized debris are retained to protect the pumps and pipes. The wastewater then flows by gravity into an intermediate tank, where the levels of suspended solids, COD, and BOD are significantly reduced.

**Photo 12. Tank collects wastewater; check and adjust PH**

### Step 2. Collect wastewater, then check and adjust PH

Wastewater is collected, separated, and directed to the intermediate tank.

The intermediate tank stabilizes the flow rate and load of wastewater.

Variations in wastewater flow throughout the day are managed by the intermediate tank to ensure a steady supply to the anaerobic digestion tank.

Wastewater is mixed with activated sludge from the anaerobic biogas tank to stabilize pH.

pH adjustment chemicals are added if necessary, maintaining the pH between 6.5 - 7.5 for optimal degradation and biogas production.

**Photo 13. Anaerobic biogas digester**

### Step 3. Anaerobic biogas digester

- After checking the quantity and pH level, the wastewater is pumped into the biogas tank.
- Anaerobic microorganisms decompose organic matter in the wastewater and produce biogas.
- The sludge generated from the anaerobic tank is partially recycled back to the intermediate tank to stabilize the wastewater composition before it enters the anaerobic tank.

### Step 4. Collect and distribute biogas

- Biogas produced in the anaerobic digestion tank is collected using perforated plastic pipes arranged along the perimeter of the tank.
- The gas is directed to the main gas collection pipeline.
- Biogas passes through a dehumidification system, then a pressure check system, and safety valves.
- The gas is treated for hydrogen sulphide ($H_2S$), which makes up approximately 0.5 per cent of the biogas.

**Photo 14. Converting wastewater into biofuel for coffee drying or electricity generation**

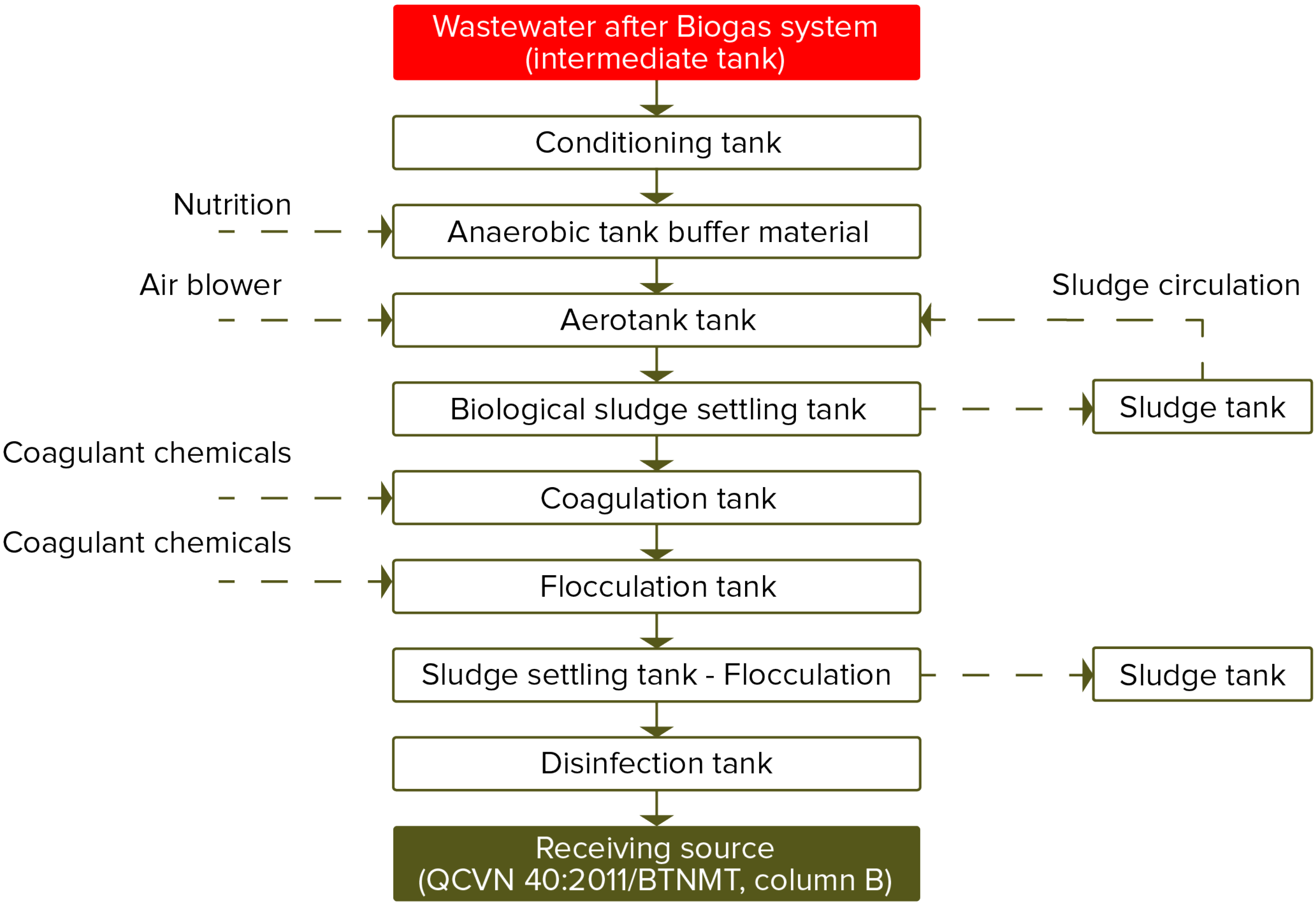

From here, biogas is supplied by an air blower to the combustion system within the facility. Inside the facility, the biogas is burned in coffee drying ovens or used to power generators.

**Photo 15. Using biogas from wastewater treatment for drying coffee**

## Step 5. Wastewater treatment

The wastewater treated in the anaerobic biogas digestion tank achieves a treatment efficiency of approximately 80 - 90 per cent. The collected production wastewater, after undergoing anaerobic treatment in the biogas digestion tank, is further treated using a combination of biological and physico-chemical technologies, following the process outlined in the diagram below:

**Figure 9. Wastewater treatment in large-scale facilities**




The treated wastewater must meet the standards specified in Column B of the National Technical Regulation on Industrial Wastewater (QCVN 40:2011/BTNMT) for discharge into water bodies not intended for domestic water supply. The treated wastewater is utilized by the enterprise for cleaning floors and equipment during coffee processing operations.

**Photo 16. Wastewater treatment system using bio-chemical and physico-chemical technology**

## Highlighted technical requirements

- Requirements for wastewater treatment volume: Ensure an adequate input volume of wastewater for treatment according to the designed capacity, with a treatment efficiency rate of ≥ 90 per cent.

- Quality of treated wastewater: Meets Viet Nam's National Technical Regulation on Industrial Wastewater (QCVN 40:2011/BTNMT) or local regulations:
  - BOD5: ≤ 30 mg/L
  - COD: ≤ 50 mg/L
  - pH: 6 - 8.5
  - Total suspended solids (TSS): ≤ 50 mg/L
  - Nitrogen and Phosphorus: As per specific local requirements
- Biogas production requirements:
  - ≥ 80% of COD is converted into biogas.
  - Methane ($CH_4$) content: ≥ 60 per cent.
  - Impurities such as $H_2S$: ≤ 200 ppm.
- Technological design requirements:
  - Anaerobic digester in the form of fermentation tanks or UASB (Upflow Anaerobic Sludge Blanket).
  - Primary treatment systems (e.g., trash screening, sedimentation tanks) and secondary systems (e.g., biological filters, chemical treatments).
  - Safety requirements also needed (e.g. gas storage/leak monitoring; burner or generator requirements; safety measures for biogas handling).
- Retention time: Hydraulic retention time (HRT) of 15 - 25 days, depending on the system design (e.g., anaerobic digester, UASB tank, or other technologies).
- Risks and risk mitigation: One significant challenge in maintaining coffee processing wastewater treatment systems is the seasonal nature of coffee harvesting and processing. During the harvest season, the volume of wastewater is extremely high, but outside of this period, wastewater production decreases sharply or ceases entirely. This makes it difficult and inefficient to maintain wastewater treatment systems, especially systems like biogas plants. Below are some proposed CE solutions to address this issue:
  - **Integrating wastewater sources from other industries**: Utilize wastewater from other agricultural or industrial activities in the region during the coffee off-season or use other agricultural byproducts, such as rice straw or livestock manure, to supplement feedstock for biogas systems. This solution helps to maintain the continuous operation of the treatment system year-round, improve system utilization, and reduce operational costs. By using wastewater from other agricultural activities, this solution reduces waste and fits within a broader CE approach to agricultural production.
  - **Storing and gradual treatment of wastewater**: Build large storage tanks to collect wastewater generated during the coffee harvest season and treat it gradually throughout the year. Use sealed storage tanks to minimize environmental pollution and preserve the organic matter needed for treatment. This solution helps to avoid processing overload during peak periods and provide a consistent feedstock supply for biogas systems.
  - **Community support and value chain integration**: Encourage cooperatives and small businesses to collaborate on building centralized treatment systems that serve multiple households or processing facilities. People in cooperatives can share wastewater from neighbouring regions with similar feedstock materials and share costs among members to maintain systems effectively. This solution helps to scale up systems to reduce investment costs for individual households and ensure stable operations even during off-seasons. This builds on a fundamental CE principle of sharing resources, illustrating how CE approaches can help advance a more sustainable agricultural system.

**Policy opportunity related to Model 4: Develop technical regulations to govern the safe transfer and use of treated wastewater for agricultural purposes**

Currently, Viet Nam lacks specific regulations governing the transfer and reuse of treated wastewater from industrial or agro-processing activities, such as coffee processing, for agricultural irrigation. While QCVN 01-195:2022/BNNPTNT provides standards for the use of livestock wastewater in crop cultivation, and QCVN 40:2011/BTNMT sets the permissible discharge limits for industrial wastewater (including coffee processing effluents), there is still no dedicated technical regulation that governs the quality, conditions, or procedures for transferring treated wastewater between enterprises for reuse purposes. QCVN 08:2023/BTNMT establishes national technical standards for surface water quality, mainly used to classify and assess receiving water bodies but it does not regulate treated wastewater intended for agricultural reuse. This regulatory gap limits the potential for sustainable water resource management, particularly in coffee-producing areas where wastewater reuse could reduce freshwater use and enhance environmental protection.

It is recommended that Viet Nam develop specific technical guidelines or regulations on the safe use of treated wastewater for crops, including clear water quality standards for reuse, transfer mechanisms, monitoring requirements, and pilot models to promote safe and effective agricultural reuse.

Chapter 4

# ECONOMIC AND ENVIRONMENTAL BENEFITS OF CIRCULAR MODELS IN COFFEE PRODUCTION

## 4.1 Cost-benefit analyses

### 4.1.1 Model 1: Intercropping in coffee cultivation

At baseline prices, the NPV of the coffee-avocado intercrop reaches VND 4,467.77 million per hectare, about 57 per cent higher than the VND 2,860.68 million per hectare achieved by coffee monocropping. Annualized returns (EAA) under intercropping are also 50 - 60 per cent higher, where coffee monoculture generates an EAA between VND 181 - 209 millionper hectare per year, and the coffee-avocado intercrop yields between VND 299 - 327 million per hectare per year. The IRR for coffee monoculture is approximately 51 per cent, while that of coffee-avocado intercropping reaches around 67 per cent, substantially exceeding typical market discount rates. Moreover, the payback period shortens from four years to three years when adopting the intercropping model.

In the first five years, the net accumulated cash flow from coffee-avocado intercropping is VND 259.47 million per hectare, which is more than three times higher than the VND 78.74 million per hectare achieved under monocropping.

Even under scenarios where coffee and avocado prices decrease, intercropping remains financially more resilient. While the monocrop model may face a negative cash flow (approximately VND -28.68 million per hectare) after five years under a price drop scenario, the intercropping model still maintains a positive net cash flow of about VND 139.31 million per hectare.

**Overall, the economic analysis demonstrates that coffee-avocado intercropping provides significantly higher financial returns, faster investment recovery, and better resilience to price fluctuations compared to coffee monocropping. A detailed table of estimation can be found in Annex 2.**

### 4.1.2 Model 2: Producing organic fertilizer from coffee husks

The results of monitoring coffee yield over time indicate that the model utilizing fertilizer made from coffee husks shows stable and higher yields compared to the conventional coffee monoculture model (DARD Lam Dong, 2022). In this model, the average yield reached 4.43 tons of beans per hectare, which is 0.2 tons per hectare higher than traditional coffee production. Furthermore, the use of coffee husk fertilizer improved soil fertility, promoting stable plant growth, reducing aging, and ensuring more consistent yields (DARD Lam Dong, 2022).

**Table 11. Production cost of 1 ha of robusta coffee in Lam Dong province**

| No. | Category | Unit | Conventional production model | Model using coffee husks as fertilizer | Change |
|---|---|---|---|---|---|
| **I** | **Total cost of production** | **VND/ha** | **58,575,000** | **53,275,000** | **-10.2%** |
| 1 | Fertilizer | VND/ha | 24,875,000 | 19,595,000 | -21.2% |
| 1.1 | Organic fertilizer | VND/ha | 9,000,000 | 6,000,000 | -33.3% |
| 1.2 | Inorganic fertilizer | VND/ha | 15,875,000 | 13,595,000 | -14.4% |
| | - urea | VND/ha | 4,500,000 | 3,725,000 | -17.2% |
| | - SA Ammonium Sulphate | VND/ha | 1,400,000 | 1,290,000 | -7.9% |
| | - superphosphate | VND/ha | 2,475,000 | 2,205,000 | -10.9% |
| | - Kali - Potassium fertilizer (potash) | VND/ha | 5,000,000 | 4,250,000 | -15.0% |
| | - lime | VND/ha | 2,500,000 | 2,125,000 | -15.0% |

| No. | Category | Unit | Conventional production model | Model using coffee husks as fertilizer | Change |
|---|---|---|---|---|---|
| 2 | Plant protection chemicals | VND/ha | 3,600,000 | 3,460,000 | -3.9% |
| 3 | Production of gasoline, oil, and electricity | VND/ha | 7,500,000 | 7,500,000 | 0.0% |
| 4 | Other materials for coffee production | VND/ha | 1,000,000 | 1,000,000 | 0.0% |
| **II** | **Hired labour cost** | **VND/ha** | **21,600,000** | **21,720,000** | **0.6%** |
| 1 | Land preparation labour | VND/ha | 2,000,000 | 2,000,000 | 0.0% |
| 2 | Pruning and canopy shaping labour | VND/ha | 8,000,000 | 8,000,000 | 0.0% |
| 3 | Weeding and garden maintenance labour | VND/ha | 3,000,000 | 3,000,000 | 0.0% |
| 4 | Plant protection chemical spraying labour | VND/ha | 3,000,000 | 2,850,000 | -5.0% |
| 5 | Fertilizer application labour | VND/ha | 2,400,000 | 2,670,000 | 11.3% |
| 6 | Irrigation labour | VND/ha | 3,200,000 | 3,200,000 | 0.0% |
| **III** | **Productivity** | **ton/ha** | **3.26** | **3.46** | **6.0%** |
| **IV** | **Product price** | **VND/kg** | **80,373** | **80,373** | **0.0%** |
| **V** | **Gross product** | **VND/ha** | **262,015,980** | **278,090,580** | **6.0%** |
| **VI** | **Gross margin** | **VND/ha** | **203,440,980** | **224,815.580** | **10.5%** |

*Source: Lam Dong DARD and households surveyed in 2024*

The model in which residents in Lam Dong province utilize coffee husks as organic fertilizer has helped reduce production costs by 10.2 per cent compared to conventional production models. Specifically, the cost of organic fertilizer decreased by 33.3 per cent, and the cost of using urea fertilizer was reduced by 17.2 per cent, among other cost savings.

To compare the economic efficiency between two production models in Lam Dong province (traditional robusta coffee farming and utilizing coffee husks as fertilizer) the research team used the average price of robusta coffee in Lam Dong during Q1/2024, which was 80,373 VND/kg (dry weight).

Model 2 yielded a higher profit of VND 223.1 million/ha due to increased productivity and lower fertilizer costs. This approach not only reduces investment in chemical fertilizers but also contributes to environmental protection by minimizing the use of harmful chemicals. Furthermore, utilizing the husks, which are already a byproduct of coffee processing, not only saves costs but also produces high-quality organic fertilizer that enhances soil fertility and supports sustainable agricultural production.

**Overall, Model 2's benefits are clear: by reusing waste in a closed-loop system, farmers can reduce the requirements for chemical inputs, improve yields, save costs, and advance collective sustainable agricultural development.**

### 4.1.3 Models 3A & 3B: Improving wastewater treatment in coffee processing at small- and large-scale facilities

An economic analysis was conducted for a coffee processing plant with a production scale of 1,000 tons of fresh coffee cherries per year that was investing in a biogas wastewater treatment system. The investment cost of the biogas system was VND 250 million, with an expected operational lifespan of 15 years.

The system produces an estimated annual volume of 4,500 - 7,500 $m^3$ of biogas, resulting in annual savings from replaced liquefied petroleum gas (LPG, e.g., propane or butane) and electricity generation totalling between VND 81 - 135 million. After deducting annual operation and maintenance costs, the net annual benefit ranges from VND 79 - 133 million.

Over 15 years, the total present value of the net benefits is estimated between VND 735 - 1,233 million. After accounting for the initial investment, the NPV is calculated to range from VND 485 - 983 million at a discount rate of 10 per cent. The IRR is estimated to be between 28 per cent and 34 per cent, significantly higher than the assumed market discount rate of 10 per cent.

**Overall, with an initial investment of VND 250 million, installing a biogas wastewater treatment system in a coffee processing facility is considered highly profitable, offering substantial financial returns over its operational life** (Refer to Annex 2 for details).

## 4.2 Carbon footprint analyses

One of the key objectives of this Handbook is to provide technical information to support MAE in including CE practices in Viet Nam's NDC 3.0. The following section outlines how the models in this Handbook can help to achieve climate mitigation goals through reduced carbon emissions by reducing waste, optimizing resource use, and minimizing environmental impacts in coffee production.

**A carbon footprint (CF)** represents the amount of $CO_2$ emissions associated with a product's lifecycle, and is typically expressed in tons of $CO_2$ equivalent ($CO_2$e) per unit of area, weight, volume, or time. While CF methodologies offer critical insights into direct and indirect emissions, they often fall short of capturing broader environmental and systemic impacts. For example, conventional CFs typically exclude net carbon flows (such as sequestration through biomass) and externalities like deforestation, biodiversity loss, or water and soil degradation. They also tend to overlook the carbon storage potential of production systems. In coffee cultivation, particularly robusta systems in Viet Nam, intercropping and agroforestry models have demonstrated higher carbon sequestration potential compared to unshaded monocultures, which contribute less to atmospheric $CO_2$ removal.

To address these limitations and ensure a more holistic and actionable assessment of sustainability, the CE-NDC Toolbox provides a comprehensive framework for identifying and integrating CE interventions into national climate planning. While 28 per cent of current NDCs, as of 2023, explicitly reference CE strategies, circular principles such as regenerative production, waste reduction, and carbon retention are highly relevant to the coffee sector and could be incorporated. Applying the CE-NDC Toolbox to coffee supply chains could help policymakers prioritize high-impact, low-emission farming models and define enabling policy instruments. The IPCC Greenhouse Gas (GHG) Inventory Guidelines provided a methodological framework to calculate emissions used for the development of this Handbook.

Furthermore, it is essential to complement CF analysis with other sustainability metrics such as social life cycle assessments (available in the CE-NDC Toolbox), which capture labour conditions, social equity, and livelihood impacts. This integrated approach aligns with the objectives of this Handbook as a technical reference intended to support the update of Viet Nam's NDC 3.0. By embedding CE thinking and socio-environmental co-benefits into carbon accounting, Viet Nam can advance toward a more ambitious, inclusive, and climate-resilient coffee strategy.

#### Contributors to coffee's carbon footprint

The CF of coffee refers to the total GHG emissions measured in $CO_2e$ that are generated throughout its supply chain from cultivation to consumption and disposal.

The cultivation stage contributes the largest share of emissions, primarily due to the application of nitrogen-based fertilizers which release $N_2O$, a potent GHG. Emissions also arise from the production and transport of fertilizers and pesticides, as well as the use of fossil fuels for irrigation, fieldwork, and on-farm transportation. In some cases, deforestation and land-use change to establish coffee plantations further increase emissions at this stage.

The processing phase adds to the CF, particularly for wet-processed coffee (common in arabica) which requires substantial water and energy use. Dry processing, more typical for robusta, is less water-intensive but still involves emissions from sun-drying or mechanical drying processes (e.g., from the use of diesel or biomass-fueled dryers, or methane released during fermentation if not well managed).. Electricity and fuel consumption during hulling, grading, and milling further contribute to total emissions.

Transport and export represent another significant source of emissions. Coffee is often moved long distances from farms to local mills, ports, and finally to consumer markets overseas. While sea freight is relatively carbon-efficient, air freight, though rare, can drastically increase the product's carbon intensity.

Roasting and packaging also play a critical role. Roasting coffee beans consumes a considerable amount of energy and packaging materials (especially non-recyclable or multi-layer plastics) add upstream emissions. Additionally, storage and retail activities, particularly those involving refrigeration or long-distance distribution, contribute to the overall footprint.

At the consumption stage, the method of brewing has a notable impact. For instance, espresso machines use more energy compared to manual brewing methods like pour-over or French press. The addition of milk significantly increases emissions, often doubling or tripling the footprint of a single cup. The use of single-use pods or non-compostable takeaway cups exacerbates environmental impact even further.

Finally, end-of-life emissions arise from how waste is managed. Improper disposal of coffee grounds, filters, and packaging materials, especially when composting or recycling systems are not in place, adds to the overall environmental burden. Together, these stages illustrate that coffee's CF is shaped not only by how and where it is grown but also by how it is processed, transported, consumed, and discarded.

### 4.2.1 Carbon footprints of conventional and circular coffee production in Viet Nam

A recent study by Mai Van Trinh et al. (2024) analyses GHG emissions generated across the robusta coffee supply chain in three major production districts located in the Central Highlands of Viet Nam: Di Linh districts in Lam Dong province, and Cu M'gar and Krong Nang districts in Dak Lak province. The study compares emissions between monoculture and intercropping models and evaluates GHG intensity per hectare and per kg of green coffee, as well as the net carbon footprint after biomass sequestration.

**GHG emissions per hectare** from coffee cultivation revealed notable spatial and systemic differences:

- Di Linh (Lam Dong): Intercropping led to an 8.5 per cent reduction in emissions.
  - Monoculture: 3,174.36 kg $CO_2e$/ha
  - Intercropping: 2,906.04 kg $CO_2e$/ha

- Cu M'gar (Dak Lak): Emissions increased by 12.2 per cent in intercropping, likely due to input-intensive companion crops.
  - Monoculture: 2,483.16 kg $CO_2$e/ha
  - Intercropping: 2,786.47 kg $CO_2$e/ha
- Krong Nang (Dak Lak): A modest reduction of 1.8 per cent with intercropping.
  - Monoculture: 3,226.53 kg $CO_2$e/ha
  - Intercropping: 3,166.98 kg $CO_2$e/ha

These results indicate that while intercropping may reduce emissions in some contexts, its effectiveness is not uniform and may depend heavily on local agricultural practices and crop combinations.

#### Carbon footprint per kilogram of green coffee (kg $CO_2$e/kg)

When assessed based on product output (i.e., per kg of green coffee), the carbon intensity provides a clearer picture of system efficiency:

- Di Linh (Lam Dong): Intercropping increased emissions by 9.4 per cent, indicating potential inefficiencies.
  - Monoculture: 0.96 kg $CO_2$e/kg
  - Intercropping: 1.05 kg $CO_2$e/kg
- Cu M'gar (Dak Lak): A marginal decrease of 0.85 per cent in the intercropping model.
  - Monoculture: 1.17 kg $CO_2$e/kg
  - Intercropping: 1.16 kg $CO_2$e/kg
- Krong Nang (Dak Lak): A more significant reduction of 10.7 per cent in the intercropping model.
  - Monoculture: 1.22 kg $CO_2$e/kg
  - Intercropping: 1.09 kg $CO_2$e/kg

These results suggest that Krong Nang District's intercropping model with avocado, durian, and pepper is the most GHG-efficient on a per-unit basis.

#### Net carbon footprint of coffee after biomass sequestration

The net carbon footprint accounts for the carbon sequestered by coffee trees and intercropped species through biomass accumulation:

- Di Linh (Lam Dong): Notably, the coffee-black pepper model exhibited the highest net footprint at 0.53 kg $CO_2$e/kg.
  - Monoculture: 0.29 kg $CO_2$e/kg
  - Intercropping: 0.28 kg $CO_2$e/kg
- Cu M'gar (Dak Lak): The coffee-black pepper-durian model recorded a net footprint of 0.41 kg $CO_2$e/kg.
  - Monoculture: 0.12 kg $CO_2$e/kg
  - Intercropping: 0.31 kg $CO_2$e/kg
- Krong Nang (Dak Lak): monoculture has the highest net carbon footprint, at 0.48 kg $CO_2$e/kg.
  - Monoculture: 0.48 kg $CO_2$e/kg
  - Intercropping: 0.41 kg $CO_2$e/kg

### 4.2.2 Carbon footprint of the coffee supply chain

Across all locations, positive net carbon values confirm that these systems remain net GHG emitters, though sequestration helps mitigate total impact. Interestingly, certain intercropping models such as coffee-black pepper and coffee-durian, while promoting agro-diversity, may inadvertently increase emissions due to higher input requirements or lower yield efficiency.

These CF analyses reveal that emissions arise from multiple stages of the supply chain, with varying levels of contribution. The primary sources of GHG emissions include:

- $N_2O$ emissions from soil, primarily resulting from nitrogen fertilizer application, which account for the highest proportion, ranging from 24.5 - 49.5 per cent of total emissions.
- Fertilizer production is the second-largest contributor, responsible for 20.8 - 38.0 per cent of total GHG emissions.
- Fuel consumption for on-farm and post-harvest production activities contributes between 2.3 - 44.3 per cent, depending on the farming system and energy source.
- Transportation-related emissions range from 1.2 - 18.8 per cent, with variation depending on logistics, distance to market, and mode of transport.
- Other sources, such as the production of pesticides, contribute a negligible share to total emissions.

The results by Mai Van Trinh et. al (2024) on the assessment of GHG emissions within green coffee production systems revealed that the three most significant sources of emissions are: (i) the application of nitrogen-based fertilizers to agricultural soils; (ii) the industrial production of fertilizers; and (iii) the use of fossil-based energy during cultivation and post-harvest processing operations.

**These sources represent key emission hotspots that require targeted interventions to achieve meaningful reductions in sector-wide carbon intensity. To address these challenges, three mitigation strategies are proposed:**

1. First, **optimizing fertilizer usage** through improved nutrient formulations and calibrated application rates is essential to reduce emissions from $N_2O$, a potent GHG resulting from nitrogen fertilization;
2. Second, **enhancing energy efficiency** along the coffee supply chain, from farm-level mechanization to processing and transportation, is critical for reducing $CO_2$ emissions; and
3. Third, **transitioning strategically toward a sustainable and low-emission coffee production model** is required. This transition should be based on the adoption of environmentally responsible practices, such as agroforestry, renewable energy integration, and low-impact processing technologies.

**The adoption of these mitigation measures is expected to yield several co-benefits. At the production level, coffee growers are likely to experience increased value added and higher farm incomes due to improved resource use efficiency. At the processing and distribution stages, actors in the supply chain may benefit from enhanced operational efficiency and reduced input costs. Lastly, the promotion of sustainable production models is anticipated to improve the sector's investment attractiveness and scalability, thereby supporting the development of resilient, low-carbon agricultural systems aligned with national and international climate commitments.**

### 4.2.3 Carbon footprint from coffee processing wastewater

Research has shown that wastewater from wet coffee processing typically contains a COD concentration ranging from 20,000 - 50,000 mg/L. Assuming that processing 1 ton of coffee discharges 15 $m^3$ (15,000 L) of wastewater, the total COD is 450 kg.

**Total COD = 15,000 L × 30,000 mg/L = 450,000,000 mg = 450 kg COD.**

Under anaerobic conditions, a portion of the COD is converted into methane ($CH_4$), with an approximate conversion rate of 0.25 - 0.5 kg of $CH_4$ per kg of COD. Assuming a rate of 0.35 kg $CH_4$ per kg of COD, the methane emissions resulting from processing 1 ton of coffee (or from

450 kg of COD) is 157.5kg

$$\mathbf{CH_4\ emissions = 450\ kg\ COD \times 0.35 = 157.5\ kg\ CH_4.}$$

Since methane has a global warming potential (GWP) 28 times greater than that of $CO_2$, the equivalent $CO_2$ emissions are **4,410 kg$CO_2$eq**.

The discharge of untreated coffee wastewater has several significant environmental impacts. Firstly, methane, a potent GHG gas, is released, contributing to global warming. Secondly, the high concentration of organic matter in untreated wastewater can cause severe water pollution, contaminating both groundwater and surface water. Lastly, the decomposition of organic matter in the wastewater generates gases such as hydrogen sulphide ($H_2S$) and ammonia ($NH_3$), leading to unpleasant odours and a reduction in air quality.

To reduce the environmental impact of coffee wastewater, several solutions can be implemented for small-scale and large-scale coffee processing facilities, as outlined in this Handbook. One effective approach is controlled anaerobic treatment, which captures methane for use as biogas instead of releasing it into the environment. Additionally, biological agents such as microorganisms or enzymes can be applied to reduce the BOD and COD of wastewater, thereby limiting methane production. Finally, water recycling systems can be introduced to reduce both the volume of wastewater generated and its organic load, improving overall processing efficiency and minimizing environmental harm.

# CONCLUSION

This Handbook has outlined the benefits of three circular models for coffee production and technical steps to implement them, which ideally equips farmers, coffee production stakeholders, and policymakers to adopt CE models on the ground.

The analysis above illustrates how coffee production using the circular methods outlined in this Handbook (intercropping, using waste for organic fertilizer, and treating wastewater in small and large facilities), stands to (i) reduce the carbon footprint of coffee production, and (ii) lessen environmental harms from pollution and improper waste disposal, while generating socio-economic co-benefits. In this way, the application of CE models in coffee production can contribute to achieving Viet Nam's climate and development ambitions.

Further, the economic analysis illustrates how these models can make coffee production more profitable and economically advantageous for farmers by (i) reducing the need for crop inputs like chemical fertilizer, (ii) increasing yields, and (iii) diversifying income streams. By simultaneously involving communities in environmental stewardship, CE models in coffee production have environmental, economic, and social benefits that can advance Viet Nam's sustainable agricultural development overall.

The tools used in developing the Handbook are mostly from Stage 2 of the CE-NDC Toolbox including the value chain approach and the IPCC Guidelines for National Greenhouse Gas Inventories, which provide the methodological basis for estimating emissions from agricultural activities such as coffee production.

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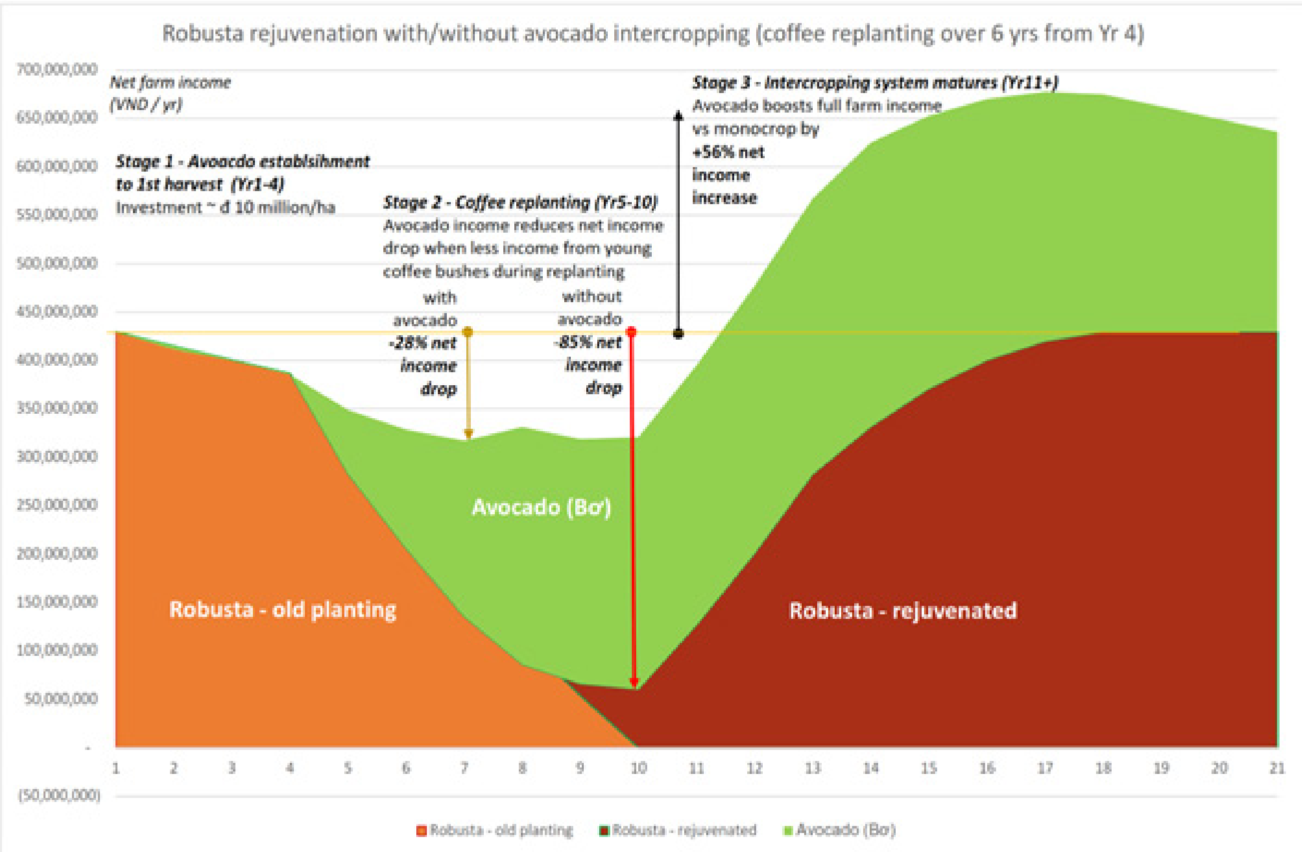
# ANNEX 1: COST-BENEFIT ANALYSIS OF COFFEE-AVOCADO INTERCROPPING VS. MONOCULTURE




*Source: Estimate by Agroinfo, 2024*

# ANNEX 2: COST-BENEFIT ANALYSIS PER TON OF COFFEE BEANS FOR THE WASTEWATER TREATMENT MODEL

## a. Assumptions

- Production scale: 1,000 tons of fresh coffee cherries per year
- Investment cost of biogas system: 250 million VND
- Operational lifespan: 15 years
- Wastewater volume per ton: 15 $m^3$
- Biogas production: 0.3 - 0.5 $m^3$ of biogas per $m^3$ of wastewater
- Operation and maintenance cost: 2 million VND/year
- Discount rate: 10%/year (average market interest rate)
- Annual biogas production:
  - 1,000 tons × 15 $m^3$ wastewater × 0.3 - 0.5 $m^3$ biogas = 4,500 - 7,500 $m^3$ biogas/year
- Annual savings from LPG replacement:
  - 4,500 - 7,500 $m^3$ biogas × 0.56 kg LPG × 25,000 VND/kg LPG = 63 - 105 million VND/year
- Annual savings from electricity generation:
  - 4,500 - 7,500 $m^3$ biogas × 2 kWh/$m^3$ biogas × 2,000 VND/kWh = 18 - 30 million VND/year
- Total annual savings: 81 - 135 million VND/year

### b. Estimation of NPV

- Average net annual benefit:
  - Net annual benefit = (81 - 135) – 2 = 79 - 133 million VND/year

$$NPV = \sum_{t=1}^{15} \frac{79-133}{(1+0.1)^t} - 250$$

- Detailed calculations:

| Year | Net benefit (millions VND) | Present value (millions VND) |
|---|---|---|
| 1 | 79 - 133 | 71.8 - 120.9 |
| 2 | 79 - 133 | 65.3 - 109.9 |
| 3 | 79 - 133 | 59.4 - 99.9 |
| ... | ... | ... |
| 15 | 79 - 133 | 18.2 - 30.6 |
| Total | 79 - 133 x 15 years | 735 - 1,233 million VND |

- NPV = 735 - 1,233 – 250 = 485 - 983 million VND.

### c. Estimation of Internal Rate of Return

- With an average net annual benefit of 106 million VND/year: IRR ≈ 28 - 34%.

In overall, with an investment cost of 250 million VND, the biogas system (for a coffee processing factory with a capacity of 1,000 tonnes of coffee/year) remains highly profitable with the NPV at a 10% discount rate of **485 - 983 million VND**, indicating substantial profitability over 15 years. The IRR is between **28 - 34%**, still far exceeding the 10% discount rate, making the investment attractive despite the increased cost.World Coffee Research (2021). Arabica and robusta Varietal Catalog.

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