



Tomas Bata University in Zlín
Faculty of Management and Economics

Doctoral Thesis

Factors affecting sustainable production with Economic growth in Coffee Industry: Evidence from Vietnam

Faktory ovlivňující udržitelnou produkci s ekonomickým růstem v kávovém průmyslu: Studie z Vietnamu

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Zlín, February 2025

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Published by **Tomas Bata University in Zlín** in the Edition **Doctoral Thesis Summary**.

The publication was issued in the year 2025

Key words: *Coffee Industry, sustainability certification, sustainable production, Vietnam,*

Key words in Czech: Kávový průmysl, certifikace udržitelnosti, udržitelná výroba, Vietnamu.

Full text of the doctoral thesis is available in the Library of TBU in Zlín.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude for the efforts of all Tomas Bata University members in carrying out my thesis. This work has been one of my life's most exciting and challenging journeys. Without inspiration, encouragement, helpful guidance, valuable suggestions, and contributions from people around me, I could not have accomplished it.

I would send my deep gratitude to Dr. Ing. Petr Novák, Ph.D., who, under their guidance, provided me with knowledge, advice, inspiration, and technical support, all of which helped me accomplish this thesis.

Furthermore, I would like to express my sincere acknowledgment to Ms. Do Thi Thanh Nhan and Mr. Lubor Homolka, who helped me tremendously to improve my thesis research and statistics analysis skills.

I would like to express my gratitude to Ms. Martina Drábková and Ms. Pavla Bartošová, as well as other members of FaME, for the tremendous support they gave me throughout my participation in the program.

In addition, I would like to use this opportunity to express my sincere gratitude to my colleagues who have supported me with knowledge related to the coffee field and farmers in DakLak, DakNong, Gia Lai, and Lam Dong, who indirectly contributed to this research.

And a special thank you to my fellow doctoral researchers at FaME, who overcame challenges and shared joys with me during my studies at Tomas University Bata in Zlin.

ABSTRACT

The study uses the Cobb-Douglas production function to examine the cost-effectiveness and profitability of sustainable coffee production in the four provinces that produce the most coffee in Vietnam. The study compares the performance of sustainable coffee producers with non-sustainable or traditional ones using a sample of 864 coffee-growing families. These findings give valuable insights for coffee growers, local governments, and governments as technological efficiency, economic variables, and external impacts on coffee production are becoming increasingly important. Technical inefficiency research reveals significant variations between certified sustainable coffee growers and conventional coffee farmers. Surprisingly, the findings contradicted the initial prediction, demonstrating that sustainable coffee producers outperformed traditional farmers. Unlike previous studies, this research emphasizes the great potential for sustainable coffee cultivation approaches to boost output. Farm size, organic fertilizer use, and certification are all important considerations in coffee production. Increased farming areas improve coffee output through both sustainable and traditional cultivation methods. Organic fertilizer use, particularly in proven sustainable coffee cultivation, increases production and adds to long-term environmental conservation. According to the research result, sustainable practices like certification improve biodiversity conservation and ecological well-being. Inorganic fertilizers such as NPK, on the other hand, have a substantial influence on conventional coffee growth. The mix of organic and inorganic fertilizers has resulted in both agricultural systems' rapid growth and economic returns. Furthermore, sustainable coffee-growing approaches are more cost-effective without considerably affecting production efficiency. This study makes a persuasive argument for the benefits of sustainable coffee production, providing insights that may guide coffee producers, local governments, and national policies in Vietnam and perhaps other places.

ABSTRAKT

Studie zkoumá nákladovou efektivitu a ziskovost udržitelné produkce kávy ve čtyřech provinciích, které vyrábějí nejvíce kávy ve Vietnamu, pomocí produkční funkce Cobb-Douglas. Výzkum porovnává výkonnost udržitelných producentů kávy s jejich konvenčními protějšky na vzorku 864 rodin pěstujících kávu. Tyto zjištění poskytují užitečné poznatky pro pěstitele kávy, místní samosprávy a vlády, protože technická efektivita, ekonomické proměnné a vnější vlivy na produkci kávy stoupají na důležitosti.

Výzkum technické efektivity ukazuje významné rozdíly v technické efektivitě certifikovaných udržitelných pěstitelů kávy ve srovnání s konvenčními pěstiteli kávy. Překvapivě, výsledky odporují původnímu předpokladu a ukazují, že udržitelní producenti kávy předčili tradiční farmáře. Na rozdíl od studií v jiných oblastech zdůrazňuje tento výzkum velký potenciál udržitelných přístupů k pěstování kávy pro zvýšení výstupu. Velikost pozemku, používání organického hnojiva a certifikace jsou všechny důležité ekonomické faktory v produkci kávy. Větší pozemky zlepšují výnos kávy pro oba udržitelné a tradiční způsoby pěstování. Používání organického hnojiva, zejména při certifikovaném udržitelném pěstování kávy, nejen zvyšuje výstup, ale přispívá i k dlouhodobé ochraně životního prostředí. Podle výzkumu udržitelné postupy, jako je certifikace, přispívají k lepší ochraně biodiverzity a ekologickému zdraví.

Na druhé straně má používání anorganického hnojiva, jako je NPK, významný vliv na růst konvenční kávy. Kombinace organického a anorganického hnojiva vedla k rychlému růstu a ekonomickým ziskům v obou zemědělských systémech. Navíc se ukázalo, že udržitelné přístupy k pěstování kávy jsou obvykle ekonomicky efektivnější a téměř nepoznamenávají výrobní efektivitu. Tato studie předkládá přesvědčivý argument pro výhody udržitelné produkce kávy a poskytuje poznatky, které mohou usměrňovat pěstitele kávy, místní vlády a národní politiky ve Vietnamu a možná i ji

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ABBREVIATIONS OF WORDS

ABBREVIATIONS	INTERPRETATION
4C	4C Common Code
AAM	Applying advanced methods
AGE	Age
AVY	Average production
B	Boron
Ca	Calcium
CEC	Commission for Environmental Cooperation
CCC	The Consumer Choice Center
Cu	Copper
DEA	Data Envelopment Analysis
DIS	Distance from Farm to City
EC	European Commission
EDUCATION	Education level
ETH	Ethnicity
EU	European Union
EVFTA	European Union-Vietnam Free Trade Agreement
EXP	Total value of coffee exports
FS	The control is farm size
FRE	The real estate price
FTAs	Free trade agreements
HER	Herbicide
INF	Inflation rate
INO	Inorganic fertilizer
IRW	Irrigation water
ITC	Intercrop
K	Potassium
LBP	Labor cost
LTR	Training on land reclamation
Mg	Magnesium
N	Nitrogen
NAFTA's	North American Free Trade Agreement
OGF	Organic fertilizer
OLS	Ordinary Least Square
P	Phosphorus
PES	Pesticide
POOLED	Pooled regression model
RFA	The Rain Forest Alliance
SFA	Stochastic frontier analysis

SMBC	The Smithsonian Migratory Bird Center
TE	Technical efficiency
USDA	The United States Department of Agriculture
UTZ	UTZ certified
VICOFA	The Vietnam Cocoa and Coffee Association
VIF	The variance inflation factor
VND	Vietnamese Dong
VNMHA	Viet Nam Meteorological and Hydrological Administration
VAR	Variety
Zn	Zinc
YLA	Experience

1. INTRODUCTION

1.1. Coffee production situation

Regarding consumption, coffee is second only to tea, and water is one of the most widely used agricultural products worldwide. Coffee production faces environmental, social, and economic difficulties in the global sustainable development framework. Additionally, to reduce adverse environmental effects, preserve biodiversity, and enhance the quality of life for producers, sustainable agricultural growth has been highlighted in the Decade of Action from 2020 and the Sustainable Development Goals (SDGs) adopted by the UN General Assembly in 2015 (Rubio-Jovel, 2023). Coffee is one of the commodities examined the most among crops (Meemken, 2020). Sustainable production certification has emerged as an essential means to address these challenges (d'Albertas et al., 2023).

Sustainable agriculture standards are an essential government intervention to reduce commodity-driven pressures on biodiversity (Lenzen et al., 2012). Sustainable coffee certification improves the economic value of products while providing environmental and social benefits to farmers (Blackmore et al., 2012; CIDIN, 2014). Certified coffee production often helps farmers achieve higher prices and encourages adopting environmentally friendly farming practices (Astuti et al., 2015; Ibnu et al., 2016). At the same time, consumers are increasingly interested in and favor products with sustainability certification, considering them a superior choice for health and environmental protection (Lee et al., 2012; Vlaeminck & Vranken, 2015). Additionally, coffee drinkers value the specifics of sustainability features and respect sustainable labels (Van Loo et al., 2015).

Although there are more than 70 coffee-exporting countries, Vietnam ranks second in the world in coffee exports after Brazil. It accounted for 14.2% of total global coffee exports in 2021, mainly Robusta coffee. The dynamic growth of the Vietnamese coffee industry, particularly in the provinces of Dak Lak, Lam Dong, Dak Nong, and Gia Lai in the Central Highlands, has benefited the global coffee market. However, the industry faces many environmental problems, such as chemical fertilizers and unsustainable irrigation, leading to soil degradation and groundwater depletion (D'haeze et al., 2005; Kuit et al., 2013). Matissek et al. (2012) pointed out that Vietnamese coffee farmers are incurring inefficient costs due to over-reliance on chemical fertilizers, and such practices contribute to soil degradation. Due to competition, coffee producers in Vietnam tend to use unsustainable methods to make quick profits through higher yield returns (Marsh, 2007).

Furthermore, while irrigation is essential in coffee cultivation (Dzung et al., 2011), it reduces the natural groundwater supply in the regions (D'haeze et al., 2003). This practice, therefore, not only harms long-term water reserves but also saturates downstream habitats. In Asia, coffee production challenges include degraded soils, de-motivating coffee prices, rising input costs, and low coffee quality (Krishnan,

2017). In addition, global coffee prices fluctuate widely (Marsh, 2007), putting significant financial pressure on farmers and forcing them to switch crops or abandon production (Ho et al., 2017).

Sustainable production seeks to improve free market valuations, guarantee fair pricing, and boost farm productivity or efficiency (Daviron & Ponte, 2005; Raynolds et al., 2007). According to Tadesse et al. (2014), fewer than 10% of Vietnam's coffee production is certified despite the advantages of sustainable cultivation. It doubts the actual effects of sustainability certification on Vietnam's coffee output. Furthermore, there hasn't been much research on the financial advantages of implementing sustainability standards, partly because few studies use rigorous and in-depth effect assessment techniques (Garrett et al., 2021; Meemken et al., 2021). Furthermore, the economic benefits of certified sustainable coffee in Vietnam remain unclear due to a lack of knowledge and understanding (Kuit et al., 2013). Hajjar et al. (2019) have shown that sustainable development in coffee production correlates with lower productivity than conventional producers. In addition, Agricultural Land Value is important to landowners, farmers, agricultural lenders, and policymakers (Nickerson et al., 2012). Thus, both high and low land values can indicate periods of financial strength or stress in the agriculture sector (Cowley, 2016).

This study identifies key factors driving sustainable growth and production in the Vietnamese coffee sector during 2013–2020. The main objective is to provide a scientific and practical basis to support policymakers in developing strategies to promote sustainable coffee production while contributing to implementing Sustainable agriculture and responsible consumption as part of the Sustainable Development Goals (SDGs). This study thoroughly explains the coffee production situation in four central Vietnamese coffee-growing provinces: Dak Lak, Lam Dong, Dak Nong, and Gia Lai. The survey sample consisted of 1,500 households that produce coffee. The findings from this study not only help identify factors driving productivity and sustainability in production but also suggest necessary policies to improve resource management, increase productivity, and minimize negative impacts on the environment. The research results are an important foundation for developing strategies to support farmers in applying technology, effectively managing resources, and using sustainable production models. These strategies not only help increase economic value but also protect the environment, meet sustainable consumption trends, and contribute positively to the comprehensive development of the Vietnamese coffee industry.

1.2. Motivation for the study and overview of Vietnam's coffee industry

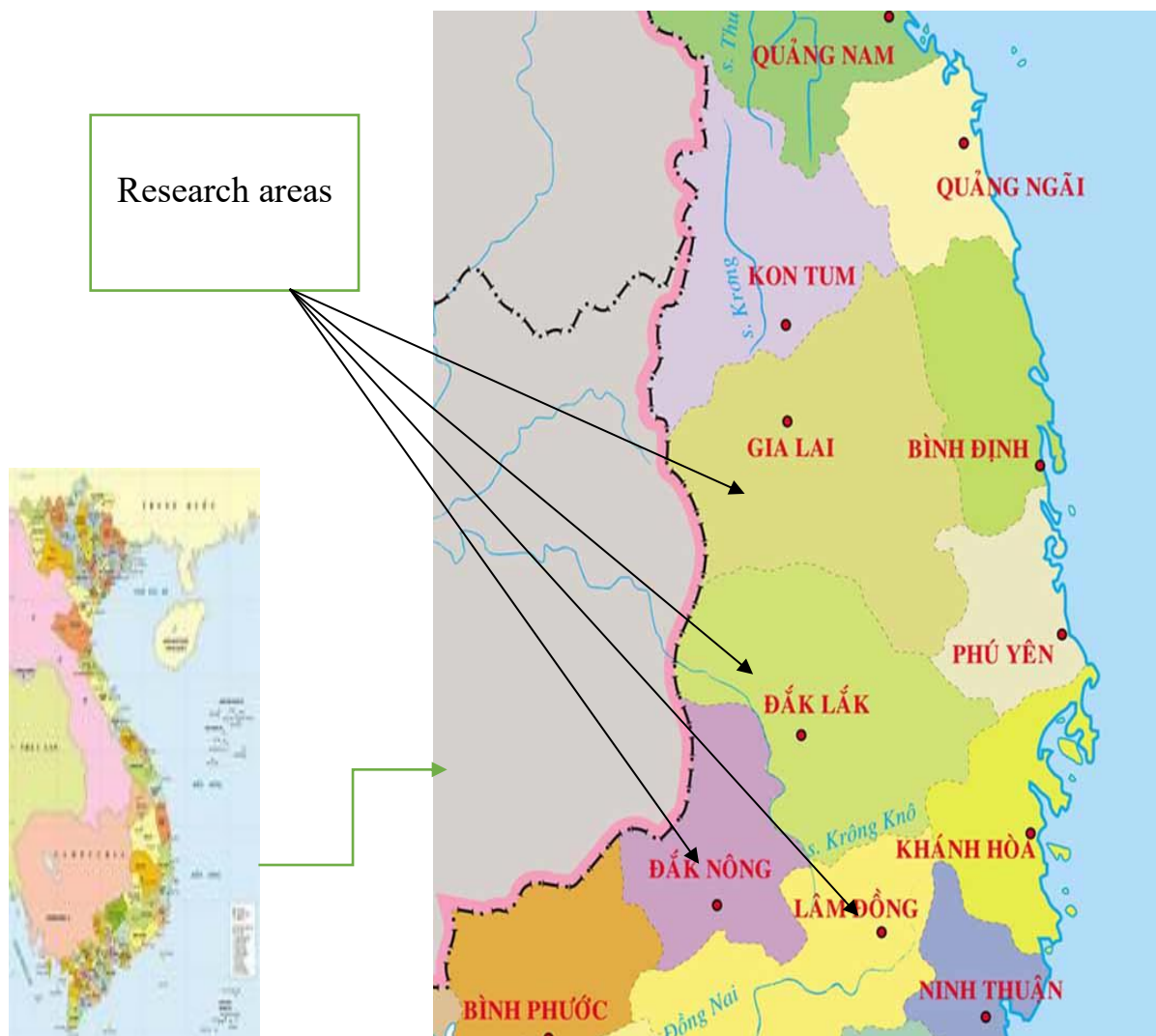


Fig. 1.1: Research area

Source: The author's works

Vietnam is one of the world's top coffee-producing and exporting countries, according to the United States Department of Agriculture (USDA) in 2022. In 2021–2022, the total amount of green coffee exported was 24.92 million 60 kg bags, or 1.5 million tons, ranking second only to Brazil. It is hoped that in 2022–2023, total coffee output is expected to reach 30.93 million bags of green coffee. Also, according to the USDA report, the rainy season came early in the 2021–2022 crop season. Thus, irrigation water is reduced, helping to reduce production costs. In addition, farmer households are maintaining stable coffee re-cultivation activities while taking advantage of new high-yield plant varieties with good pest resistance to increase harvest productivity. As a result of an in-depth survey of longtime farmers, it is known that fertilizer costs have increased by 70% compared to the 2020–2021 crop, while coffee purchasing prices at the garden have not increased in the last six months of

2022. This has caused farmers to cut back on inorganic fertilizer production for coffee and switch to organic fertilizers such as compost, which caused a negative impact on the 2022 – 2023 crop. In addition, according to observations and forecasts of the Viet Nam Meteorological and Hydrological Administration (VNMHA), temperatures in the first months of 2022 are slightly lower than average, which is ideal for the flowering and fruiting periods of coffee plants.

Furthermore, the world is promoting sustainable coffee growing and improving the quality of coffee beans. The objectives are to reach a reasonable benchmark for domestic coffee roasters and earn more profit. Most production and business activities in Vietnam have resumed due to easing some measures related to the COVID-19 epidemic. Tourism started to receive domestic tourists in mid-March 2022. Therefore, domestic coffee consumption has increased to 3.2 million bags. The USDA also added that the Vietnamese market has a great demand for instant coffee because of the convenience it brings to customers. Specifically, some local coffee processing companies said that coffee retail sales in 2021 and early 2022 have increased by 40–50%, including a significant portion of sales from the online segment. The reason is that the demand for drinking coffee at home and work has increased during the strict implementation of social distancing regulations. By increasing Vietnam's market share of processed coffee exports from 10% to 25%, the Vietnam Cocoa and Coffee Association (VICOFA) hopes to quadruple the country's coffee export revenue to USD 6 billion by 2030.¹ Vietnam benefits from advantageous tax rates because of its region's dynamic free trade agreements (FTA). Furthermore, the Vietnamese coffee sector is receiving significant investments, particularly in instant, ground, and roasted coffee, which will increase the value of exports. For the first half of the year, Vietnam exported approximately 1 million tons of coffee, bringing in over 2.3 billion USD. This is a more than 23% increase in volume and nearly 50% increase in value compared to the same period in 2021.²

¹ <https://vtv.vn/kinh-te/ca-phe-viet-nam-dat-muc-tieu-xuat-khau-6-ty-usd-20210116121704473.htm#:~:text=VTV.vn>

² <https://baotintuc.vn/infographics/6-thang-nam-2022-kim-ngach-xuat-khau-ca-phe-tang-gan-50-20220707061159832>.

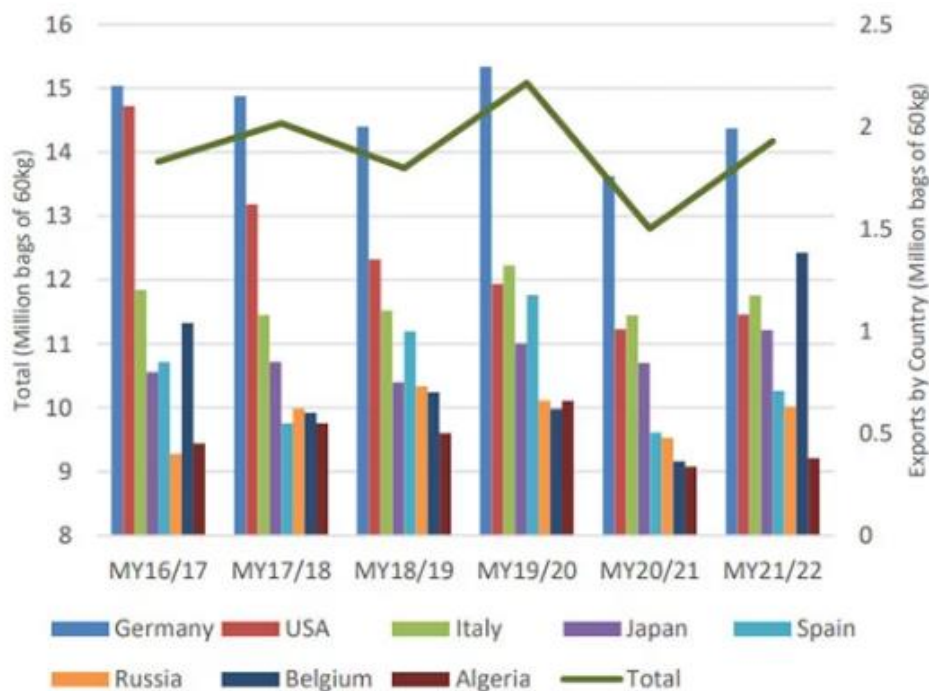


Fig. 1.2: Vietnam's coffee export turnover to several critical markets from March to October.

Source: The General Department of Customs, Vietnam

Regarding export markets of Vietnambiz,³ 2022 shows a volatile picture with bright growth spots in some countries while also recording declines in some key markets. Coffee sales in Russia, the UK, India, and Mexico have grown significantly. In particular, the Indian market recorded an impressive increase of 123.5%, while Mexico achieved a breakthrough increase of up to 18 times compared to 2021. This reflects the growth potential of emerging markets for Vietnamese coffee, opening up opportunities to expand exports in the context of difficulties in traditional markets. Nevertheless, important export destinations such as China, Japan, and the United States shrank. In particular, China's exports dropped precipitously by 19.3%, Japan's by 2.5%, and the United States' by 3.5%. Competition from other coffee providers in the worldwide market, changes in consumption demand, and the effects of import regulations could all contribute to this reduction. This is a warning that Vietnam needs to develop plans to keep and increase its market share in these important markets. About 39% of Vietnam's total exports go to the European Union (EU), which maintains its position as the country's biggest coffee consumer market. In 2022, 689,049 tons of coffee were exported to the EU, valued at around 1.5 billion USD. This represents a significant increase of 25.8% in volume and 45.4% in value over 2021. The effect of the Vietnam-EU Free Trade Agreement (EVFTA), the capacity to meet stringent EU requirements, and advances in product quality all contribute to this favorable outcome. Germany, Italy, Belgium, and Spain are typical markets in the EU.

³ <https://mediacdn.vietnambiz.vn/1881912202208555/files/2023/01/19/bao-cau-thi-truong-ca-phe-nam-2022-20230119151616421.pdf>

Although exports to Germany decreased slightly by 0.9%, other markets such as Italy, Belgium, and Spain grew impressively, with Belgium increasing by 101.5% and Spain by 71.7%. This shows the diversification of Vietnam's market access strategy in this region. Positive outcomes from coffee exports to the EU boost Vietnamese coffee's reputation internationally and provide economic value. However, to maintain this growth momentum, the coffee industry must continue investing in improving quality, building strong brands, and expanding to new markets. At the same time, restructuring the supply chain, improving logistics, and enhancing promotional measures will help strengthen the position of Vietnamese coffee, especially in the context of increasingly fierce global competition.

In 2022, an impressive year for the Vietnamese coffee industry, coffee consumption increased sharply in value and volume. Although the volume of coffee exports decreased slightly compared to 2021, the export value increased significantly thanks to high international coffee prices. The General Department of Customs reports that Vietnam met its export goal of around 1.8 million tons of coffee, generating over 4 billion USD in revenue, a 13.8% volume, and 32% value growth over the previous year. This is a record export turnover value for the Vietnamese coffee sector and the most significant export volume in the last four years. This increase can be explained through a series of influencing factors. First, the world's demand for coffee has recovered strongly after the COVID-19 pandemic. Major consumer markets such as Europe and North America recorded significant growth as economic activities gradually returned to normal. At the same time, crop failures in key producing nations like Brazil and Colombia caused a global shortage of coffee, which led to a spike in international prices. Disruptions in the supply chain in these regions also contributed to the increase in coffee prices, creating a competitive advantage for exporters from Vietnam. Another important factor supporting export growth is the improvement in logistics, especially the supply of containers and ships. Challenges in maritime transport have been partly resolved, helping to reduce the pressure on costs and delivery times for coffee-exporting enterprises. This boosted export growth and enhanced Vietnam's reputation in the world coffee market.

However, the coffee industry must face several challenges to maintain this growth momentum. In particular, dependence on external factors such as international market prices and global supply chains remains a potential risk. Investing in logistics infrastructure, improving product quality, and developing sustainable export strategies are essential for the coffee industry to maintain its competitiveness and grow steadily. In addition, positioning Vietnamese coffee as a premium product through branding strategies and applying sustainability standards can help increase added value. This will help the coffee industry take advantage of opportunities from rising demand and minimize the impact of market fluctuations in the long term.

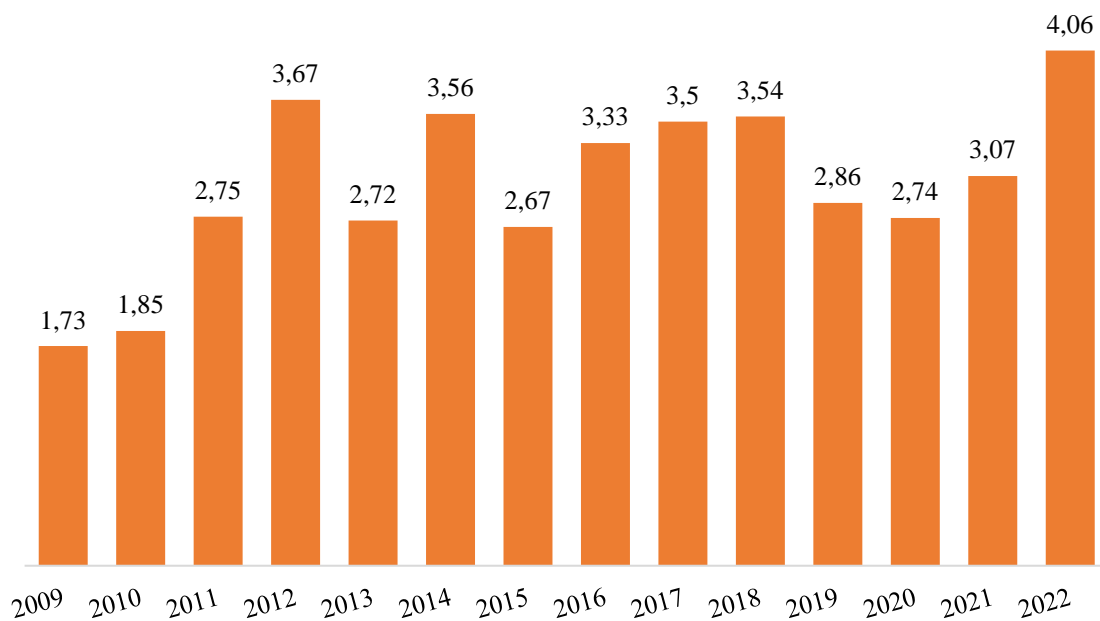


Fig. 1.3: Vietnam's coffee export turnover in 2009–2022. Unit: billion USD

Source: The General Department of Customs.

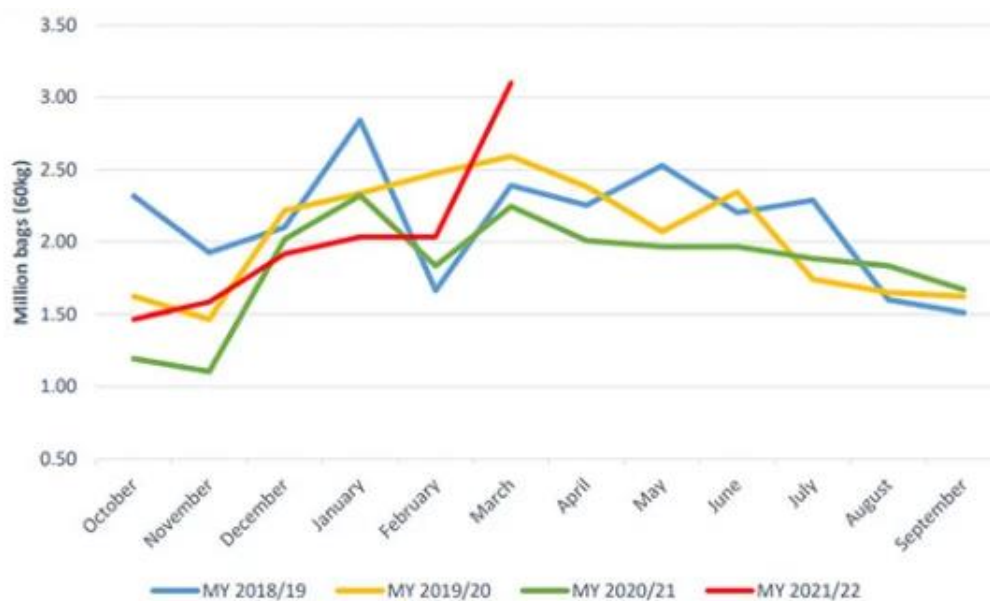


Fig. 1.4: Vietnam's green coffee export situation from 2018 - 2019 to 2021 – 2022

Source: Vietnam Customs, Coffee Traders.

Vietnam's green coffee exports saw a remarkable increase in the first half of the 2021–2022 crop year, rising by over 14% to 12.13 million bags. This increase reflects the ability to meet international market demand and highlights the coffee industry's role in contributing to a record export of over US\$4 billion in 2022. In particular, the growing demand for the European Union (EU) is a decisive factor. The EU is the largest consumer market and brings high-added value to the Vietnamese coffee

industry, thanks to stable demand and benefits from the Vietnam–EU Free Trade Agreement (EVFTA). Vietnam's coffee exports to the EU hit 72,081 tons in December 2022, marking the second consecutive month of growth. This represents an outstanding 54.6% increase over the same time in 2021. Despite rising inflation in the region, this reflects the EU's preference for Robusta coffee from Vietnam, which is more competitive than Arabica. This trend is also driven by inflationary pressures in Asia, forcing consumers to look for cheaper products. As the world's largest producer of Robusta coffee, Vietnam has taken advantage of the opportunity to consolidate its market share internationally. This shift reflects the apparent competitive advantage of Vietnamese coffee in a challenging global context. The benefits of the EVFTA go beyond lower tariffs and open up opportunities for deeper access to the European market. However, the biggest challenge for Vietnamese exporters is meeting increasingly high quality and sustainability standards. A typical example is the European Commission's (EC) announcement on December 6, 2022, on the ban on imports of products linked to deforestation, including coffee. This poses an urgent need for the Vietnamese coffee industry to improve production processes, sustainability certification, and supply chain transparency to meet these stringent requirements.

Besides the EU market, China is emerging as a significant potential opportunity. The decision to open its borders and lift quarantine restrictions on January 8, 2022, after a period of strict COVID-19 control, is expected to boost coffee consumption in this market. China is a growing market with increasing demand for coffee, especially in large urban areas. Restoring coffee exports to China will help the Vietnamese coffee industry reduce its dependence on traditional markets and expand its influence in one of the fastest-growing potential markets in the world. However, to maintain this growth momentum, Vietnam needs a comprehensive approach, including improving product quality, promoting sustainability certifications, and strengthening trade promotion activities. At the same time, businesses also need to invest heavily in logistics infrastructure, enhance transportation services, and minimize risks in the supply chain to maintain their leading position in the global coffee industry. With these efforts, the Vietnamese coffee industry can take advantage of opportunities from key markets such as the EU and China while effectively dealing with challenges from strict regulations and fierce competition in the international market.

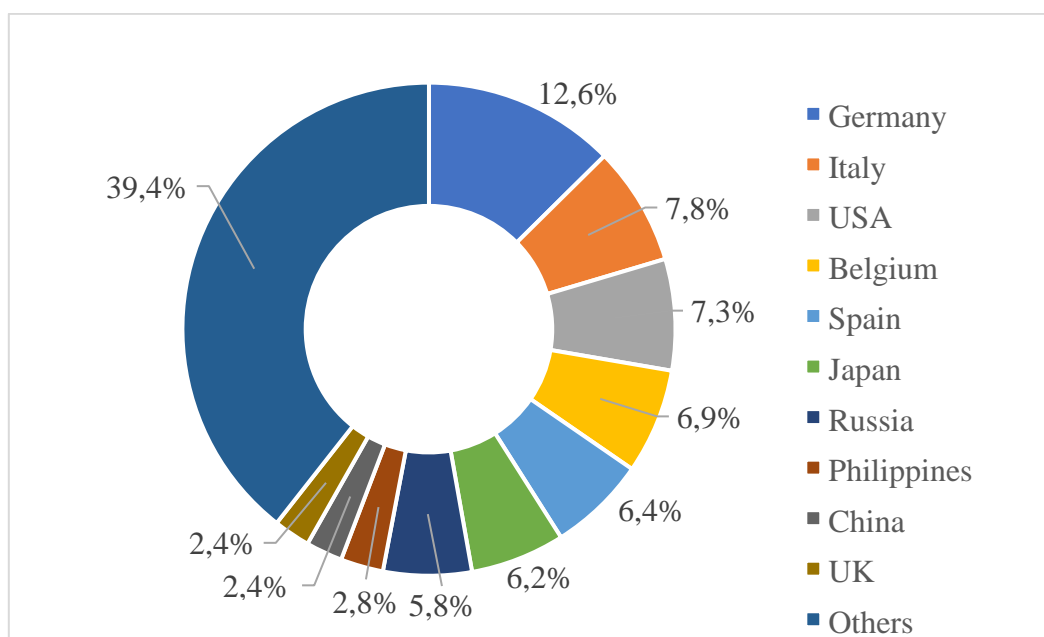


Fig. 1.5: Vietnam's 2022 Coffee Export Market Composition

Source: Data from the General Department of Customs

However, the Vietnamese coffee industry is facing significant challenges, especially in the context of increasingly fierce global competition. Brazil, the world's largest coffee exporter, continues to assert its leading position with large output and competitive prices. At the same time, Indonesia, another formidable competitor in the region, is gradually consolidating its market share with Robusta products offered at lower discounts, putting significant pressure on prices and the competitiveness of Vietnamese coffee in the international market. From April 2022 to September 2022, Vietnam's coffee exports tend to decrease as many farmers only sell coffee at high prices, leading to a decline in supply. This seriously affects the competitiveness of exporters, especially in the last months of the season when supplies are exhausted. Robusta products from Indonesia, with more reasonable prices, have become the preferred choice of many importers, causing domestic coffee prices in Vietnam to increase by up to 20%. Notably, the increase in domestic prices occurred even as prices on the London exchange fell, reflecting the imbalance between domestic supply and demand. This challenge not only affected prices but also disrupted delivery contracts. Many exporters had difficulty purchasing coffee at reasonable prices to fulfill their contracts, leading to delays in delivery through October and November.⁴ Some exporters even faced quality issues, such as damp or substandard goods, leading to complaints, returns, or even compensation. These problems not only increased business costs but also damaged the reputation of the Vietnamese coffee industry in the international market.

However, the bright spot in the analysis is that coffee export prices in the first half of the 2021-2022 crop year increased according to futures prices and were higher than

⁴ <https://www.bsc.com.vn/tin-tuc/tin-chi-tiet/982726-trien-vong-nao-cho-nganh-ca-phe-nam-2023>

the previous year. This shows there is still potential, especially when Vietnam can take advantage of opportunities from global price fluctuations. To maintain and improve its position in the international market, the Vietnamese coffee industry must enhance the quality of product, supply chain management, and a more suitable pricing strategy to compete effectively with Brazil and Indonesia. In addition, investing in post-harvest technology to ensure coffee quality is also a necessary factor. Stable product quality helps Vietnam maintain current markets and opens up opportunities to penetrate demanding markets such as Europe and North America. In addition, partnering with major importers to create long-term contracts could be a viable strategy, helping to minimize the risk of price fluctuations and ensure future stability for the coffee industry.

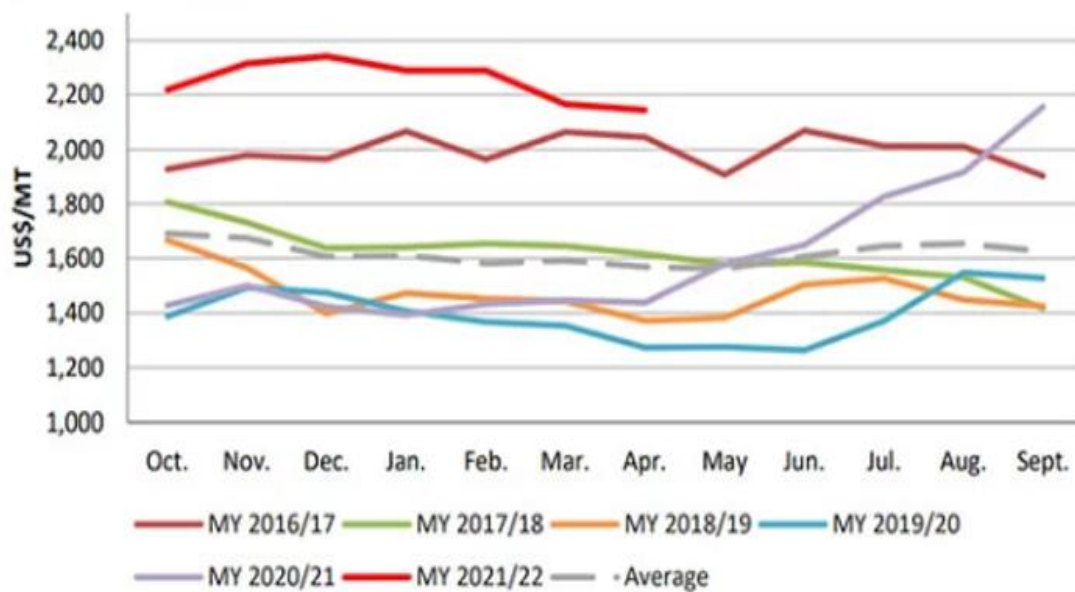


Fig. 1.6: Export price for green bean Robusta coffee, MY 2016/17 to MY2021/22.
Source: Coffee Traders.

The same thing happened with the domestic price of Robusta coffee, although still lower than in 2016 – 2017. This incentivizes Vietnamese farmers to put more effort into growing coffee during the growing season of 2022–2023.

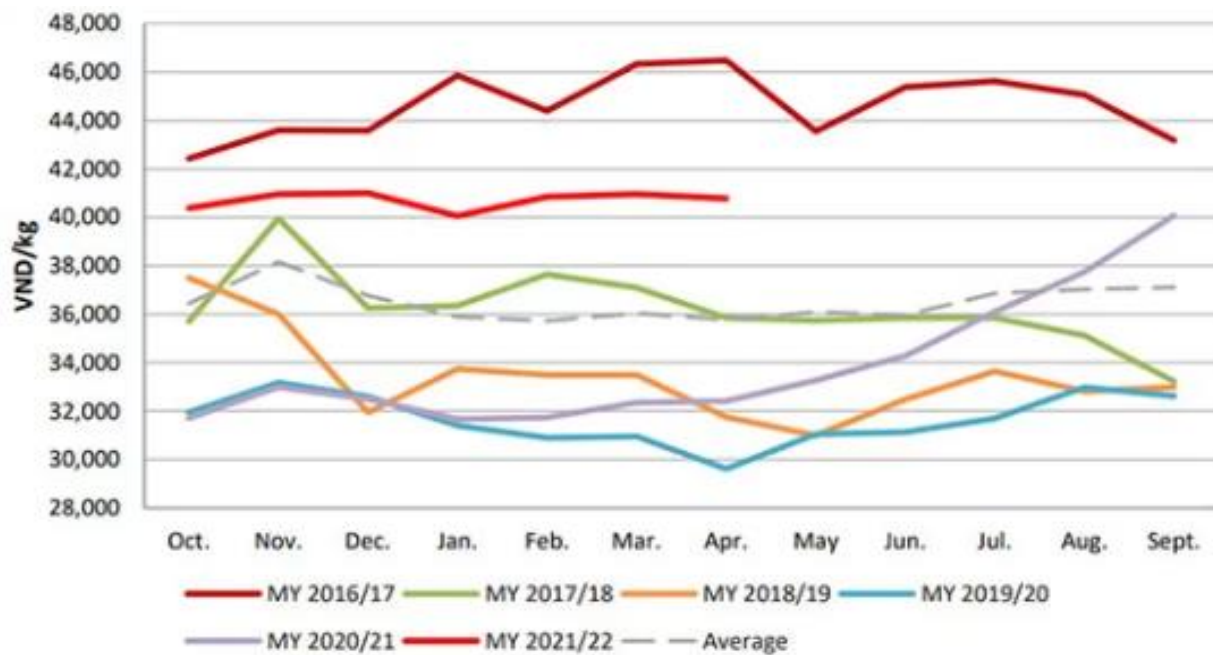


Fig. 1.7: Chart of price fluctuations in Robusta green coffee prices in Vietnam within 6 years, from 2016–2017 to 2021–2022.

Source: Coffee traders.

However, it should be noted that production costs have also increased significantly, especially fertilizer costs, which increased by about 70 – 80% over the same period last year. It contributes to pushing the selling price of Robusta coffee beans in Vietnam. The USDA has adjusted information on Vietnam's coffee reserves in the 2021 – 2022 crop to 5.59 million bags due to higher demand for coffee exports, exceeding the increase in domestic coffee production. Specifically, as of March 2022, Vietnam's coffee reserves were recorded at a high level of 10.5 – 11.8 million bags, including 3 – 4 million bags in bonded warehouses. Meanwhile, the coffee reserves in Europe have recently been at a lower level. Moreover, combined with support policies to forego obstacles for the logistics industry, Vietnam may maintain the export speed and reduce the number of coffee reserves stored until the end of the 2021 – 2022 season.

In 2022, there were also significant swings in the domestic coffee industry. Throughout the first seven months of the year, the price of green coffee beans in the Central Highlands provinces stayed between 40,000 and 44,000 VND/kg. The cost plummeted to around 31,000 VND/kg by August. In the months that followed, it veered in a downward direction. Green coffee was only 38,600 VND/kg in Lam Dong on December 31. The remaining three provinces varied between 39,200 VND/kg and 39,300 VND/kg, down more than 22% compared to the peak reached at the end of August and 5.3% over the same period in 2021. The price of coffee during the 2021–2022 harvest year is significantly higher than the five-year average. The average cost of domestic coffee in the 2021–2022 harvest year is around 43,500 VND/kg, a 25% rise over the previous crop and a 17% increase over the 5-year average. According to

Department of Crop Production data, in 2022, coffee productivity reached 28.2 tons per hectare, the most incredible level since 2005.

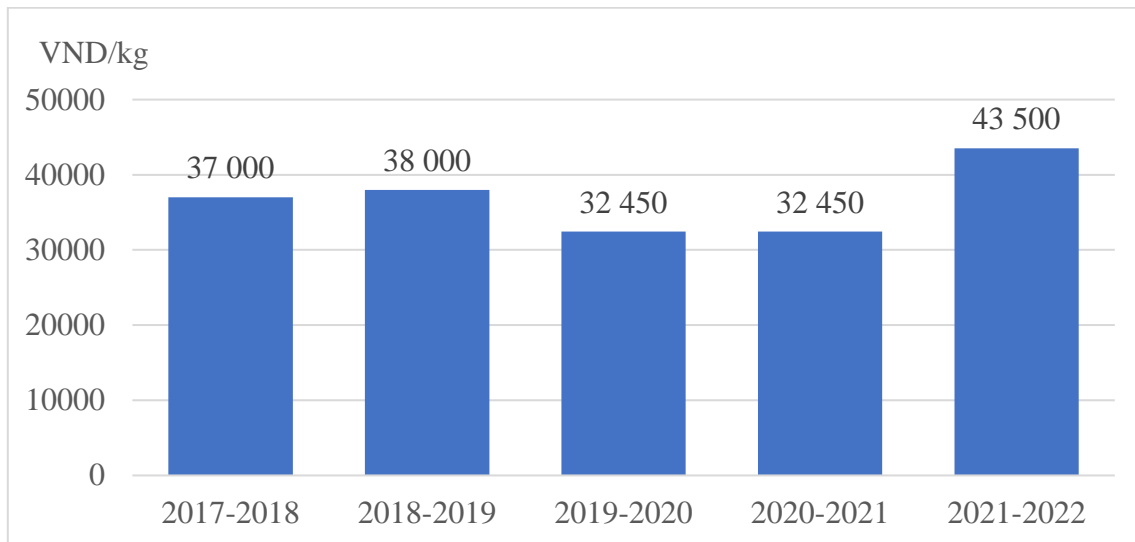


Fig. 1.8: Average coffee price from crop year 2017-2018 to 2021-2022.
 Source: VICOFA

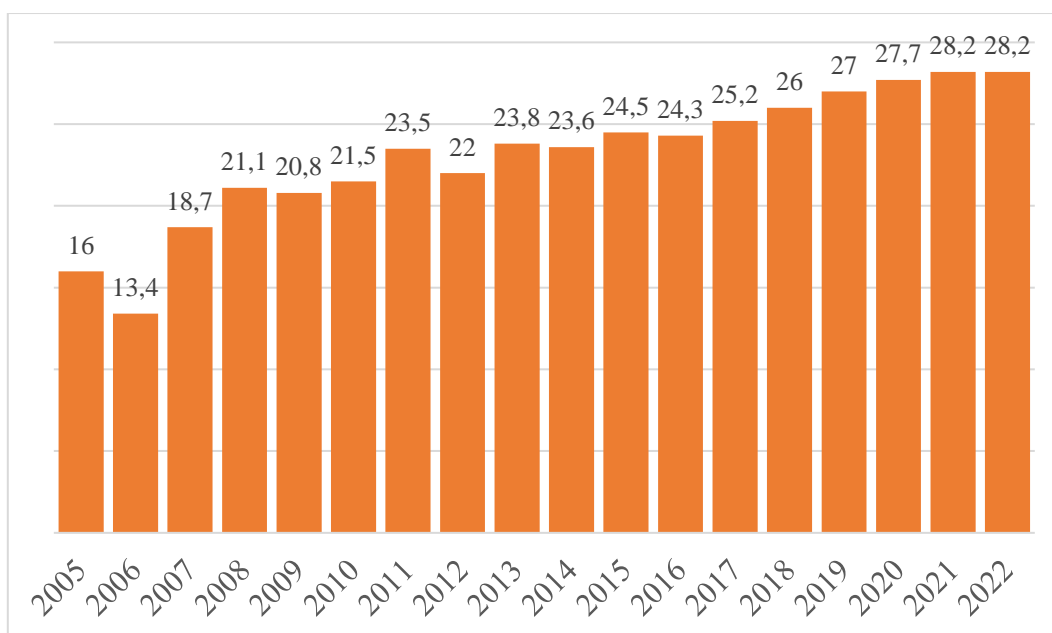


Fig. 1.9: Vietnam coffee productivity from 2005 to 2022 (unit: quintal/ha)
 Source: Import-Export Department

Vietnam's coffee production industry has excellent potential to bring more economic benefits, especially with the sustainable coffee trend. Vietnam is a prominent supplier of coffee, and all fundamental changes in coffee growth tend to start in Vietnam. Due to its scalability and impact on the global picture, studying sustainable production and certified coffee in Vietnam motivated the author.

1.3. Research gaps

According to Van Loo et al. (2015), sustainable attributes gradually become more popular with coffee consumers. Customers are willing to pay more for coffee with an organic certification from emerging countries (Basu & Hicks, 2008). However, there are still contradictions with previous studies. Specifically, some previous studies have focused on demonstrating that certification has little benefit to the coffee industry in improving farmers' income (Bolwig et al., 2009). Instead, it supports protecting biodiversity (Hardt et al., 2015) and environmental reserves (Ibanez & Blackman, 2016).

Furthermore, according to certain writers (Chiputwa et al., 2015; Ibanez & Blackman, 2016), sustainable accreditation has negligible environmental effects while generating lower yields than traditional coffee (Lyngbæk et al., 2001). Castro-Tanzi et al. (2012) show the dynamic impact of sustainable production in improving the environment but provide limited evidence to support this. Although scholars continuously debate the benefits and drawbacks of sustainable coffee operations, the farmers in Vietnam determine what works best for them and decide whether to continue the traditional approach or gradually transition to sustainable production.

Despite Vietnam being the world's second-largest producer of coffee, a large number of farmers choose to accept low-price liquidation tactics instead of applying certifications that underline chemical constraints and extra costs (Basu & Hicks, 2008). However, if the industry continues following this route, the aftereffects on the environment and land degradation will be inescapable (Ho, 2018). Furthermore, coffee farms in Vietnam functioned in a divisive mechanism with small, non-uniformed farm sizes. Doing this makes it difficult to compare the economic efficiency of sustainable coffee production with conventional coffee production. Thus, the distinction in economic efficiency between non-certificated and certified farms must be supported by empirical evidence. In terms of research scale, although there are studies related to coffee production in Vietnam, most of them focus on the Dak Lak area (Amarasinghe et al., 2015; Dzung, 2013; Maskell et al., 2021; Nguyen & Sarker, 2018). Some studies in other regions, such as Le et al. (2020), took samples in Lam Dong province, and Ho (2018) investigated three areas, including Dak Lak, Lam Dong, and Gia Lai.

Meanwhile, they are the provinces with the largest coffee-growing regions of Vietnam. To increase reliability and comprehensively view the production efficiency situation, the study enhances all four provinces to make a credible and representable sample size. Finally, my study pioneers the investigation of how real-estate prices affect coffee production in Vietnam. The author hopes there are enough supportive conclusions for the government agencies to take preventive measures on the rapid soar of real estate prices.

1.4. Research problem: Vietnam's unsustainable coffee production

Unsustainable coffee production in Vietnam is a prominent issue in the context of increasing global demand for agricultural products that comply with sustainable standards. Many previous studies have highlighted the benefits and challenges of achieving sustainability certification in coffee production. Barham & Weber (2012), Kilian et al. (2006), Méndez et al. (2010), and Ruben & Fort (2012) all emphasized the differences in costs and benefits between certified and non-certified programs. However, these analyses mainly focused on regions other than Vietnam or lacked comprehensiveness in considering factors affecting sustainable coffee production in the country. For example, Ho (2018) only conducted research in Dak Lak province, which does not fully represent the comprehensive picture of coffee production in Vietnam. Similarly, Viet et al. (2019) analyzed some technical factors affecting production efficiency but lacked a specific assessment of the impact of socio-economic factors, geography, and technological change. This leads to a gap in the research, as macro factors such as real estate prices, inflation, or average economic profit per hectare of coffee have not been fully considered. These factors directly affect productivity and indirectly shape the ability to expand and maintain sustainable coffee production.

Although Vietnam is one of the world's leading producers and exporters of coffee, one of the main issues facing the sector is that its export value per ton of coffee is less than the global average. Vietnam's dependence on raw or low-value coffee goods is shown in this. While developed markets increasingly demand sustainability and high quality, Vietnam has yet to tap this potential fully. According to the Rainforest Alliance, adopting sustainable practices can add value to coffee by achieving international certifications, ensuring long-term production, and improving its competitive position in the global market. However, the reality in Vietnam shows that implementing sustainable practices is difficult. A report from the Vietnam Coffee and Cocoa Association (VICOFA) has emphasized that sustainability certification is a prerequisite for entering developed markets and enhancing the value of Vietnamese coffee. However, the number of households achieving this certification remains very limited. The lack of comprehensive analysis of the socio-economic, geographical, and technical factors affecting the adoption of sustainability certification is a significant barrier to developing effective support policies. In addition, indirect factors such as increasing land prices also significantly impact the ability to expand sustainable production. Rising land prices increase production costs and limit farmers' access to land, especially smallholders. In addition, inflation and other economic fluctuations also affect the average profit per hectare of coffee, reducing farmers' motivation to invest in sustainable production practices.

Overall, the problem of unsustainable coffee production in Vietnam requires a more comprehensive approach. Studies must integrate detailed analysis of technical, economic, social, and macro factors to identify barriers and opportunities to promote sustainable production. This will help increase export value and ensure the long-term

sustainable development of the Vietnamese coffee industry in the international market.

1.5. Research questions and objectives

This study assesses technical inefficiencies and compares the financial gains of certified sustainable and non-certified coffee production. In addition, it provides a new frontier of land prices on crop productivity. The author wonders what impacts the productivity and efficiency of coffee production among certified and non-certified farmers and proposes three research questions as follows:

RQ1: How do input factors affect the coffee production productivity between certified and non-certified farmers?

RQ2: How do several factors (such as Age (AGE), Ethnicity (ETH), Experience (YLA), Variety (VAR), Education level (EDU), Distance from Farm to City (DIS), Intercrop (ITC), Applying advanced methods (AAM), Training on land reclamation (TLR)) during farming processes affect the technical inefficiencies in coffee production?

RQ3: How do additional external factors (such as the real estate price (PRE - primary independent variable, million/m²), Total value of coffee exports (EXP – primary independent variable, million tons), Average production (AVY, million tons/hectare), inflation rate (INF, %)) influence the production yield?

The following research objectives are designed to address the research question. In particular, to accomplish the primary goal of the study is to evaluate the impact of various input, process, and external factors on the productivity and efficiency of coffee production among certified and non-certified households:

RO1: To determine how the input factors affect the output among Certified and non-certified households.

RO2: To determine the impact of several factors (such as Age (AGE), Ethnicity (ETH), Experience (YLA), Variety (VAR), Education level (EDU), Distance from Farm to City (DIS), Intercrop (ITC), Applying advanced methods (AAM), Training on land reclamation (TLR)) during the farming process between Certified and non-certified households on the inefficiencies of the technique.

RO3: To determine the degree of influence of external factors (such as the real estate price (PRE - primary independent variable, million/m²), Total value of coffee exports (EXP – primary independent variable, million tons), Average production (AVY, million tons/hectare), inflation rate (INF, %)) on the output of Certified and non-certified households.

2. THEORETICAL BASIS AND LITERATURE REVIEW

2.1. Theoretical basis

2.1.1. Theory of cost and production function

A crucial concept in mainstream neoclassical economic theory is the production function. It is employed to distinguish between allocative efficiency, the primary focus of economics, and marginal products. The production function's primary goal is to address allocative efficiency in the input usage process. Distribute cash to those components concurrently to resolve technical problems and achieve technical efficiency. According to Fuss (2017), the literature on costs and production functions is relatively recent. Perhaps the first systematic approach to the duality of cost and production appeared in two articles by Hotelling (1932, 1935). Many developments in modern theory and the application of cost and production functions originate from Shephard's pioneering book. Market pricing for inputs and outputs is considered when a business makes economic production decisions in the decision framework. What external technology can offer is demonstrated by the production function. Primary elements like inventory can be reflected in production factors, which are inputs to the production function. The three main elements of production are capital, labor, and land. The production function can theoretically be ascertained by looking at the secondary components and intermediate goods used in manufacturing. The production function does not fully represent the entire production process. It intentionally leaves out things that some people think are essential and part of the processes utilized to make materials (e.g., errors or waste, energy use, or contaminated co-production).

In 1928, Charles Cobb and Paul Douglas introduced the Cobb-Douglas production function (Greer, 2022).

The following is an expression for the Cobb-Douglas function:

$$Q = A \times L^{\alpha} K^{\beta} \quad (1)$$

In which,

- Q is the output
- α , β output elasticity of capital and labor.
- A: technological knowledge;
- L is labor
- K is the capital used.

α and $1-\alpha$ show the output elasticities for L and K, respectively, fixed and determined by the technology. This is a homogeneous function with a homogeneous degree equal to $\alpha + (1-\alpha)$ because when multiplying L and K by some constant coefficient k, the output increases at the rate k ($\alpha + \beta$).

If $\alpha + \beta = 1$, there are constant returns to scale in the production function, which implies that output increases by 20% despite a 20% growth in labor and capital.

If $\alpha + \beta < 1$, there are decreasing returns to scale in the production function.

If $\alpha + \beta > 1$, rising returns to scale characterizes the production function. α and β represent the labor and capital contribution rates to output in a competitive market (or economy).

The algebraic form of the Cobb-Douglas function may be translated into a log-linear form using regression analysis:

$$\text{Log}Q = \text{Log}A + \alpha\text{Log}L + \beta\text{Log}K \quad (2)$$

2.1.2. Theory of efficiency

Economic theory of production provides an important basis for understanding how resources are used to optimize output in agricultural production. According to Snyder et al. (2012), production efficiency is not only related to the rational use of resources but also focuses on optimizing inputs to achieve a desired output level. This is especially important in agricultural production because agrarian resources, including land, labor, and other inputs, are often limited. Applying this theory to sustainable coffee production in Vietnam shows that, to achieve technical efficiency (TE), farmers need to optimize production factors by using modern technologies and efficient production practices.

According to Debertin (2012), the production function is crucial for measuring and improving the connection between inputs and outputs. In coffee production, a clear definition of the production function helps farmers and policy makers determine the optimal inputs, such as fertilizer, labor, and land area, to achieve higher productivity. This aligns with earlier research, like Tabe-Ojong & Molua (2017), which highlighted that agricultural productivity is the ratio of total inputs to outputs and that continuously optimizing these elements is necessary to increase production. In Vietnam, where agrarian resources are often limited, applying best practices and modern technology becomes even more critical to ensure sustainable production.

This study identified sustainable coffee farming households as using resources more efficiently, resulting in higher technical efficiency levels than conventional farming households. This result demonstrates the critical role of modern technology and management methods in agricultural production. Abate et al. (2019) pointed out that optimizing technical efficiency improves product quality and quantity and creates sustainable economic benefits for farmers. This is especially true in sustainable coffee production in Vietnam, where modern technology helps farmers achieve high productivity and minimize negative impacts on the environment. In addition, Snyder et al. (2012) also proposed that modern and advanced production systems can help farms achieve maximum output with minimum resource consumption. Coffee production can be understood as optimizing resources such as land and water through intelligent irrigation systems, soil sensors, and efficient organic fertilizers. These methods not only help reduce production costs but also ensure that agricultural resources are used sustainably.

In addition, production theory emphasizes the importance of policy support in promoting higher productivity. This includes providing farmers with financial support and training programs, helping them access modern technologies, and improving

production capacity. The combination of policy support and the application of production theory can help farmers overcome resource challenges and achieve higher efficiency in coffee production. Applying production theory and technical efficiency models in practice provides a solid theoretical basis for agricultural production and opens up opportunities to improve productivity and product quality. According to this theory, improving production variables is a crucial step towards attaining sustainable development, especially in light of the pressures from domestic and foreign markets on the Vietnamese coffee sector.

2.1.3. The measure of technical efficiency

In agricultural and economic philosophy, one of the fundamental ideas is technical efficiency (TE). To gauge how well production processes can optimize output from a given quantity of inputs, Farrell (1957) was the first to propose this idea. TE is crucial for evaluating farms' competitiveness and productivity in the context of agricultural output. It shows unequivocally whether resources—such as labor, land, and fertilizer—are being used effectively. Farrell (1957) asserts that a farm is inefficient if it is not on the efficient frontier. The author first described technical efficiency in 1957, and this idea was expanded to include economic and allocative efficiency. Technological and allocative efficiency are combined to form economic efficiency, with allocative efficiency assessing how well inputs can be used given current market pricing. For example, in a coffee production system, allocative efficiency can be understood as choosing the type of fertilizer and production tools that have the lowest cost but still achieve the desired output. According to Ndirangu et al. (2017), a farm must achieve both technical and allocative efficiency to achieve economic efficiency. In addition, other studies have added aspects related to efficiency, such as scale and cost efficiency. Färe et al. (1985) emphasized that scale efficiency is decisive in optimizing production when farm size changes. Large farms can benefit from economies of scale in coffee production, while small farms may have difficulty achieving the same efficiency. Berger & Mester (1997) have extended the concept of profit efficiency, focusing on maximizing profits rather than simply maximizing output.

In coffee production, measuring TE helps evaluate current performance and provides data to improve production processes. For example, a coffee farm with high TE can optimally use inputs such as labor, irrigation water, and fertilizer to achieve maximum yield. However, many farms still face inefficiencies due to limited resources, management skills, or access to modern technology. This requires specific solutions, such as technical training for farmers and improved agricultural infrastructure. In addition, the application of advanced agricultural technologies also contributes significantly to enhancing TE. According to Snyder et al. (2012), modern irrigation systems and soil sensor technology can help farms manage resources more effectively, improving production efficiency.

Furthermore, the transition from traditional to sustainable production methods, such as using organic fertilizers, improves TE and contributes to environmental

protection. This factor is increasingly important in the context of climate change. Measuring technical efficiency is important in assessing and enhancing coffee production performance. This concept not only helps to identify the strengths and weaknesses of farms but also provides a basis for developing strategies to improve production efficiency. In the context of the coffee industry facing many challenges from global competition and sustainability pressures, the application of TE measurement tools, as proposed by Farrell (1957), is necessary to ensure the sustainable development and competitiveness of the industry.

2.1.4. Definition of sustainable development

Sustainable development is a concept that has evolved significantly since its inception, especially with the establishment of the United Nations Sustainable Development Goals (SDGs) in 2015. As defined by the World Commission on Environment and Development in 1987, sustainable development is "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Adhikari & Shah, 2021; Patuelli & Saracco, 2023). The concept of sustainable development is built on three main pillars: economic, social, and environmental. This principle is clearly expressed in the 1992 United Nations Agreement⁵ in Rio de Janeiro on the extension of sustainable development in the long term. (1) Economic pillar: focuses on promoting natural advantages, improving resource efficiency, optimizing production costs, improving product quality, and diversifying markets. (2) Social pillar: emphasizes ensuring national security, increasing income, reducing poverty, improving living conditions, and creating safe employment opportunities. (3) Environmental pillar: requires sustainable management of land and water resources and the use of environmentally friendly production methods. The SDGs include 17 goals to address global challenges such as poverty, inequality, climate change, environmental degradation, peace, and justice (Gupta & Vegelin, 2016). The comprehensive nature of the SDGs encourages a holistic approach to policymaking and implementation to avoid unintended consequences or failure to achieve expected results (Mio et al., 2020). This requires the participation of many stakeholders, including governments, businesses, and civil society. In particular, businesses are seen as important in achieving these goals through their resources, innovation capabilities, and capacity to promote sustainable practices (Claro & Esteves, 2021; Van Tulder et al., 2021).

In education, educational institutions increasingly recognize the importance of integrating sustainability into the curriculum to equip future generations with the knowledge and skills needed to address sustainable development challenges (Cruz et al., 2018). At the same time, ethical perspectives also play an important role in the discourse on sustainable development, emphasizing a just transition and considering

⁵ United Nations. *Documentation, Reference, & Terminology Section. (1992). Environment and Development (Vol. 2). UN.*

the needs of minority communities and future generations (Wartini, 2024). Sustainable coffee production is a specific example of sustainability in the industry, where supply chains and producers must adhere to economic, social, and environmental standards. Coffee that meets these criteria can be certified by independent organizations such as the Smithsonian Migratory Bird Center (SMBC), the NAFTA Environmental Cooperation Commission (CEC), and the Consumer Choice Center (CCC). This represents a progression from basic to more complex production methods aimed at ensuring sustainability (Kim et al., 2019).

2.2. Literature review

2.2.1. Current research on variables that affect sustainable agriculture products

As one of the essential industries in developing countries, the coffee industry is receiving attention from researchers (E.g., Chiputwa et al., 2015; Giuliani et al., 2017; Luong & Tauer, 2006; Nguyen & Vo, 2021). Some studies focus on technical aspects such as genetics (Goldfarb et al., 2005), but most studies address the benefits to coffee farmers and the effectiveness of certification programs for sustainability (Barham & Weber, 2012; Méndez et al., 2010; Ruben & Fort, 2012; Samper & Quiñones-Ruiz, 2017). According to (Purvis et al., 2019), the coffee industry has three pillars of sustainable development: the environment, society, and economy. However, Rice (2003) also argues that previous definitions of sustainable coffee representing ecology and trade equity reflect the social aspect, which is not entirely accurate. Dankers et al. (2003) and Giovannucci (2001), who studied the field of early sustainable coffee estimation, found that the initial commercial coffee volume was only estimated because there was no body, including a certification organization. Giovannucci (2001) demonstrated that most global coffee businesses disagree on two fundamental goals of sustainable development: environmental conservation and social justice. However, efforts are still being made to promote an environmentally friendly coffee business while considering economic and social benefits. Meanwhile, Giovannucci & Koekoek (2007) and Kilian et al. (2006) argue that fair trade, organic, and environmentally friendly coffee brings attractive benefits to farmers and coffee businesses through higher revenues. However, according to Giovannucci & Koekoek (2007) and Kilian et al. (2006), the underlying data to make reasonable predictions about the organic market are inadequate, especially regarding prices and production costs.

Moreover, Kilian et al. (2006) contend that economic interests, sustainable coffee production, and sustainability certification make impacts by lessening the aftermath of low coffee prices. To minimize the exploitation of manufacturing inputs, companies are now justified in adopting an alternative market positioning and modifying their production cost structure. Some Central American coffee growers have switched to sustainable coffee production. However, some farmers were less productive when enrolled in sustainable programs. Ho (2018) proposed that credit, farmer education, agricultural experience, and local government activities are

essential keys to improving the effectiveness of sustainable coffee. Becoming an association member helps coffee farmers grow their production effectively (Binam et al., 2003; Wollni & Brümmer, 2012). Castro-Tanzi et al. (2012) examined technology choice, productivity, and efficiency. The authors systematically used a method introduced to account for selection bias in stochastic frontier analysis (Greene et al., 2009). Farmers with more coffee-growing experience, higher levels of education, larger farms, and links to corporations are more likely to respond to incentives and use production technology to improve productivity and quality. According to these results, organic coffee growers outperform conventional coffee growers in terms of efficiency. Collaboration, marketing, and diversification initiatives are important. They concluded that when using technology, revenue sources other than coffee, the age and experience of farmers, and other socioeconomic factors are all critical factors affecting output efficiency.

Additionally, crop productivity influences society (Binam et al., 2003; Rios & Shively, 2006; Vedenov et al., 2007). Despite extensive experience, according to D'haeze et al. (2005), quality has not improved due to environmental challenges and market circumstances. Among the first ecological challenges mentioned in publications on sustainable solutions are soil nutrient retention, water conservation, and climate change (Chengappa et al., 2017; de Queiroz et al., 2018; Haggard & Schepp, 2012). The relevance of household size in preserving sustainable agricultural culture is emphasized (Jarosz, 2000). Furthermore, extensive use of low-cost, low-quality inputs and inadequate irrigation systems have resulted in soil degradation and decreased water quality (Ali & Byerlee, 2002; Ishfaq et al., 2020; Zulfiqar & Thapa, 2017). Adoption of the Alternate Wetting and Drying method (AWD) enhanced revenues by 38–42% in field experiments owing to lower water input in pumped irrigation systems (i.e., piped irrigation) and greater productivity (Kürschner et al., 2010; Lampayan et al., 2015). Similarly, Alam et al. (2009) have shown that farmers benefit from an AWD irrigation system because it is labor-saving, cost-effective, and ecologically friendly (Nalley et al., 2015). The long-term productivity and sustainability of safe agriculture in Pakistan are also mentioned by Ali & Byerlee (2002). The average growth in total productivity is high at 1.26% for all crops and livestock. Still, the difference in productivity growth between regions is not high, with wheat and rice having negative growth. The underlying impacts of resource degradation are then examined by applying a cost function to a second soil and water quality data set. Modern technology and the increased use of fertilizer are partly to blame for the decline in the health of agricultural ecosystems. Additionally, in many mountainous regions, hillside farming is common. However, soil and water protection in these places can be achieved by converting them into terraced fields (C.-A. Liu et al., 2013). Liu et al. (2013) in the semi-arid loess region.

In the Tarraz region, fungal diseases are a significant problem for coffee production. Castro-Tanzi et al. (2012) showed that excessive fertilizer reduces soil Ca exchange and enhances Al³⁺ toxicity. Applying inorganic fertilizer treatment may not always guarantee a yield because soil water loss persists, but it jeopardizes the long-

term viability of the economy (Zulfiqar & Thapa, 2017). Calcium (Ca) has become the most important nutrient for coffee production. The use of agricultural chemicals in Costa Rica is inappropriate due to the country's reputation as a pioneer in sustainability. De Groote et al. (2005) noted that maize productivity and output have improved significantly since Kenya's maize industry liberalization.

Notwithstanding the decrease in cost, fewer fertilizers are being utilized on average per hectare than in the past. According to econometric studies, fertilization intensity significantly affects yield. In addition, female-headed farming households have lower productivity. Similarly, Ogada & Nyangena (2015) show that inorganic fertilizer and new maize varieties greatly increase yields when applied as a package instead of separately. For competent farmers, using such technologies is relatively easy.

Additionally, pesticides have cumulative adverse long-term effects on ecosystems, plant and animal survival, and human health. Shattar et al. (2016) show a specific classification of organic pesticides. The authors also consider how they affect human health and the environment. According to Ibanez & Blackman (2016), using pulp and organic fertilizers makes certification beneficial for the environment. Moreover, it aids in lowering the need for artificial pesticides and fertilizers. These findings align with those of Blackman & Naranjo (2012) and Darnall & Sides (2008).

2.2.2. Outlook of global conventional coffee and certified coffee production

Coffee is a crop of global importance (ICO, 2011)⁶, and in Ecuador, it is one of the prime elements in generating foreign exchange (COFENAC, 2011). However, the country's agricultural practice uses improper fertilizer, leading to crop loss of nutrients. Capa Mora (2015) determines the ideal mineral and organic fertilizer dosage. Greenhouse gas emissions start diminishing when cultivation adopts mineral and organic fertilizers. And using organic fertilizer in production is no longer a fresh ideology. The problem is that organic fertilizers often cost more than inorganic fertilizers. Kilian et al. (2006) demonstrated that conventional farms in Central America produce and sell coffee cheaper than organic ones.

Furthermore, rising prices only help farmers increase their revenue in the nearby. As demand and supply increase, sustainable coffee prices will likely fall in the long term. Due to customers' growing desire for goods produced with social norms, ethical manufacturing, and acceptable retail prices, the demand for sustainable coffee raises an excellent potential for leverage. Developing countries have natural advantages in coffee production, and when the scalability matures, they start moving toward sustainability. Some farmers have turned to organic farming because of the price difference, the possibility of bullish future markets, and preparation for stricter environmental requirements from developed markets (Kilian et al., 2006).

In contrast, sustainable programs are accompanied by competitive input costs. These results are consistent with a widespread perception that organic farming harms

⁶ *International Coffee Organization (ICO) (2011). Annual Review. 2009/10 [ICO Document]. London.*

the financial bottom line and often dampers overall economic gains (Lyngbæk et al., 2001; Vossen, 2005), such as exacerbating or maintaining poverty (Valkila, 2014). Hence, it creates barriers to further fostering organic certification or maintaining current certification speed. In Niger, located in the central region and producing a lot of rice, Okoruwa et al. (2006) showed that all socioeconomic characteristics have a positive correlation with efficiency.

Household size, farm size, and gender are statistically significant at different levels, and they comprehend all production efficiency indicators in the delta system with exceptional experience. Authors have extensively emphasized the enormous impact of farm size on enhancing efficiency differentials (Amara et al., 1999; Bravo-Ureta & Rieger, 1991). They also demonstrated how better seeds affect each farmer's production. Despite significantly contributing to Ethiopia's economy, Bati et al. (2017) show that maize production is inefficient. Education level affects technical level, distribution, and economic efficiency in a statistically meaningful way.

Meanwhile, soil fertility and fragmentation are the main factors affecting technical efficiency. Ateka et al. (2018) found that farmers participating in the Farmers School (FFS) program produced more tea. This result is agreed by Onduru et al. (2012). They discovered that FFS participants had a favorable and significant impact on Kenya's tea production. There is little correlation between productivity and parameters such as household size, per capita expenditure, age, and education level of the household head, among other variables. These findings indicate that using manual labor disconnects with the optimum yield output. Ample studies, such as Owuor et al. (2011) and Owuor & Obanda (2001), have emphasized the importance of limiting labor in tea growing. However, farm profitability still encounters obstacles to reducing overall production costs involving labor. Basnayake & Gunaratne (2002) showed that the farmer's age, occupation, occupation level, and crop type substantially impacted production efficiency; in other words, these factors have negative coefficients in the inefficiency model.

On the other hand, it is not technically inefficient to tap non-tea revenue streams (Katungwe et al., 2017). The Tobit model was utilized by Bich Hong & Yabe (2015) to determine the factors impacting these impacts across tea farms after estimating resource efficiency using the TE and the translog stochastic production frontier model. The authors conclude that more frequent resources used at the study site were insufficient. The authors highlight the essential role of government in improving farmer accessibility to agriculture promotion programs, farm size expansion, and water reservation practice, as well as delivering farmer knowledge about water waste. The element of gender underlined that male farmers tend to yield a positive relationship with output (Adesina & Djato, 1997; Due & Gladwin, 1991).

The Rain Forest Alliance (RFA) claims that promoting sustainable development in the coffee industry increases production efficiency amid long-term impacts and improves farmers' living standards. Giovannucci & Koekoek (2007) and Kilian et al. (2006) concurred by linking fair trade, organic, and environmentally friendly coffee programs to farmer interests through more significant sales opportunities. In addition,

joining associations also contributes to helping coffee producers develop more efficiently (Binam et al., 2003; Wollni & Brümmer, 2012). On the contrary, research by Giovannucci (2001) shows that with sustainable coffee in North America, most coffee organizations do not agree with the goal of sustainable development due to a lack of engagement with sales improvement. Ho et al. (2018) found that farmers in Daklak province in Vietnam were less likely to achieve significant production figures when adopting sustainable programs. According to D’haeze et al. (2005), coffee growers' livelihoods face exposure to ecological threats and market conditions. The author simultaneously evaluates direct and indirect variables to fill the gap from previous studies. In addition, considering the external factors that add to the coffee production efficiency between certified and non-certified coffee growers in Vietnam, the author hopes to provide empirical evidence and recommendations on the optimal level for each variable in coffee growing. This study is expected to help the Government, coffee experts, coffee organizations, corporations, and farmers decide to maximize benefits while still complying with sustainable requirements for future growth.

Table 2.1: Statistics of reference studies

No.	Variables	Reference	Dependent		Note
			Output	Technical inefficiency	
1	Organic fertilizer (kilograms)	<u>Bich Hong & Yabe (2015), Capa Mora (2015), De Groote et al. (2005), Ibanez & Blackman (2016), and Liu et al. (2013)</u>	✓	✓	
		<u>Bich Hong & Yabe (2015); De Groote et al. (2005) and Liu et al. (2013)</u>	✓		
2	Inorganic fertilizer (kilograms)	<u>Ali & Byerlee (2002), Basnayake & Gunaratne (2002), Capa Mora (2015), Castro-Tanzi et al. (2012) and Ogada & Nyangena (2015)</u>	✓	✓	
		<u>Bich Hong & Yabe (2015), De Groote et al. (2005) and Liu et al. (2013)</u>	✓		
3	Herbicide (liter)	<u>Ali & Byerlee (2002), Basnayake & Gunaratne</u>	✓	✓	

		<u>(2002), Castro-Tanzi et al. (2012) and Katungwe et al. (2017)</u>			
4	Pesticide (liter)	<u>Ali & Byerlee (2002), Basnayake & Gunaratne (2002), Castro-Tanzi et al. (2012), Ibanez & Blackman (2016) and Katungwe et al. (2017)</u>	✓	✓	
		<u>Shattar et al. (2016)</u>		✓	
5	Irrigation water (m ³)	<u>Ali & Byerlee (2002) and Ishfaq et al. (2020)</u>	✓	✓	
		<u>Bich Hong & Yabe (2015)</u>	✓		
6	Labor cost (vnd/hectare)	<u>Basnayake & Gunaratne (2002), Katungwe et al. (2017), Suranjan Priyanath et al. (2018) and Wollni & Brümmer (2012),</u>	✓	✓	
		<u>Bich Hong & Yabe (2015) and Gatimbu & Ogada (2020)</u>	✓		
7	Age	<u>Basnayake & Gunaratne (2002), Bich Hong & Yabe (2015), Ho et al. (2018), Okoruwa et al. (2006), Suranjan Priyanath et al. (2018) and Wollni & Brümmer (2012)</u>	✓		
		<u>Basnayake & Gunaratne (2002), Ho et al. (2018), Suranjan Priyanath et al. (2018), Wollni & Brümmer (2012)</u>	✓	✓	
8	Experience	<u>Basnayake & Gunaratne (2002), Gatimbu & Ogada (2020), Ho et al. (2018), Katungwe et al. (2017) and Suranjan Priyanath et al. (2018)</u>	✓	✓	

		<u>Bich Hong & Yabe (2015), Gatimbu & Ogada (2020) and Okoruwa et al. (2006)</u>	✓		
9	Gender	<u>Bich Hong & Yabe (2015), De Groote et al. (2005) and Okoruwa et al. (2006)</u>	✓		
		<u>Wollni & Brümmer (2012)</u>	✓	✓	
10	Education level	<u>Bich Hong & Yabe (2015) and Okoruwa et al. (2006)</u>	✓		
		<u>Basnayake & Gunaratne (2002), Katungwe et al. (2017) and Wollni & Brümmer (2012)</u>	✓	✓	
11	Ethnicity	<u>Bich Hong & Yabe (2015)</u>	✓		
12	Applying advanced methods (breeding improvement, mechanization)	<u>De Groote et al. (2005)</u>	✓		
13	Farm size	<u>Bich Hong & Yabe (2015), Gatimbu & Ogada (2020) and Okoruwa et al. (2006)</u>	✓		
		<u>Katungwe et al. (2017) and Wollni & Brümmer (2012)</u>	✓	✓	
14	Training on land reclamation				New
15	Real estate prices				New
16	Average export price	<u>Bacon (2005), Daviron & Ponte (2005) and Kilian et al. (2006)</u>	✓		
17	The total value of				New

	coffee exports (million USD)				
18	Average production (MT/ha)				New
19	Inflation rate				New

Source: Compiled by the author

Although some studies highlight the economic benefits of sustainable coffee production (e.g., higher revenues from fair trade and organic coffee), there is still a gap in understanding the cost structure—detailed costs, profits, and long-term economic impact, especially for Vietnamese coffee farmers. Furthermore, the effectiveness of certification programs varies. In Vietnam, it especially needs to be investigated more thoroughly. Comparative studies that prove the variations in sustainability, economic benefits, and productivity between Vietnam's certified and non-certified coffee growers are needed. This includes understanding their impact on the productivity and financial sustainability of both small- and large-scale farmers.

Regarding research places, although there are studies related to coffee production in Vietnam, most of them focus on the Dak Lak area (Amarasinghe et al., 2015; N. Dzung, 2013; Maskell et al., 2021; G. N. T. Nguyen & Sarker, 2018). Some studies in other areas, such as those in the Lam Dong Province (Le et al., 2020) and Ho (2018), surveyed three regions, including Dak Lak, Lam Dong, and Gia Lai. These studies ignore DakNong, which is also one of the provinces that contributes to high output.

The specific environmental challenges facing Vietnamese coffee farmers, such as soil degradation, water conservation, and climate change, require more targeted research. In addition, solutions such as applying advanced methods to confirm their effectiveness in Vietnam. Finally, the previous studies have not mentioned the relationship between real estate prices and coffee output. This is the first study to address this relationship.

2.3. Hypotheses development

Fertilizer, one of the essential and indispensable elements in agriculture, plays a decisive role in providing necessary nutrients to plants and enhancing production performance. In the contemporary world of agriculture, two main fertilizers are used: chemical fertilizers and organic fertilizers. Chemical fertilizers, often called inorganic fertilizers, are products of industrial processes produced from artificial chemical compounds and minerals. They contain nutrients such as nitrogen (N), phosphorus (P), potassium (K), copper (Cu), zinc (Zn), bohrium (B), calcium (Ca), magnesium (Mg), and many other types of micronutrients. In contrast, organic fertilizers are products of the natural decomposition or processing of organic materials such as human or animal excrement, leaves and twigs, peat, agricultural residues, and other

biological waste. Organic fertilizers provide a range of natural and valuable nutrients to plants, helping to improve soil fertility and porosity by enhancing the presence of organic matter, humus, and nutrients.

According to Liu et al. (2013), farmers on the Loess Plateau in China switched from using chemical fertilizers to organic fertilizers in a short period to reduce the potential for losses in productivity. Although long-term use of organic fertilizers can support agricultural productivity and facilitate more fertile soil, this has been confirmed by the results of Ali & Byerlee (2002). Additionally, in Costa Rica, inorganic fertilizers have been used to enhance coffee yields, as demonstrated by studies by Basnayake & Gunaratne (2002), Capa Mora (2015), Castro-Tanzi et al. (2012), Ogada & Nyangena (2015) and Suranjan Priyanath et al. (2018). However, in some cases, such as De Groote et al. (2005), there was a study about new maize varieties in Kenya, and it was concluded that neither organic nor inorganic fertilizers positively impacted productivity. Ibanez & Blackman (2016) did not have enough evidence to conclude that organic fertilizers affect coffee productivity in Colombia. Nevertheless, the author's prediction suggests that inorganic fertilizers may positively affect coffee yields. In contrast, using organic fertilizers may produce environmental benefits and not cause harm to soil and groundwater.

A visible shift between chemical and organic fertilizers may reflect farmers' sophistication in managing natural resources and the environment. The choice between these two fertilizers also depends on the specific conditions of the soil and crop. To have a more comprehensive and accurate view of the impact of fertilizers on agricultural productivity, the author continues to research and further explore related factors such as environmental conditions and land management. The author has the following hypotheses:

H_{1a}: Organic fertilizer has positively affected certified coffee

H_{1b}: Organic fertilizer has negatively impacted the productivity of uncertified coffee yield.

H_{2a}: Inorganic fertilizer has positively affected the productivity of uncertified coffee yield.

H_{2b}: Inorganic fertilizer has negatively affected certified coffee yield.

In the agricultural sector, the use of pesticides and herbicides has become an indispensable part of the crop production process. These chemicals, including chemical and biological constituents such as bacteria, viruses, antibacterial agents, and disinfectants, can prevent or cause pests and unwanted plants to grow. Become weak or inactive. However, their broad use has raised significant concerns about their negative impact on the environment, including soil and water environments. Many studies have focused on evaluating the effects of pesticides and herbicides on the productivity and quality of agricultural products. In a study conducted in Costa Rica, Castro-Tanzi et al. (2012) found that the use of pesticides and herbicides contributed to increased coffee production in this region. Similarly, Basnayake & Gunaratne

(2002) conducted a similar study with tea in Sri Lanka and noted some positive effects on yields. However, studies such as those of Ibanez & Blackman (2016) and Katungwe et al. (2017) do not find clear evidence of the impact of pesticides and herbicides on agricultural yields.

Despite these positive findings on productivity, it cannot be denied that the use of pesticides and herbicides significantly impacts the environment. These chemicals can accumulate in the atmosphere, creating long-lasting and harmful effects on both plants and animals living in that environment. Furthermore, their impact is not limited to the individual but extends to the community and ecosystem. It can be seen that excessive use of these chemicals can cause severe environmental and human health problems. However, some efforts have been made to reduce the adverse effects of pesticides and herbicides. For example, according to the study of Shattar et al. (2016), using montmorillonite to adsorb organic pesticides has brought significant advances in this industry. This method helps reduce the amount of chemicals needed and minimizes the negative impact on the environment. This demonstrates that there is a way to optimize the use of these drugs, creating a balance between production efficiency and environmental protection.

With developments and advancements in agriculture and environmental science, it is hoped that more new methods will be used. Technologies will become available to help minimize the impact of pesticides and herbicides on the environment while at the same time still ensuring the productivity and quality of agricultural products. This has significant environmental implications and positively affects human health and quality of life. However, with the pressure from regulations on certified households, what is different? To consider this, the author has the following hypotheses:

H3: Pesticides have a positive effect on coffee yield.

H4: Herbicides have a positive effect on coffee yield

According to Boonwichai et al. (2018), Climate change can increase water scarcity. Both areas with abundant rainfall and desert, drought-prone regions are experiencing water shortages (Pereira et al., 2002). A significant current challenge in agriculture is the sustainable use of water (Tura & Tolossa, 2020). This increasingly finite resource can be saved by applying yield conservation measures while saving irrigation water (Topcu et al., 2007). Furthermore, according to Fereres & Soriano (2007), irrigation aims to increase net revenue, reduce the risk of crop failure, and ensure the sustainability of agricultural output rather than water use productivity. Irrigation needs to be handled more skillfully and sustainably to save water, increase yields, and reduce sources of environmental pollution (Tura & Tolossa, 2020).

In a series of previous studies (Ali & Byerlee, 2002; Ishfaq et al., 2020; Zulfiqar & Thapa, 2017), there have been important observations on the impact of water quality on productivity in agriculture. These studies have shown that using cheap and low-quality water sources can lead to a decline in crop yield quality. A notable study by Ali & Byerlee (2002) illustrated that poor water quality has significantly decreased annual wheat and rice production in Pakistan. This decline affects output and could

negatively impact the economy and public health. Cucumbers' fresh fruit output at every growth stage is significantly impacted by the irrigation water used (Mao et al., 2003). Yield can be significantly reduced by reducing the availability of water (Fereres & Soriano, 2007). By limiting drainage, ensuring sufficient soil water availability, and enhancing water usage productivity, soil moisture monitoring can reduce the chance of production loss (Blanco-Canqui, 2018).

However, according to Bich Hong & Yabe (2015), there is no consensus on the negative impact of water quality on productivity. While there are studies that demonstrate this association, there are also other studies that find no such effect. Woli et al. (2016) showed higher tuber yields, less irrigation, higher nitrogen rates, and heavier soils. Moreover, subsurface drip irrigation saves water, increases yield, and improves the quality of greenhouse crop production (Y. Liu et al., 2019). This may be partly due to differences in local conditions, research methods, and the different variables with which researchers have approached the problem. From the conflicting results between studies, the author hypothesizes that water quality may have a negative impact on agricultural productivity.

H₅: Irrigation water quantity has a negative relationship with coffee yield.

The availability of labor is crucial for scheduling operations in the production cycle, as it is frequently the major input (Dahlin & Rusinamhodzi, 2019). According to research by Bich Hong & Yabe (2015), Gatimbu & Ogada (2020), Katungwe et al. (2017), Okoruwa et al. (2006), Suranjan Priyanath et al. (2018), and Wollni & Brümmer (2012), labor significantly and favorably contributes to increased agricultural productivity. Labor is often the primary input, and availability is important for timing operations in the production cycle (Dahlin & Rusinamhodzi, 2019). Bich Hong & Yabe (2015), Gatimbu & Ogada (2020), Katungwe et al. (2017), Okoruwa et al. (2006), Suranjan Priyanath et al. (2018), and Wollni & Brümmer (2012) found that labor plays a significant and positive role in improving productivity in agriculture. These studies have clarified that investing in labor brings economic benefits and enhances farm production efficiency. Amaruchkul (2021) stated that sugarcane harvesting often requires migrant labor when the domestic labor supply or harvesting machines are insufficient.

However, according to Sheng et al. (2019), the more hired labor utilized for agricultural production, the more monitoring expenses rise over time. Productivity may not increase with increased worker input because supervision expenses rise at the same pace as hired human resources. Basnayake & Gunaratne (2002) found that in some cases, family labor is insufficient, or the farm has to outsource labor due to its large size, which may require a more significant amount of labor than expected. Moreover, intercropping systems can short-term lower companion cereal yields (Franke et al., 2018) and frequently raise labor needs for weeding (Ransom, 1990; Rusinamhodzi et al., 2012). This calls into question how labor use is managed and considered in agriculture. Based on these observations, hypothesis 6 can be posed as follows:

H₆: High labor costs have a positive impact on coffee yield.

The connection between coffee farm size and output in development economics is a well-known and fascinating subject (Sheng et al., 2019). The scale of a farm is not simply about physical factors such as land area, number of crops, or amount of labor but also reflects farmers' organization, management, and production activities. For the coffee industry, farm size can affect production efficiency and farmer income through effective management and use of resources. Okoruwa et al. (2006) and Wollni & Brümmer (2012) have reaffirmed the positive relationship between farm size and coffee productivity. They have shown that large farms can often use resources and modern technology better, producing larger coffee yields. Large farms can be more efficient than small ones, especially in dealing with climate change and coffee price fluctuations (Otsuka et al., 2013).

However, not all studies agree with this view. According to Desiere & Jolliffe (2018), productivity and size have an inverse connection, suggesting that small farms can outperform large farms in output, perhaps due to their flexibility in management and production practices. Huang & Ding (2016) also discovered a complicated connection between coffee output and farm size. When farm size reaches a certain threshold, this relationship can reverse. In addition, some studies (Bich Hong & Yabe, 2015; Gatimbu & Ogada, 2020; Katungwe et al., 2017) could not establish a clear link between farm size and coffee productivity. This may reflect the complexity of factors affecting productivity, including climate change, geographical conditions, and variation in resource allocation and use across farms.

H₇: Larger Farm size is positively connected to coffee yield.

Intercropping systems often have higher land use efficiency than monocropping systems (H. G. Hong et al., 2019). Intercropping, or growing multiple crops on the same land, is an effective farming method for enhancing resource use. Li et al. (2011) showed that intercropping enhances the use of light, water, and soil nutrients, thereby improving yields and land use efficiency. Farmers can achieve higher yields without increasing their resource investment, enhancing TE.

In addition, intercropping also helps control pests and weeds naturally. By intercropping crops that are resistant to pests or that can compete with weeds, farmers can reduce the use of pesticides and herbicides. This reduces production costs and helps maintain and improve soil quality, enhancing TE. For example, Brooker et al. (2015) showed that intercropping with legumes and cereals can reduce pest and disease pressure and improve soil ecosystem health, thereby increasing production efficiency.

In addition, intercropping can optimize resource allocation and use throughout the cropping season. Zhang et al. (2015) demonstrated that intercropping can improve water use efficiency, as different crops have different water requirements and growth periods, thereby reducing water waste and increasing TE. In addition, the combination of crops in intercropping systems improves soil structure and fertility, thanks to the

addition of nutrients from legumes and deep-rooted crops (Lithourgidis et al., 2011). Furthermore, intercropping can help reduce risks from climate change and unpredictable fluctuations in agricultural production. Farmers can reduce losses due to extreme weather, pests, and market fluctuations by growing crops in the same area. Altieri (1999) showed that diversified agricultural systems, such as intercropping, are more resilient to environmental shocks, thereby maintaining stable yields and technical efficiency. In addition, the primary discovery of Hong et al. (2019) is that intercropping significantly improves total energy efficiency (TE). This suggests that any possible drawbacks to intercropping's better land-use efficiency relative to monocropping are more than compensatory.

The author then advances the following theory:

H₈: Intercropping have a positive impact on technical efficiency

Developing new crop varieties through genetic improvement has played an important role in modern agriculture. These new crop varieties improve yields and positively impact technical efficiency (TE) in agricultural production. Genetic improvement through breeding disease-resistant varieties is a sustainable method to reduce yield losses without increasing the use of chemical pesticides. Abro et al. (2017) highlighted that breeding programs can help farmers reduce losses from pests and diseases while maintaining high yields. This saves on input costs and improves farmers' TE, as they can achieve maximum yield from available resources.

Crop improvement has been widely applied in many different crops, especially maize. The discovery of hybrid vigor led to the development of hybrid maize varieties, dramatically improving yields. Chavas & Mitchell (2018) point out that this development has brought significant advances in maize production while also helping to increase farmers' TE. Using hybrid maize varieties helps optimize the cultivation process, minimize resource waste, and increase adaptability to different environmental conditions. However, the adoption of new varieties also faces some challenges. According to Goldstein et al. (2012), when grown for hybrid production, parent varieties developed in organic programs often lack vigor and nutrition and are less competitive with weeds. This can negatively affect technical efficiency, as farmers must use additional cultural and management practices to ensure their crops thrive. Furthermore, purebred and organic grain production also face problems with contamination from genetically modified organisms, limited soil nutrients, and unstable climates (W. Goldstein, 2023). These factors can reduce TE if not correctly managed.

In the coffee sector, improved varieties have yielded positive results. Diro & Erko (2019) show that improved coffee varieties increase yields and improve smallholder farmers' and gross incomes. This suggests that new varieties can help farmers achieve higher TE by optimizing resource use and minimizing production risks. To ensure the success of improved varieties, government nurseries need to play an important role in the distribution of seedlings, providing farmers with easier access to varieties with the potential to enhance TE (Diro & Erko, 2019).

In addition, Joshi et al. (2017) also confirmed that new wheat varieties, especially those from the PVS program, provide a yield advantage of 5–17% over older varieties. Although higher yields do not always equate to higher TE, these new varieties allow farmers to produce more with the same level of inputs, thereby improving TE. However, Walker et al. (2015) emphasized that without apparent yield differences between improved and conventional varieties, farmers may not see a reason to adopt new varieties, reducing the potential for improved TE.

Dam et al. (2019) found that traditional or improved rice varieties can increase yields and TE, particularly in saline soil conditions. This emphasizes that enhanced and conventional varieties, if used correctly, can improve TE, especially in harsh environments. Thanks to their disease resistance and resource optimization, new crop varieties positively impact farmers' technical efficiency (TE). Adopting improved crop varieties will help farmers achieve higher yields from the same amount of inputs, thereby improving technical efficiency in agricultural production. Therefore, the study hypothesis is as follows:

H₉: New coffee variety diversity has a positive impact on technical efficiency

Erenstein (2003) detailedly studied the factors affecting production efficiency in lowland areas. This study showed that experience, household size, farm size, and gender were all statistically significant at different levels, significantly affecting production efficiency measures, except for the experience factor. Farm size was significant among these, as size differences significantly affected livestock efficiency. Many other authors have also analyzed the impact of farm size on production efficiency in-depth, such as Amara et al. (1999) and Bravo-Ureta & Rieger (1991). One of the most essential factors emphasized in the study was the education level of households. Bati et al. (2017) demonstrated that education level significantly impacts technical efficiency, resource allocation, and economic efficiency. This suggests that investment in education for agricultural households is necessary to increase production efficiency.

According to Bich Hong & Yabe (2015), the gender of the household head is also an important factor. The results show that male household heads tend to achieve higher output than female ones. This finding is similar to Adesina & Djato (1997) and Due & Gladwin (1991). In addition, Bich Hong & Yabe (2015) also analyzed factors such as education, age of household head, household size, and ethnicity. However, when they delved into the variables related to ethnicity, they found that this variable only contributed modestly to the findings. This is noteworthy in Vietnam, which has 54 ethnic groups, of which the “Kinh” ethnic group is the majority.

Wollni & Brümmer (2012) concluded that there is no clear relationship between gender and productivity. However, production experience is important, especially in cultivating specific crops. Basnayake & Gunaratne (2002) pointed out that farmers with experience in tea cultivation tend to achieve higher technical efficiency. This is explained by the ability of those with higher expertise to use inputs more efficiently.

The above studies provide a broad view of the factors affecting agricultural production efficiency and show this issue's complexity and multidimensionality. From education level, gender, and experience to farm size, all play important roles and require appropriate policies to improve production efficiency. Investing in education, supporting gender equality, and optimizing production scale are necessary to improve agricultural households' productivity and economic efficiency.

The author's hypotheses are as follows, based on the references to earlier studies:

H₁₀: Experience of farmers negatively correlates with technical inefficiency

H₁₁: The education of farmers negatively correlates with technical inefficiency.

H₁₂: Kinh ethnicity farmers negatively correlate with technical inefficiency.

H₁₃: Technical inefficiency has a positive relationship with age.

According to Palanivel & Surianarayanan (2019), conventional agricultural methods, inadequate irrigation systems, decreased soil fertility, and unstable climate change are all contributing factors to low crop yield that must be addressed. Increased maize yields from improved growing techniques might increase food self-sufficiency and feed for people and animals (Çelik et al., 2010). In agricultural production in OECD nations, mechanization services, such as plant and machinery leasing and technical/management services, have traditionally been considered adjuncts to privately held machinery (Qing et al., 2019). Agricultural machinery boosts agricultural output while lowering labor costs and time spent on agricultural tasks (Abdel Hamid et al., 2021). Mottaleb et al. (2016) show that The spread of agricultural machinery will increase the efficiency of agricultural output in small rural farms. Awotide et al. (2015) found that smallholder farmers' income and agricultural production are impacted by improved agricultural technology.

In the study of Ishfaq et al. (2020), rice yield has been considered when applying the technique to irrigation water in some countries. However, the results were unexpected and had a negative relationship with yield. De Groote et al. (2005) concluded that neither inorganic nor organic fertilizer increased yield with new maize varieties in Kenya. Meanwhile, Ogada & Nyangena (2015) studied the effects of a single pack of inorganic fertilizer and new maize varieties on yield in Kenya. The authors' study demonstrates that the new maize varieties significantly increase yield. In this study, the author proposes the hypothesis as follows:

H₁₄: Applying advanced methods (breeding improvement, mechanization) negatively affects technical inefficiency.

According to Yu et al. (2023), agricultural training and extension services play an important role in shaping farmers' behavior. In particular, producers on large farms have superior knowledge scores in corn cultivation and fertilizer use. This group possesses better skills and actively participates in agricultural education programs. Through this, they adopt advanced fertilization methods such as formulated fertilizers or slow-release/controlled-release fertilizers, improving production efficiency and protecting the environment. Challa & Tilahun (2014) pointed out that training farmers

in technological applications can significantly enhance their understanding of agricultural innovation. Training is about providing knowledge and helping farmers access and use advanced technologies in production. Disseminating these technologies is an effective strategy to promote production and reduce poverty in rural areas, as Nakano et al. (2018) emphasized.

Huang et al. (2015) found that trained Chinese farmers were better able to absorb scientific information, especially in fertilization and fertilizer management. This skill improved economic efficiency and helped reduce negative environmental impacts. Lei et al. (2024) further added that well-trained farmers were more likely to engage in green production. This suggests that training improves productivity and orients farmers toward sustainable farming methods.

Nakano et al. (2018) emphasized that training materials must focus on practical agricultural production elements to persuade farmers to adopt new technologies. However, many existing studies still only provide general information through extended classes. Guidance standards must be improved to improve efficiency, especially for green production methods and land improvement. Both total production and sustainable land use are closely related to the quality of training farmers receive. The above studies confirm the important role of training and extension in upgrading skills, improving productivity, and promoting sustainable production. To achieve optimal efficiency, training programs must focus on providing practical knowledge and technology applications while encouraging farmers to participate in green production. These efforts will contribute to improving rural livelihoods and support sustainable agricultural development.

The author believes total output and land reclamation training are related to this issue.

H₁₅: Farmers participating in soil improvement training will help reduce the negative impact of technical inefficiency.

H₁₆: Distance from the farm to the city positively affects technical inefficiency.

Bacon (2005), Daviron & Ponte (2005), and Kilian et al. (2006) conducted a series of studies to examine the impact of coffee prices on the production activities of farming communities. Among the factors affecting the economy, coffee prices are identified as one of the factors that frequently cause fluctuations (Lukanima & Swaray, 2014). Valenciano-Salazar et al. (2023) have shown that coffee producers are often the most severely affected group in the supply chain. Farmers are particularly exposed to the impact of price fluctuations, low prices, and weather events such as floods, droughts, and worsening climate changes (Baptista & Jenkins, 2017). Price declines also affect producers' short- and long-term profits, thereby limiting investment in coffee growing and increasing the susceptibility of coffee plants to diseases and pests (Avelino et al., 2015). Eakin et al. (2014) reported that reduced crop productivity caused a double crisis for farmers, as reduced productivity became more severe than falling coffee prices. Hafner (2003) conducted a more thorough study of the link between GDP and productivity, while Elder (2004) and Grier & Perry

(2000) addressed the decline in economic growth. However, from the studies of Bredin et al. (2009) and Fountas et al. (2006), there is no clear evidence of a relationship between output growth or output uncertainty in G7 countries and some Asian countries with inflation uncertainty. The author added new variables to the study, such as real estate prices, average economic profit per hectare of coffee-growing land, and inflation rate. From there, the author makes the following hypothesis:

H₁₇, H₁₈: The average production and total value of coffee exports positively correlate with coffee yield.

H₁₉, H₂₀: The price of real estate and the inflation rate are negatively correlated with coffee yield.

Based on the theory of Cost Theory and Production Function and Technical Efficiency, a research gap, the author builds a research framework (Figure 1) to show the influence of input factors that affect output in production. In addition, some external factors affecting coffee production productivity in households in the provinces in the study sample are shown.

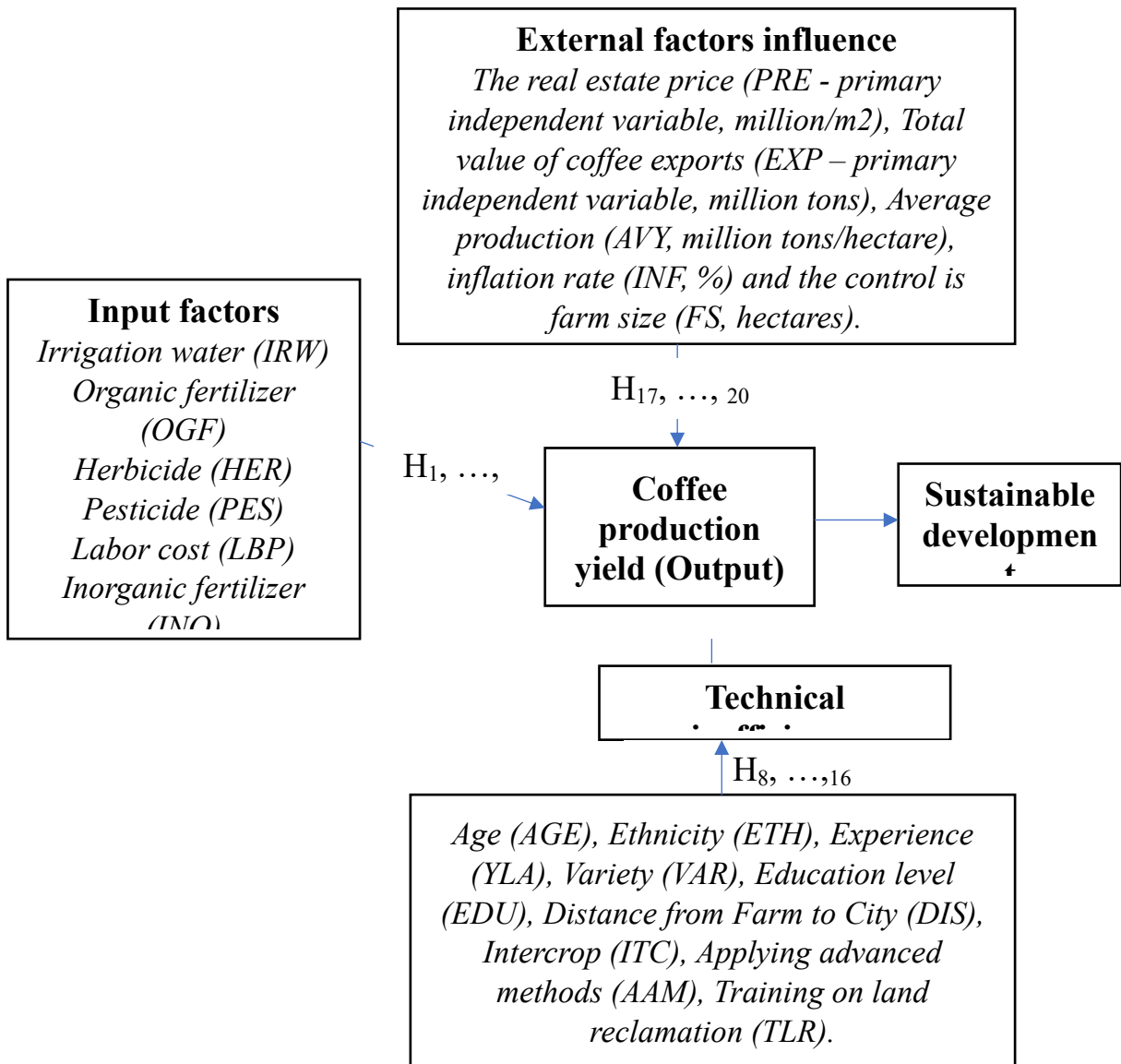


Fig. 2.1: Conceptual framework
 Source: The author's work

3. METHODOLOGY

3.1. Research process

Related academic and theoretical gaps are explored from previous studies. The author formed a research conceptual framework, hypotheses, and a questionnaire. Combining quantitative (survey) and qualitative (in-depth interviews) research will help make the research more in-depth and rigorous. The study protocol is summarized in Table 1.

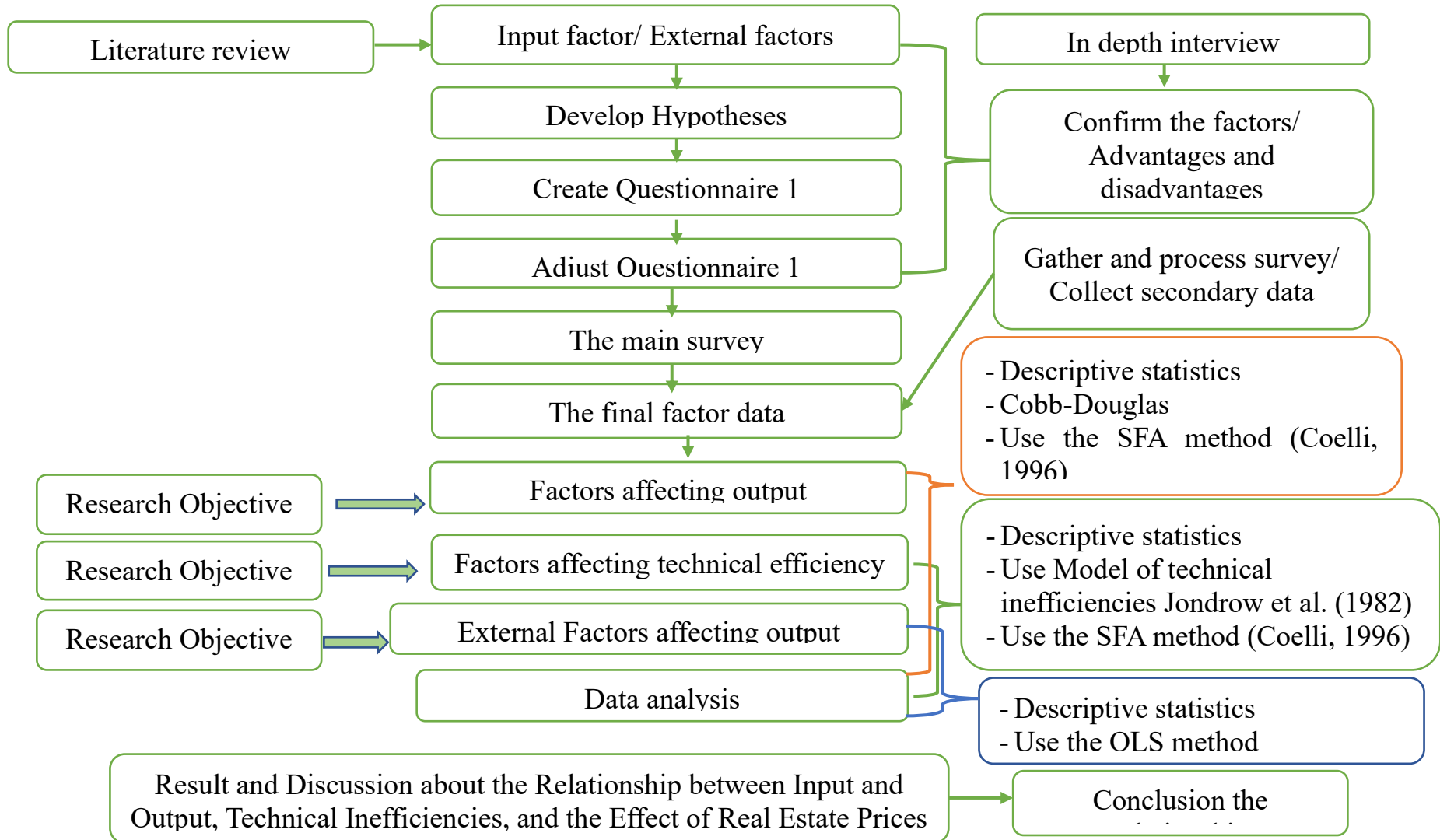


Fig. 3.1: Research process.
Source: The author's work

3.2. Methodology

The author uses qualitative and quantitative methods in the thesis, in which quantitative research is based on and based on qualitative methods. Qualitative methods develop and complete survey questionnaires of appropriate size and play an important role in identifying key factors, establishing a theoretical framework, and designing the initial questionnaire. Qualitative techniques include personal interviews with local officials and farmers with long-term production experience, observation during interviews, and analysis of documents collected after interviews. This method helps to collect information on opinions related to the coffee production situation in the areas. Document analysis helps to check the findings and provide a theoretical basis for completing the questionnaire. Quantitative methods follow qualitative research, using survey questionnaires designed from previous studies and completed after consulting local officials and farmers with long-term experience.

3.2.1. Qualitative research

The qualitative research methodology employed in this study aims to gather in-depth information regarding the factors influencing sustainable production in Vietnam's coffee industry. According to Hennink et al. (2020) and Tran et al. (2022), qualitative research is commonly utilized to explore the perspectives of an individual or a group, providing a comprehensive understanding of the socio-economic and environmental context of the research site. A key characteristic of this method is its flexibility, allowing for interview questions to be adjusted based on new information emerging during the research process. This adaptability ensures that the study accurately reflects the realities of coffee production in Vietnam, particularly the challenges and opportunities associated with sustainable production. However, qualitative research also presents certain limitations, including difficulties in generalizing findings, the subjectivity of respondents, and constraints on sample size, which may impact the reliability of the study (Hennink et al., 2020). Despite these limitations, qualitative analysis in this study primarily serves as a secondary basis to refine the survey questionnaire for coffee farmers, ensuring that the measurement scales align with the practical conditions of coffee production and export in Vietnam.

Qualitative data collection process

Selection of interview participants

The study interviewed 16 participants, comprising 8 coffee farmers with at least 10 years of experience and 8 local or regional officials involved in coffee production management. Each selected research area included two farmers and one local official (see Appendix 1A). The sampling method employed a purposive sampling approach combined with snowball sampling, as Hong et al. (2012) and Yin (1994) recommended. This approach ensures that interviewees possess extensive knowledge about coffee production and can provide valuable insights into the realities of sustainable coffee farming. Snowball sampling further aids in expanding the interview pool by allowing initial participants to recommend additional suitable interviewees.

Planning and approach to interviews

Before conducting interviews, the researcher undertook preparatory steps to optimize the data collection process and ensure the quality of information obtained:

Defining interview objectives: The questions explored farmers' perspectives on sustainable coffee production, challenges, and how they adapt to climate change, market fluctuations, and management policies. For local officials, the interview focused on support policies, administrative difficulties, and sustainable coffee development strategies. At the same time, confirm the survey questionnaire.

Compiling a list of interviewees: Participants were identified through recommendations from coffee industry experts, cooperatives, and local authorities.

Scheduling interviews: Participants were contacted in advance via phone or email to arrange interview appointments. During this initial contact, the researcher introduced the study's objectives and explained data confidentiality to build trust and encourage participation.

Conducting interviews

The interviews were conducted in two formats: (1) In-person interviews, Held conveniently for participants at their homes or coffee farms. Interviewing in person allowed the researcher to observe production activities firsthand, assess body language, and ask follow-up questions when necessary; (2) Online interviews: For cases where in-person meetings were not feasible due to constraints such as the COVID-19 pandemic or participants' tight schedules, interviews were conducted via phone or digital platforms like Zoom. This approach ensured flexibility while maintaining research progress.

Each interview lasted approximately 45 to 60 minutes. Before starting, the researcher reiterated the confidentiality of the information and requested permission to record the interview for accurate documentation. If a participant declined to be recorded, detailed notes were taken to ensure no critical data was lost. Additionally, the interviews followed a semi-structured format, meaning that while pre-prepared questions guided the discussion, flexibility was maintained to adjust the questions based on respondents' answers. According to Gruber et al. (2008), using a semi-structured approach ensures coherence in interview content while allowing participants to express their views naturally. Following the completion of each interview, a summary of the discussion was sent to the participant within one week for verification or additional input. This step enhanced data accuracy and maintained transparency throughout the research process.

Qualitative data processing and analysis

Once the data collection phase was completed, the researcher conducted data analysis using the content-coding method proposed by Braun & Clarke (2006). This process involved reviewing notes and audio recordings to identify key themes, then categorize information into relevant topics such as sustainable production, policy impacts, climate change challenges, production costs, and other influential factors in coffee farming. The study continued to review comments on the questionnaire to ensure a detailed understanding of the input factors that should be captured in the

survey. The collected data was processed using Microsoft Word and Excel, facilitating systematic organization and analysis. Additionally, the study applied the case study analysis method Yin (1994) suggested. Hong et al. (2012) compare data across different participant groups, highlighting similarities and differences in perspectives between coffee farmers and local officials regarding sustainable coffee production.

3.2.2. Quantitative methods

Data envelopment analysis (DEA) and stochastic frontier analysis (SFA) are currently popular approaches in the existing literature to quantify production efficiency. DEA was initially proposed as a non-parametric approach to mathematical programming by Charnes et al. (1978). It has the advantage of transforming inputs into several outputs. When inputs and outputs have different units of measurement that may be used to quantify them, this method is highly productive. DEA is frequently employed due to its efficiency and less dependence on the input-output relationship. The data envelope analysis (DEA) is often used to study production efficiency (Dutta et al., 2022). The DEA method has been widely accepted to measure performance across different fields. It was created by Charnes et al. (1978). However, the DEA method has high sensitivity. It is subject to errors because it neither removes confounding effects from the production frontier nor simultaneously evaluates and analyzes the efficiency, effects, and factors on the efficiency level in the same period.

Moreover, Nguyen & Pham (2020) argued that the stochastic frontier analysis (SFA) model estimates higher efficiency points and less significant variability than the DEA model. To avoid some shortcomings when using the DEA method, some researchers use SFA as an alternative method to gauge production efficiency (Battese & Coelli, 1995). The advantages of SFA have been widely applied in recent research. It evaluates the effectiveness of agricultural production technology in several countries. SFA is a methodological parametric approach that uses econometric models for analysis. Specifically, SFA was used in the study of Rahman et al. (2012) to assess the TE of rice production in Bangladesh. In Nepal, Mishra et al. (2018) used SFA to assess and evaluate the TE of rice-producing families in rural and urban locations. Huynh et al. (2011) also used SFA to evaluate the TE of rice growers in Vietnam. Essentially, all studies using the SFA method to justify the environmental performance of agricultural production are based on the assessment of the use of production inputs (including standard inputs such as labor and capital), environmental hazards (such as fertilizer, pesticides, etc.), and other factors of production. It proposes solutions to effectively use input factors to limit redundant factors adversely affecting the environment.

In this study, the author employs the SFA approach (Coelli, 1996) through a sample set of sustainable and unsustainable coffee farmers to produce maximum probability estimates for a subset of stochastic marginal production and cost functions. The following is a description of the stochastic frontier production function utilized to calculate the overall yield of coffee farmers:

$$\ln(y_i) = \beta_0 + \sum \beta_j \ln(\text{Independent variables}_{ij}) + v_i - u_i, i = 1, 2, \dots, n \quad (3)$$

In which y_i denotes coffee yield (tons per hectare); independent variables x_{ij} ($j = 1, \dots, 16$) are the input independent variables, including Farm size (FS), Organic fertilizer (OGF), Inorganic fertilizer (INO), Herbicide (HER), Pesticide (PES), Irrigation water (IRW), and Labor costs (LBP).

v_i is the model's independent, uniform, and symmetric random error ($V_i \sim N[0, \delta_v^2]$) representing noise effects beyond the household's control, such as weather, chance, other statistical errors, etc. u_i is an independent unexpected error that follows a half-normal distribution ($U_i \geq 0$). ($U_i \sim N^+[0, \delta_u^2]$) represents the technical inefficiency of the production model. Kalirajan (1981) and Pitt & Lee (1981) suggest that inefficiencies are partly caused by the mismatch between the model boundaries used to predict inefficiencies and the production technology boundaries typically utilized across sectors. Using mixed data to approximate the stochastic marginal production function, Battese & Coelli (1995) improve the model to evaluate variables that impact inefficiencies. The mean of the factors influencing underperformance is linearly linked to the observed variable in the presence of a known truncated constant variance normal distribution. The model facilitates the calculation of random boundaries of technical change and TE over time.

In terms of inefficiency, it is formulated from the difference between the natural levels of productivity (Y_i) and its maximum feasible yield value ($Y_{i\max}$) as determined by the stochastic frontier production function, namely, $\max(Y_i - Y_{i\max})$. If $u_i = 0$, the household's production activity is on the frontier. This means that maximum productivity is achieved using the available production components. If $u_i > 0$, the household's production activity is below the frontier, representing $Y_i < Y_{i\max}$, and the difference between Y_i and $Y_{i\max}$ is the inefficient component in which the higher this coefficient, the less technically efficient it becomes (Coelli et al., 2005). Based on the ratio of the measured yield to the appropriate marginal productivity, a farmer's TE in production is determined via this function:

$$IEE = \frac{F(x_{ij})\exp(v_i - u_i)}{f(x_{ij})\exp(v_i)} = \exp(-u_i) \quad (4)$$

Then, u_i is a technical inefficiency function that illustrates the elements influencing technological inefficiency. As a result, the negative sign of the predicted coefficient in the technical inefficiency function is interpreted as being positively connected to technical efficiency. The inefficient function is as per hereunder function:

$$u_i = \alpha_0 + \sum_{j=1}^k \alpha_j W_{ij} + \xi_i \quad (5)$$

W_{ij} represents the factors affecting technical inefficiencies (farm household characteristics, production model characteristics, etc.); ξ_i is the error value representing factors outside the model. However, the underperformance estimate u_i in equation (2) is often complex and cannot be separated from the random effects v_i . According to Maddala & Singh (1977), the mean and the overall variance of u separated from v are estimated by:

$$E(u) = \delta_u \sqrt{\frac{2}{\pi}} \quad \text{Var}(u) = \delta_u^2 (\pi - 2)/\pi \quad (6)$$

Jondrow et al. (1982) present a way to calculate efficiency that excludes randomness. The assumption is that the u_i of each observation is calculated by the conditional distribution of u_i for a given e_i . With a given standard distribution v_i and a semi-normal of u_i , the expectation of the level of inefficiency for each farm u_i for a given e_i is: $E\left(\frac{u_j}{e_j}\right) = \delta \left[\frac{f(\cdot)}{1-F(\cdot)} - \frac{\lambda e_j}{\delta} \right]$ (7)

In which, $\delta^2 = \delta_u^2 \delta_v^2 / \delta^2$, $\lambda = \frac{\delta_u}{\delta_v}$, $\delta = \sqrt{\delta_u^2 + \delta_v^2}$, $f(\cdot)$ and $F(\cdot)$ is the standard density distribution function and the cumulative probability, respectively, at $\frac{\lambda e_j}{\delta}$. According to Battese & Coelli (1992), the ratio of variance $\lambda = \left(\frac{\delta_u^2}{\delta^2}\right)$ is generally within the range of 0 to 1, and it explains which part of the error affects and changes the actual productivity or profit relative to maximum productivity or profit. If the ratio of variance λ approaches 1, the inefficiency is mainly due to the influence of factors that farmers can control. If λ comes 0, the inefficiency of the household is primarily because of the impact of random factors.

In this study, we have the following formula:

$$|U_i| = \delta_0 + \delta_1 \text{Independent} + W_i \quad (8)$$

In which Independent are the specific variables of Age (AGE), Ethnicity (ETH), Experience (YLA), Variety (VAR), Education level (EDU), Distance from Farm to City (DIS), Intercrop (ITC), Applying advanced methods (AAM), Training on land reclamation (TLR). The author uses multivariate regression in his research on the influence of variables on the total coffee crop.

Researchers worldwide, including those in Vietnam, employ the variable regression with the Ordinary Least Square (OLS) model to examine the connection between independent and dependent variables. This approach is often utilized since it is perceived as a traditional principle of straightforwardness and reliability.

The external factors that influence the coffee production yield are as follows:

$$Y_i = \alpha_0 + \alpha_1 q_1 + \alpha_2 q_2 + \dots + \alpha_6 q_6 + v_i \quad (9)$$

In which q_i is the specific variables of the real estate price (PRE - primary independent variable, million/m²), Total value of coffee exports (EXP - primary independent variable, million tons), Average production (AVY, million tons/hectare), inflation rate (INF, %) and the control is farm size (FS, hectares).

3.3. Data

Secondary data is collected from some agencies in Vietnam, including the General Statistics Office, the Ministry of Agriculture and Rural Development, the Department of Agriculture and Rural Development, online newspapers, the Vietnam Coffee and Cocoa Association, and other sources. Questionnairing is deployed to gather primary data from 1,500 households in coffee cultivation across four provinces by formal questionnaire: Lam Dong, Dak Lak, Dak Nong, and Gia Lai. It covers data on production resources, coffee cultivation practices, production costs, product consumption patterns, access to information and services, and credit utilization.

Furthermore, the author interviewed one official from each locality (four officials representing four regions were interviewed) to gain more insight into supporting farmers to improve the quality of their operations. Before being used for research purposes, the data were refined to eliminate unreliable or incomplete records, and essential data were coded and recalculated before being used in the research.

The data is separated into two groups: Group 1 consists of farmers with sustainability certification, whereas Group 2 consists of farmers with sustainability non-certification.

The author uses the G-power tool to find the minimum sample for the study. With the assumption of 2 groups, the power ($1 - \beta$ err prob.) = 0.95, α err prob. = 0.05, and the effect size $f = 0.2294$ (calculated through the variance with direct 0.05), the result is a total sample size of 250. The author conducted a survey of 1,500 houses in four provinces. After surveying and collecting the results, the results were 846/1500 valid questions; households that grow conventional trees have 564 surveys, and families that grow trees sustainably have 282 surveys.

4. SUMMARY OF THE COFFEE SITUATION IN VIETNAM AND RESEARCH RESULTS

4.1. Result of qualitative

This qualitative study was conducted to gain a deeper understanding of coffee farmers' challenges and opportunities and to analyze the advantages and disadvantages of adopting sustainable practices in coffee production. At the same time, the draft questionnaire was confirmed before finalizing it for a final questionnaire to serve the quantitative study.

The research method was based on interviews with 16 participants, including eight farmers with at least 10 years of experience in coffee growing and eight local officials with experience years. The interviews were conducted in person (mostly face-to-face) and by telephone (mainly by telephone to confirm information) to ensure adequate information collection in different situations. Below are the study results and critical information obtained from the interviews.

Each farmer participating in the study had at least 10 years of experience in coffee growing, indicating that they had accumulated a lot of knowledge and experience in farm management. The size of the farms of these farmers varied from a few hectares to more than 10 hectares. Most farmers grew Robusta coffee as the climate and geographical conditions were more suitable for this variety. However, land with suitable altitudes was used to grow Arabica coffee, although the area planted for Arabica coffee was insignificant. Notably, the farmers interviewed said they did not intend to switch to using new coffee varieties because the application of new varieties required a long waiting time and affected the economic efficiency of the farm. Therefore, they mainly used old coffee and high-yielding varieties that were familiar with the care and production methods. In addition, many farmers said that they grew coffee together with other fruit trees, such as avocado, durian, macadamia, passion fruit, and pepper trees, to increase land value and minimize risks due to fluctuations in the coffee market. Some households have from 50 to 500 macadamia trees or 20 to 300 durian trees, depending on each family's size and land conditions.

- *Regarding climate and geographical conditions affecting coffee production:*

Climate conditions are an important factor affecting coffee productivity and quality. Farmers and agricultural officials in the province shared that last year's weather had significant changes, especially during the long hot season, leading to a severe water shortage for coffee plants. This reduced productivity and affected the health of the plants. However, in the 2021-2022 crop season, the weather was more favorable when the rainy season came early, helping to provide enough water for the plants throughout the season. However, the problem of heavy rain during harvest time seriously affected the quality of coffee, as heavy rain made it difficult to harvest and dry coffee, especially in provinces such as Gia Lai, Kon Tum, and Dak Lak.

In addition to climate issues, the terrain in coffee-growing areas, especially in the Central Highlands, also faced many difficulties. The mountainous terrain, rugged terrain, and the coffee-growing regions located far from the city center make it very

difficult to transport materials and harvest coffee. This not only affects production costs but also reduces the value of the product when it is brought to the market.

- *Regarding coffee growing methods and fertilizer use*

In coffee production, many farmers have switched to organic methods, using organic fertilizers and minimizing the use of inorganic fertilizers to meet the requirements of sustainable certification. Some farmers have applied this method for a long time and reported results in improving soil fertility and coffee growth. However, Mr. Tho and Ms. Hoa affirmed that not all farmers succeed with this method. Some coffee growers said yields may decrease when using organic fertilizers because this method requires time for the soil to recover and increase nutrients.

Farmers who have just started applying organic methods said they have not seen a clear yield improvement and are concerned about the investment costs in organic coffee production. Although organic coffee prices may be slightly higher than conventional coffee, they are worried that as more farmers adopt this method, the selling price will not be as attractive as initially expected. Six out of eight farmers interviewed expressed concern about whether they can maintain a stable income from selling organic coffee in the future, as their living expenses depend mainly on the profit from coffee production.

- *Challenges that farmers have faced in coffee production:*

The significant challenges coffee farmers face in the production process include climate change, pests and diseases, and fluctuations in coffee prices. Climate change has complicated coffee growing conditions, with heavy rains affecting coffee harvesting and processing. Pests and diseases are also important factors in reducing coffee yield and quality. Farmers shared that they have to deal with many types of pests, such as fungi, aphids, and caterpillars, which affect the growth of coffee plants.

Another problem is that coffee prices fluctuate considerably, making it difficult for farmers to maintain stable profits. The fact that coffee has to go through many intermediaries reduces the actual value of coffee, and farmers do not receive a price commensurate with their efforts. In addition, input costs such as fertilizer, fuel, and labor are all increasing, reducing farmers' ability to invest in coffee production. This puts pressure on farmers to maintain production and achieve sustainable profits.

- *Sustainable management in coffee production:*

According to Mr. Hung, Thien, and Chinh, many farmers have sought to protect the environment and maintain sustainability in production to cope with the challenges in coffee production. Farmers apply measures such as using organic fertilizers, protecting biodiversity, and keeping the balance of the ecosystem. Farmers also focus on improving coffee productivity and quality through reasonable irrigation and effective pest control.

Some farmers cooperate with social organizations and participate in support programs to achieve sustainability certification. However, agricultural officials and farmers interviewed also admitted that attaining this certification is complicated and requires much effort, time, and resources. In addition, having enough resources and support from authorities is also an important factor to help them achieve this goal.

Officials representing the provinces all shared the view that there should be a plan for coffee production development to expand the area and improve the quality of the products. Some farmers interviewed said they planned to contact and cooperate with certification organizations within the radius of the households they knew to participate in the production monitoring process. From there, these households could increase the value of their coffee, achieve certification, and improve their income. However, they also faced significant pressure from production output, price fluctuations, and the situation of many intermediaries in the supply chain. They hoped that the local government would have appropriate solutions to reduce the number of intermediaries and increase the value of their products. Local officials also expressed their maximum support for people in the province to achieve sustainable certification to improve their quality of life.

- *Advice for beginner coffee growers:*

Farmers who participated in the study advised those new to coffee growing to thoroughly understand the growing process and how to cope with climate change. They stressed that coffee growing is not a simple job and requires financial and time investment. In addition, with the current trend towards organic coffee, farmers advised those without certification to participate in support programs to achieve sustainability certification.

- *Feedback on the survey questionnaire:*

In addition to studying coffee-growing households' advantages, difficulties, and challenges, the author also asked for opinions on the survey questionnaire. This survey is different from other qualitative studies. The author did not use the Likert scale but wanted to use this survey to obtain specific numbers on input and output materials. The results after consulting with eight farming households and eight officials representing four provinces are as follows:

All interviewees said that the questionnaire was too detailed and complete, but 7/8 farming households said that they could not fully answer the information requested by the questionnaire. Local officials also expressed their uncertainty about whether the households participating in the survey could fully complete all the questions because most people in the area do not record detailed input materials over many crops like that. Therefore, they suggested that the author reduce the number of seasons in the survey from 5 seasons to 3 seasons. Besides, they are not good at technology and are not familiar with filling in information via digital platforms to store complete details. Some opinions pointed out that sending questionnaires via email links may not be effective. Farmers do not have enough time and technology skills to answer via links. Instead, the author should go directly to households to collect information on the best option. Farmers said going directly will help get more accurate information and build better trust in data collection.

From there, the author adjusted the seasons (from 5 to 3 seasons) to ensure a more significant number of valid surveys and more accurate information because the longer the season, the lower the possibility of recording accurate information. In addition, some phrases in the questions were adjusted to make them easier to understand and

suitable for the educational level of the provinces participating in the study. The complete questionnaire used for the formal survey is detailed in Appendix 1C.

4.2. Demographic characteristics

In this study, the author surveyed 1,500 coffee-farming households across four provinces: Lam Dong, Dak Lak, Dak Nong, and Gia Lai. A total of 846 valid questionnaires were obtained, with 564 reflecting households that have not attained certification and 282 responses indicating households that have successfully received certification.

First, the author classified the demographic characteristics of coffee-growing households according to each province and city, as shown in the table:

Table 4.1: Summary of demographic characteristics in the study areas

			Province			
			Lam Dong	Dak Nong	Dak Lak	Gia Lai
Number of farms			300	127	202	217
Age	Min		35	31	28	29
	Max		77	78	83	86
	Mean		56	55	54	56
Ethnicity	Other	No.	17	0	6	2
		%	2.0%	0.0%	0.7%	0.2%
	Kinh	No.	283	127	196	215
		%	33.5%	15.0%	23.2%	25.4%
Gender	Female	No.	17	12	15	7
		%	2.0%	1.4%	1.8%	0.8%
	Male	No.	283	115	187	210
		%	33.5%	13.6%	22.1%	24.8%
Education	None	No.	3	0	0	1
		%	0.4%	0.0%	0.0%	0.1%
	Elementary	No.	0	0	0	0
		%	0.0%	0.0%	0.0%	0.0%
	Junior high school	No.	87	18	59	128
		%	10.3%	2.1%	7.0%	15.1%
	High school	No.	161	85	106	74
		%	19.0%	10.0%	12.5%	8.7%
University	No.	49	24	37	14	
	%	5.8%	2.8%	4.4%	1.7%	

Source: Computed by SPSS

Looking at the age of coffee producers provides a comprehensive picture of the age distribution in the agricultural sector. Data collected from 361 coffee-producing households indicate that their ages ranged from 28 to 86 years, with an average age of 55.63. This reflects the general characteristics of Vietnam’s agricultural sector, where most of the workforce is middle-aged or elderly. There is no significant variation in the average age distribution of farmers across coffee-growing provinces. However, some notable specific characteristics were noted. Dak Lak, one of the largest coffee production centers, has the youngest average age of 54.

Meanwhile, Lam Dong and Gia Lai, two important coffee sector provinces, have slightly older average ages. This may reflect differences in economic, cultural, and social factors between provinces, affecting the inheritance and transfer of agricultural activities from the younger generation. When analyzed further, it can be seen that the majority age group in the coffee industry is between 50 and under 60 years old, accounting for 42.67% of the total number of households. This is the core workforce with long-term experience and knowledge in coffee farming. The second largest group is those over 60, accounting for 31.91%. This means that there is a notable issue: the aging of the agricultural workforce. The limited presence of the group under 40 years old, accounting for only 3.2%, further highlights the risk of a shortage of young successor workers. This age structure raises many questions about the long-term sustainability of the coffee production industry. With many middle-aged and elderly farmers, the coffee industry may face risks in transferring knowledge and farming experience to the next generation. In addition, the low proportion of young workers suggests that the industry is not very attractive to young people, possibly due to unstable income, harsh working conditions, or the tendency to migrate to the city for other career opportunities. (See Figure 4.1 for details on the age distribution of coffee-producing households.)

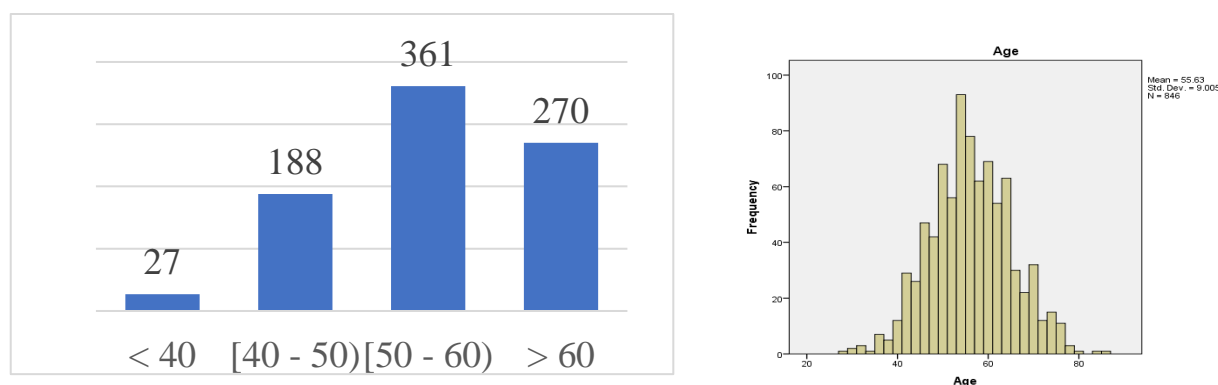


Fig. 4.1: The age group and distribution of farm owners.
 Source: The author’s works and computed by SPSS

In Vietnam, the Central Highlands are the region typified by the highest degree of ethnic demography in the country; however, in the author's study, the number of Kinh households accounts for the majority in the examined provinces. Specifically, Lam Dong has 283 Kinh households, and 33.5 % of them cultivate coffee. There are merely

17 households representing other ethnic groups, reflecting 2% of the total coffee-growing population. Dak Nong alone has no other ethnic households in the sample study. Notably, most household heads are men due to culture and the physically demanding nature of agricultural work. In the specific case of Lam Dong, the prevalence of male household heads is the most noticeable, numbering 283 farmers. At the same time, female household counterparts in Lam Dong also feature 17 households and represent 2% of the total.

In this study, the author categorized educational attainment into five levels: elementary, junior high, high school, and university. In general, the sample exhibits a humble digit, with the 54.6% majority of household heads hardly finishing highschool. Lam Dong emerges as a province exceptionally distinguished by an elevated educational figure, with 5.8% of household heads holding a university degree. The significance of academic levels extends beyond statistical observations, as it is anticipated to facilitate coffee-growing household owners in accessing and applying innovative methods to enhance coffee cultivation productivity.

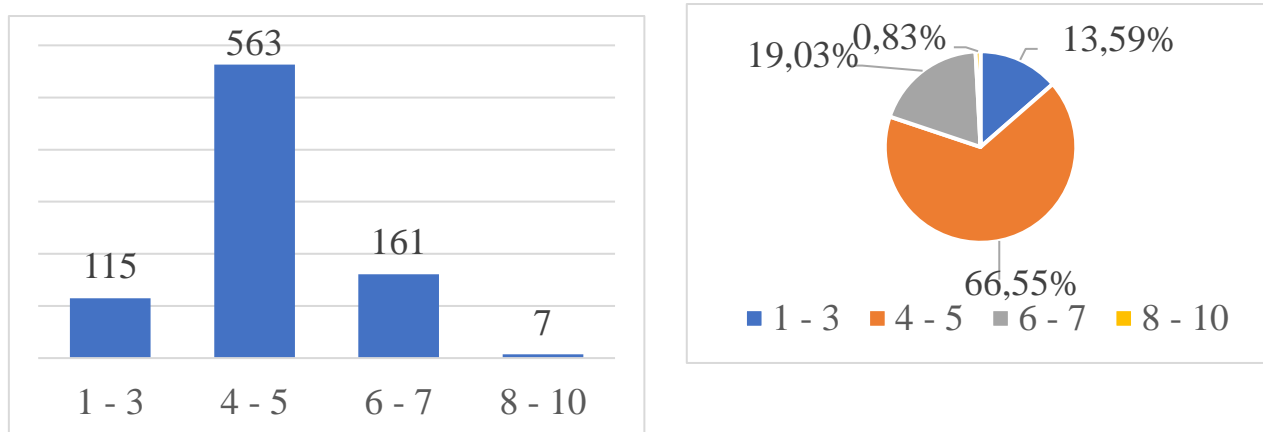


Fig. 4.2: Household size in the research sample.

Source: The author's works

The analysis of family size findings in Vietnam's coffee production demonstrates a clear correlation between the number of family members and the capacity to provide the labor demand in farming activities. The average household size is 4.57, which is typical of coffee-producing regions in poor nations where family work is crucial. The household size distribution shows that more than 66.55% of households have 4 to 5 people, while the group of households with 5 to 7 people accounts for 19.03%. This distribution shows the suitability of moderate family size in meeting the labor demand in different stages of production. Households with 4 to 5 people can utilize internal labor effectively, reducing dependence on outsourced labor. This is particularly important in coffee production, where farming activities, from crop care to harvesting, require regular and focused involvement. Larger households, with five to seven members, can better cope with labor-intensive periods such as harvesting but may face

challenges in allocating work without proper organization. Conversely, smaller households with fewer than four members may face labor resource constraints, forcing them to outsource during peak periods. This increases production costs and can impact overall efficiency, especially when labor costs are disproportionate to the returns on coffee production.

4.3. Economic characteristics of coffee farming

Among the farmer households selected as a sample, 66.66% of coffee farming households have yet to obtain any sustainability certification. In contrast, a minority of 33.33% of households have successfully achieved such accreditation. The Specialty Coffee Association (SCA) identifies six types of certification related to sustainable coffee, embracing organic, fair trade certified (fair trade), rainforest alliance (rainforest alliance), Smithsonian Bird Friendly, UTZ certified (UTZ), and 4C Common Code (4C). Each certification corresponds to a specific set of objectives. Specifically, UTZ positions to establish a sustainable agricultural supply chain, 4C aspires to attain global leadership in innovation while enhancing production and processing conditions, and Rainforest Alliance seeks to integrate diverse conservation biology practices. Within the study context of the four research provinces, the author found that 4C, Fair Trade, Rain Forest, and UTZ are the predominant sustainable programs, with the highest prevalence observed in 4C certification, with 244 households achieving it, followed by UTZ with 31 households. A finite number of households attain Fair Trade and Rain Forest certifications. Lam Dong soars as the region with the most certifications among the four provinces, mainly 4C and UTZ certificates. Meanwhile, Gia Lai secured the second-highest rank with 99 certified households.

Table 4.2: Status of achieving sustainable certification by provinces

Name of certificate	LamDong		DakNong		DakLak		GiaLai		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
4C	101	41.39%	6	2.46%	42	17.21%	95	38.93%	244	86.52%
Fair Trade	0	0.00%	0	0.00%	1	100%	0	0.00%	1	0.35%
Rainforest	2	50.00%	0	0.00%	0	0.00%	2	50.00%	4	1.42%
UTZ	28	90.32%	1	3.23%	0	0.00%	2	6.45%	31	10.99%
4C, UTZ	2	100%	0	0.00%	0	0.00%	0	0.00%	2	0.71%

Source: computed by SPSS

Based on data on certified households obtained in 3 crop seasons (2019–2020, 2020–2021, and 2021–2022), certification rates remained unchanged during COVID-19 due to delays in validating and assessing processes for certification. Notably, there was a significant increase in certified households after the COVID-19 pandemic, specifically from 222 households in the 2020–2021 crop year to 282 households in

the 2021–2022 crop year. This shift underscores the coffee farmers' commitment to augment productivity and foster sustainable coffee development, with the two parallel objectives of demanding higher selling prices and producing premium agricultural products. Such efforts contribute remarkably to enhancing the prominence of Vietnamese coffee and enabling its entrance into demanding markets.

Table 4.3: Productivity over three seasons in the studied provinces

	LamDong		DakNong		DakLak		GiaLai	
	Non-cer	Cer	Non-cer	Cer	Non-cer	Cer	Non-cer	Cer
2019-2020	194	106	121	6	165	37	143	74
2020-2021	194	106	121	6	165	37	143	74
2021-2022	167	229	120	7	159	43	118	99

Source: computed by SPSS

Regarding production output, during the 2021–2022 crop, the aggregated output from the surveyed households amounted to 8,124.2 tons of unprocessed green coffee. A substantial contribution to this result derives from certified households, yielding 5,022.5 tons of raw material, constituting 61.82%. The output spectrum displayed significant variability, ranging from 0.8 to 136.3 tons per crop. Within this range, the households in Lam Dong Province stand out as the highest producers, yielding 136.3 tons per crop, whereas the households in Dak Lak show the lowest output at 0.8 tons per crop. A regional analysis highlights the Gia Lai area as having the highest average output, totaling 12.5 tons per season. Noteworthy, the apex of average dried coffee bean output for the 2021–2022 season was observed among certified households, notably in Gia Lai with 19.1 tons/crop, Dak Nong with 18.9 tons/crop, and Lam Dong with 18.3 tons/crop. Conversely, households lacking certification demonstrated a comparatively diminished output compared to their certified counterparts.

The findings originate from the table underscore a notable prevalence of households producing less than 10 tons per crop. This is particularly evident in the Lam Dong area, where 184 households display this characteristic, comprising 152 certified and 32 uncertified households—Dak Lak portrays closely in this pattern. In contrast, only three areas—Lam Dong, Dak Lak, and Gia Lai—attain an output exceeding 50 tons, represented by 4 certified households in Lam Dong, 1 certified household in Dak Lak, and four certified households in Gia Lai. This remark accentuates the exclusive occurrence of high-output households among those with existing certification.

Table 4.4: Descriptive statistics of productivity in the studied provinces

	Lam Dong		Dak Nong		Dak Lak		Gia Lai	
	Non-cer	Cer	Non-cer	Cer	Non-cer	Cer	Non-cer	Cer
Total output (tons)	891	2,438	673.9	132.2	723.3	557.7	813.5	1,894.6

Mean	5.3	18.3	5.6	18.9	4.5	13.0	6.9	19.1
Std.	3.2	14.9	3.5	9.1	2.0	9.9	5.0	15.9
Min	1.4	4.1	1.2	9.3	0.8	3.8	2	0.9
Max	21.5	236.3	20	35.4	12.5	63.8	43	95.7
Average (Tons)	11.1		6.3		6.3		12.5	
Number of hold house								
< 10 (tons)	152	32	106	1	155	19	104	25
10 < x < 20 (tons)	14	66	13	3	4	16	11	47
20 < x < 50 (tons)	1	31	1	3	0	7	3	23
> 50 (tons)	0	4	0	0	0	1	0	4
Farm size (ha)								
Mean	2.0	2.4	2.3	2.6	1.8	1.6	2.1	1.9
Std.	0.9	1.9	1.4	1.3	0.7	1.2	1.2	1.5
Min	1.2	0.7	1.2	1.5	1.2	0.4	1.2	0.5
Max	5.5	16.0	13.0	5.0	4.0	7.0	9.0	10.0

Source: computed by SPSS

The analysis of cultivated land area is an important factor in explaining the increased green coffee yields observed in households with sustainability certification. The study results indicate that these households own large land areas and actively participate in coffee production according to established sustainability standards. These standards ensure high-quality products and increase technical efficiency in production, thereby boosting output. Among the surveyed households, some outstanding cases demonstrate a strong association between large land areas and success in achieving sustainability certification. A typical household in Lam Dong province, with a land area of up to 16 hectares, is one of the outstanding examples of making the most of land advantages in sustainable coffee production. Similarly, another household in Gia Lai owns 10 hectares of cultivated land, demonstrating that land size is important in increasing yields and ensuring compliance with certification standards. These households produce high yields and significantly contribute to the coffee industry's sustainable development. Notably, the land sizes of the surveyed households show considerable diversity, ranging from 0.4 hectares to 16 hectares. Although the minor household, 0.4 hectares, is located in Dak Lak, it still shows an effort to apply sustainable practices to optimize productivity on limited land size. This reflects that sustainable production practices depend on land size and how they manage and apply advanced farming techniques. However, the average land holdings between certified and non-certified households did not differ significantly, suggesting that land holdings may not be the sole determinant. Instead, compliance with sustainability standards and efficient use of land resources play a more important role.

The comprehensive analysis in Table 4.4 provides insight into the relationship between land holdings, sustainability certification, and output, highlighting the importance of efficient land resource management in sustainable coffee production.

Table 4.5: Descriptive statistics of input factors in the 2021–2022 crop season.

		Lam Dong		Dak Nong		Dak Lak		Gia Lai	
		Non - Cer	Cer	Non - Cer	Cer	Non - Cer	Cer	Non - Cer	Cer
Irrigation _water	Mean	1,722	1,776	1,759	1,944	1,781	1,692	1,736	1,737
	Max.	2,495	2,481	2,495	2,398	2,485	2,500	2,499	2,497
	Min.	1,015	1,014	1,001	1,084	1,012	1,018	1,021	1,046
	Std.	432	426	417	515	426	425	410	391
Organic fertilizer	Mean	1,930	1,378	2,180	1,376	1,865	1,436	1,842	1,378
	Max.	2,995	1,598	2,999	1,550	2,960	1,597	2,885	1,591
	Min.	604	790	556	890	572	953	557	763
	Std.	422	198	477	224	368	127	353	199
Inorganic	Mean	1,869	1,354	1,894	1,360	1,866	1,366	1,857	1,316
	Max.	2,233	1,650	2,287	1,632	2,270	1,649	2,248	1,641
	Min.	1,273	751	1,170	845	1,018	1,188	1,277	826
	Std.	150	195	177	251	201	131	148	133
Herbicide	Mean	2	2	2	2	2	2	2	2
	Max.	3	3	3	3	3	3	3	3
	Min.	1	2	1	2	1	2	1	2
	Std.	1	1	1	1	1	1	1	1
Pesticide	Mean	2	2	2	2	2	2	2	2
	Max.	3	3	3	3	3	3	3	3
	Min.	1	2	1	2	1	2	1	2
	Std.	1	1	1	1	1	1	1	1
Labor cost	Mean	6,242,156	14,404,211	5,628,667	12,760,000	6,004,780	13,322,791	5,730,847	13,626,667
	Max.	10,240,000	30,800,000	8,960,000	18,480,000	10,240,000	21,560,000	7,680,000	21,560,000
	Min.	2,560,000	6,160,000	1,280,000	9,240,000	2,280,000	6,160,000	2,560,000	6,160,000

	Std.	1,568,136	3,801,608	1,400,035	2,771,185	1,446,150	3,474,296	1,290,117	3,439,070
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Source: Computed by SPSS

Table 4.5 briefly delineates the fundamental input for coffee cultivation, sourced from a comprehensive survey that embraces 846 coffee-growing households across four provinces. These inputs, construed as pivotal factors of production and direct costs, form the crux of the investigation. The author methodically deploys a set of critical variables on one hectare of coffee, such as Irrigation Water, Fertilizer, Pesticide, Herbicide, and Labor Costs. Initially, the mean water utilization for a hectare of coffee per crop is approximately 1,722 m³, varying from 1,001 m³ to 2,500 m³. This average closely aligns with the findings of a research project on groundwater use management in the Central Highlands of Vietnam, funded by the Australian Centre for International Agricultural Research (ACIAR)⁷, which reported a comparable result of about 1,700 m³. Notably, individual coffee trees necessitate around 550 liters of water per irrigation, with irrigation occurring at a 20-day interval and each tree undergoing three watering sessions during the dry season. Specific households exhibit water-saving practices, potentially reducing the average water consumption by 30–40%.

In Dak Nong, irrigation activities show the difference between certified and unproved households. The certified households show the average water consumption of 1944 m³/ha/crop. In contrast, households are not certified to closely reflect this use, with an average of 1,759 m³/ha/crop. This shows that noncertified households use more irrigation water than certified households. Other provinces indicate less perceptible differentials, exemplified by Lam Dong with averages of 1,722 m³ (non-certified) and 1,776 m³ (certified), Dak Lak with averages of 1,781 m³ (non-certified) and 1692 m³ (certified), and Gia Lai with averages of 1,736 m³ (non-certified) and 1,737 m³ (certified). The predominant irrigation methods, tap water and healthy water, have undergone a discernible shift, with tap water emerging as the dominant choice due to the diminishing abundance of healthy water. This scarcity is primarily attributed to climate change-induced alterations, particularly the prolonged hot season adversely impacting water resources in the Central Highlands.

⁷ [https://crawford.anu.edu.au/pdf/staff/jeff_bennett/vietnam/GroundWaterVietnam_\(RB1\)Viet%20Sept08.pdf](https://crawford.anu.edu.au/pdf/staff/jeff_bennett/vietnam/GroundWaterVietnam_(RB1)Viet%20Sept08.pdf)

Additionally, farmers adhere to traditional irrigation practices, predominantly focusing on root-watering techniques. Integrating tap water with advanced irrigation technologies, notably drip irrigation, has proven cost-effective. As Mr. Nguyen Hoai Duong articulated, the region boasts an extensive water infrastructure comprising 607 reservoirs, 117 dams, and 57 pumping stations that cater to the multifaceted requirements of irrigation, agricultural production, and daily life. Several successfully executed projects, including the Ea Sup Thuong Lake, Krong Buk Ha, Ea Nhai, and Ea Kao, have significantly contributed to the region's water management. Despite these commendable efforts, the existing irrigation infrastructure faces challenges in meeting the escalating demands, particularly during the dry season. The insufficiency becomes evident when juxtaposed with the difficulties of crop irrigation. In light of this, the utilization of tap water pivots as a strategic advantage, enabling simultaneous watering and fertilization while optimizing labor and investment capital. Furthermore, the longevity of the tap water-based irrigation system surpasses that of alternative technologies. The prevalence of tap water adoption is peculiarly high in Dak Nong, Dak Lak, and Gia Lai; however, Lam Dong remains reliant on healthy water, indicating a regional disparity in technological uptake. Despite the advancements witnessed in neighboring provinces, this discrepancy underscores the ongoing relevance of traditional well-based irrigation practices in Lam Dong.

In fertilizers, the predominant choices presently include organic and inorganic variants. The historical impact of inorganic fertilizers on heightened crop yields, especially since the green revolution (Chemura, 2014), is indisputable. Farmers utilize inorganic fertilizers, such as NPK (nitrogen, phosphorus, and potassium), alongside the addition of calcium (Ca) and magnesium (Mg) to enhance coffee plant nutrition. Analyzing the data in Table 4.5, it becomes apparent that Dak Nong stands out as the province with the highest reliance on inorganic fertilizers, averaging 2864 kg/hectare/crop. Dak Lak and Lam Dong-Gia Lai follow closely, unveiling minimal disproportion at 1641 kg and 1610 kg, respectively. Scholarly observations by Hoang & Nguyen (2013) emphasize the environmental aftermath of excessive nitrogen and phosphate in inorganic fertilizers, leading to soil and groundwater degradation over time. The resultant acidic and microorganism-depleted soil renders exclusive dependence on inorganic fertilizers unsustainable (Chemura, 2014), contributing to shrinking yields even with consistent usage (Nyalemegbe et al., 2010). In response to this ecological concern, more households are transitioning towards sustainable coffee production, progressively adopting organic fertilizers. The variance in organic fertilizer utilization is remarkable across provinces and certified and non-certified households, ranging from 556 kg to 2,999 kg/hectare/crop. Primary organic fertilizer sources include crop residue, agricultural waste, livestock manure, and similar materials (Dikinya & Mufwanzala, 2010; Satyanarayana et al., 2002). Referencing Table 4.5, certified households in Lam Dong use an average of 1378 kg, whereas non-certified counterparts average 1930 kg/hectare.

Similarly, for Dak Nong, Dak Lak, and Gia Lai, the averages are 2180 kg (non-certificate) to 1376 kg (certificate), 1865 kg (non-certificate) to 1436 kg (certificate),

and 1842 kg (non-certificate) to 1378 kg (certificate). Noteworthy is Lam Dong, which emerged as the leading province in organic fertilizer usage. Kilian et al. (2006) relate sustainable agriculture to reforming traditional farming methods and management systems that yield immediate and enduring benefits for the environment, economy, and society. This division is evident between certified and non-certified households, as the former prioritizes organic fertilizer to foster environmental sustainability and ensure future soil efficacy. Furthermore, Chemura (2014) posits that inorganic fertilizers are more effective in high-water conditions, while organic fertilizers demonstrate superior potency when water levels are limited. With water scarcity and stringent certification requirements, coffee growers progressively shift from inorganic to organic fertilizers. Applying pesticides and herbicides facilitates the augmentation of coffee yield, as Ho (2018) established. An examination of herbicide usage in the four provinces reveals a consistent average of 2 liters per hectare per crop during the 2021–2022 crop season within the surveyed households, with application rates varying between 1 and 3 liters. Correspondingly, pesticide usage exhibits a similar pattern across provinces, with application rates fluctuating between 1 and 3 liters per hectare per crop. Intriguingly, an atypical trend emerges in this study sample, indicating that certified households tend to employ more pesticides and herbicides than their non-certified counterparts. This divergence in usage patterns raises noteworthy implications and warrants further investigation into the factors influencing the differential adoption of pest and weed management practices among certified and non-certified coffee-producing households.

The labor costs associated with the harvesting and maintaining coffee trees exhibit considerable variation across provinces, with Lam Dong province registering the highest average labor cost per hectare or crop at 9,860,667 VND. A closely aligned cost is observed for hybrid cultivation, amounting to 9,333,088 VND. In contrast, Dak Nong and Dak Lak provinces record modest labor costs at 6,021,732 VND and 7,562,574 VND, respectively. The structure of labor costs stretches from 1,280,000 VND to 30,800,000 VND, indicating a significant domain in the financial commitment required for coffee cultivation. However, it is imperative to note that labor costs are highly related to household demographics, particularly the number of individuals within a household. Families with a substantial workforce in the employable age bracket lessen the burden of labor costs associated with coffee cultivation. For instance, despite having the lofty labor cost, Lam Dong is characterized by a relatively large family size. However, a substantial number of family members of school age necessitates outsourcing labor at elevated rates, contributing to the expensive labor costs in the region. This interaction between labor costs and household composition underscores the nuance influencing the economic aspects of coffee cultivation across provinces.

The current survey, governing 846 households across four provinces, depicts the prevalence of three distinct coffee varieties: old, high-yield, and new. In addition, the preponderance of households in the research sample opt for old varieties, constituting 77.19% of the total (Lam Dong: 25.41%, Dak Nong: 12.29%, Dak Lak: 19.62%, and

Gia Lai: 19.86%). Conversely, cultivating high-yield varieties is limited, comprising a mere 3.55% of the total. While some households experiment with adopting new varieties, the overall adoption rate remains modest at 19.27%. Interestingly, households lacking certification are more inclined to experiment with new varieties than their certified counterparts. For instance, in Dak Nong, the utilization of new varieties is strikingly higher among non-certified households, with 19 households compared to the two accredited households engaging in such experimentation. This disparity underscores the visible influence of certification status on the willingness of households to explore and incorporate novel coffee varieties into their cultivation practices.

Intercropping in coffee cultivation has gained popularity, supported by findings from Kufa et al. (2001), underlining the benefits of combining coffee with avocado for coffee plants' shading effect. Alemu & Dufera (2017) further emphasize the advantages of intercropping bananas with coffee, elucidating the role of bananas in offering shade, controlling evaporation during droughts, and exhibiting less demand for water compared to other shade trees. Intercropping not only aids in mitigating soil erosion but also ensures continuous ground cover. In-depth interviews with local officials augmented the understanding of prevalent intercropping crops among farmers in the provinces, revealing common choices such as persimmon, macadamia, durian, jackfruit, pepper, avocado, grapefruit, and lemon. Notably, durian and macadamia emerge as the preferred intercropping options, with the number of intercropped trees varying between 20 and 300 for durian and 50 to 500 for macadamia, contingent upon individual farmer preferences. Despite the potential advantages of intercropping, not all coffee-growing households engage in this practice. Those abstaining may encounter disadvantages, including a reduction in the scope and number of coffee trees. Notably, smaller plots pose challenges to intercropping, primarily when coffee is the primary crop. The survey data indicates that only 44.44% of households participate in intercropping, with Dak Lak exhibiting the highest intercropping rate at 19.74% (167 out of 296 households).

In contrast, Lam Dong has a modest 6.74% of households practicing intercropping, Dak Nong 5.91%, and Gia Lai 12.06%. A substantial portion, constituting 55.56% or 470 households, abstain from intercropping. Additionally, the adoption of advanced methods in coffee production is not widespread across all four provinces, with only 48.35% (409 out of 846) of households applying these techniques. Certified households exhibit a greater propensity for advanced methods, while non-certified households display hesitancy. For instance, 129 certified households employ advanced methods in Lam Dong compared to 54 non-certified households. Similar patterns are observed in Dak Lak (41 certified vs. 32 non-certified households) and Gia Lai (99 certified vs. 27 non-certified households). However, Dak Nong presents a deviation, with a higher application rate among non-certified households, comprising 21 compared to 6 certified households. Finally, it is noteworthy that participation in land reclamation training among coffee-growing households is an integral aspect of agricultural practices. This engagement underscores acquiring

knowledge and skills related to sustainable land use and cultivation practices. Lam Dong and Gia Lai demonstrate a higher incidence of certified households engaging in training sessions than their non-certified counterparts, with participation rates of 133 out of 71 households and 99 out of 65 households, respectively. Contrarily, Dak Nong and Dak Lak present an inverse trend. Nevertheless, the aggregate participation rate in land reclamation training among coffee-growing households is substantial, reaching 72.93%. This statistic spotlights coffee growers' widespread commitment to participate in educational initiatives focused on sustainable land management practices despite variances in participation rates and certification status across specific provinces.

Table 4.6: Descriptive statistics of factors affecting production efficiency in the 2021-2022 season

		Lam Dong				Dak Nong				Dak Lak				Gia Lai			
		Non - Cer		Cer		Non - Cer		Cer		Non - Cer		Cer		Non - Cer		Cer	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Variety	Old	113	13.36%	102	12.06%	99	11.70%	5	0.59%	127	15.01%	39	4.61%	91	10.76%	77	9.10%
	Cao san	6	0.71%	8	0.95%	2	0.24%	0	0.00%	1	0.12%	1	0.12%	8	0.95%	4	0.47%
	New	48	5.67%	23	2.72%	19	2.25%	2	0.24%	31	3.66%	3	0.35%	19	2.25%	18	2.13%
Intercrop	No	145	17.14%	98	11.58%	74	8.75%	3	0.35%	24	2.84%	11	1.30%	67	7.92%	48	5.67%
	Yes	22	2.60%	35	4.14%	46	5.44%	4	0.47%	135	15.96%	32	3.78%	51	6.03%	51	6.03%
AAM	No	113	13.36%	4	0.47%	99	11.70%	1	0.12%	127	15.01%	2	0.24%	91	10.76%	0	0.00%
	Yes	54	6.38%	129	15.25%	21	2.48%	6	0.71%	32	3.78%	41	4.85%	27	3.19%	99	11.70%
TLR	No	96	11.35%	0	0.00%	59	6.97%	0	0.00%	21	2.48%	0	0.00%	53	6.26%	0	0.00%
	Yes	71	8.39%	133	15.72%	61	7.21%	7	0.83%	138	16.31%	43	5.08%	65	7.68%	99	11.70%

Source: Computed by SPSS

4.4. Test the factors

It is necessary to confirm that there are no multicollinearity issues or other issues affecting the study findings for the variables in the model to satisfy the correlation criteria. In response, the writer conducted several tests.

4.4.1. Test the correlation between variables.

The author evaluated the correlation between variables using the Pearson correlation coefficient test. The Pearson correlation coefficient, represented by the letter r , is frequently used in statistical analysis to measure the degree of a linear relationship between two quantitative variables, as Gayen (1951) pointed out. It is crucial to remember that the Pearson correlation analysis is inappropriate if one or both variables are not quantitative (for example, by being binary or qualitative). Consequently, the author exclusively conducted correlation analysis for quantitative variables, with the findings outlined in Table 4.7.

Table 4.7: Correlation system between variables

Correlations												
		OPU	FS	IRW	OGF	INO	HER	PES	LBP	AGE	YLA	DIS
OPU	Pearson Correlation	1	0.684**	0.008	-0.303**	-0.401**	0.041	0.068*	0.540**	0.050	0.104**	-0.096**
	Sig. (2-tailed)		0.000	0.814	0.000	0.000	0.232	0.047	0.000	0.149	0.003	0.005
FS	Pearson Correlation	0.684**	1	0.034	0.022	0.050	0.002	-0.016	0.124**	0.074*	0.029	0.022
	Sig. (2-tailed)	0.000		0.326	0.523	0.147	0.964	0.648	0.000	0.032	0.403	0.528
	N	846	846	846	846	846	846	846	846	846	846	846
IRW	Pearson Correlation	0.008	0.034	1	0.057	0.006	0.003	0.039	0.010	0.009	0.000	0.002
	Sig. (2-tailed)	0.814	0.326		0.096	0.867	0.938	0.263	0.770	0.796	1.000	0.950
OGF	Pearson Correlation	-0.303**	0.022	0.057	1	0.689**	-0.085*	-0.061	-0.490**	-0.087*	-0.142**	0.193**
	Sig. (2-tailed)	0.000	0.523	0.096		0.000	0.014	0.076	0.000	0.012	0.000	0.000
INO	Pearson Correlation	-0.401**	0.050	0.006	0.689**	1	-0.115**	-0.122**	-0.663**	0.023	-0.040	0.112**
	Sig. (2-tailed)	0.000	0.147	0.867	0.000		0.001	0.000	0.000	0.502	0.250	0.001
HER	Pearson Correlation	0.041	0.002	0.003	-0.085*	-0.115**	1	-0.018	0.091**	-0.013	0.011	-0.032

	Sig. (2-tailed)	0.232	0.964	0.938	0.014	0.001		0.607	0.008	0.705	0.750	0.359
PES	Pearson Correlation	0.068*	-0.016	0.039	-0.061	-0.122**	-0.018	1	0.064	-0.007	0.014	0.005
	Sig. (2-tailed)	0.047	0.648	0.263	0.076	0.000	0.607		0.062	0.832	0.677	0.895
LBP	Pearson Correlation	0.540**	0.124**	0.010	-0.490**	-0.663**	0.091**	0.064	1	0.054	0.145**	-0.132**
	Sig. (2-tailed)	0.000	0.000	0.770	0.000	0.000	0.008	0.062		0.113	0.000	0.000
AGE	Pearson Correlation	0.050	0.074*	0.009	-0.087*	0.023	-0.013	-0.007	0.054	1	0.115**	-0.011
	Sig. (2-tailed)	0.149	0.032	0.796	0.012	0.502	0.705	0.832	0.113		0.001	0.743
YLA	Pearson Correlation	0.104**	0.029	0.000	-0.142**	-0.040	0.011	0.014	0.145**	0.115**	1	-0.105**
	Sig. (2-tailed)	0.003	0.403	1.000	0.000	0.250	0.750	0.677	0.000	0.001		0.002
DIS	Pearson Correlation	-0.096**	0.022	0.002	0.193**	0.112**	-0.032	0.005	-0.132**	-0.011	-0.105**	1
	Sig. (2-tailed)	0.005	0.528	0.950	0.000	0.001	0.359	0.895	0.000	0.743	0.002	

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Source: Computed by SPSS

Analyzing the study's findings revealed that using Pearson correlation coefficients for investigating at the link between independent and dependent variables produced some amazing results. In this study, the relationship between the independent variables—FS (farm size), OGF (organic fertilizer), INO (inorganic fertilizer), PES (pesticides), LBP (labor cost), YLA (experience growing coffee), DIS (farm-to-city distance), IRW (irrigation water), HER (herbicides), and AGE (age)—and the dependent variable, OPU (output yield), was investigated. The findings demonstrated a significant linear association between the independent variables and the dependent variable, with sig values less than 0.05 for all save IRW, HER, and AGE. There was no discernible relationship between OPU and the IRW, HER, and AGE variables, according to sig values larger than 0.05. This indicates that these factors have a very minor impact on output yield.

In contrast, FS, OGF, and YLA showed significant linear relationships with yield, confirming the important role of farm size, organic fertilizer, and coffee growing experience in improving yield. Another important aspect of analysis was the multicollinearity test between the independent variables. Although multicollinearity is theoretically more likely when two independent variables have a significance level (sig) below 0.05 and an absolute correlation coefficient greater than 0.7 (Dormann et al., 2013), the analysis findings displayed no signs of multicollinearity, allowing us to confirm that the independent variables in the model are not severely correlated to the point where they impair the predictive power of the model. Pearson correlation analysis also provides a clear view of the role of each variable. For example, farm area (FS) showed a significant relationship and a steady increase in yield as the area expanded. Similarly, organic fertilizer use (OGF) was positively associated with yield, reflecting the need for sustainable improvements in agriculture. Meanwhile, coffee growing experience (YLA) also showed a positive relationship, suggesting that the accumulation of knowledge improves technical capacity and helps farmers make more effective decisions. Notably, irrigation water (IRW) and herbicides (HER), although not significantly associated with yield, their roles should not be excluded entirely in future studies. This lack of correlation may be due to other factors, such as local conditions or applied methods, which require further analysis to determine their potential role.

Finally, the absence of multicollinearity in the data set is an important strength of the study. This not only ensures the validity of the regression results but also strengthens the accuracy of the conclusions. From a practical perspective, the study results provide helpful information for policymakers and farmers to understand better the factors affecting coffee productivity. Focusing on factors such as farm area, organic fertilizers, and agricultural experience can help improve production efficiency while also moving toward sustainability in coffee production.

4.4.2. Multicollinearity test

However, the author also conducted a multicollinearity test to be more specific, and the results are in table 4.8.

Table 4.8: Multicollinearity test results

Variable	1/VIF	VIF
FS	0.944	1.060
IRW	0.991	1.009
OGF	0.475	2.104
INO	0.319	3.137
HER	0.980	1.020
PES	0.981	1.020
AGE	0.945	1.058
ETH	0.969	1.032
YLA	0.764	1.308
EDU	0.964	1.038
LBP	0.438	2.281
DIS	0.931	1.074
ITC	0.454	2.204
AAM	0.300	3.333
TLR	0.306	3.266
Mean		1.730

Source: computed by SPSS

A traditional method of multicollinearity detection is to use the variance inflation factor (VIF), a measure of the correlation and intensity of connection between predictor variables in a regression model. VIF values commence at 1 and lack an upper limit. Upon examination of the VIF column in the results, all values were below 5. This observation leads to the straightforward conclusion that multicollinearity is absent among the variables in the model. The findings derived from testing correlation and multicollinearity between variables affirm the suitability of these variables for inclusion in the research model. Consequently, the author opts to retain all variables for implementation and proceeds with regression operations.

4.5. Research result

Coffee productivity is a multifaceted outcome influenced by various factors, ranging from the producer's subjective considerations to each farm's distinctive

attributes and encompassing objective elements stemming from the surrounding environment. To systematically evaluate the effect of these factors on the coffee productivity of the investigated households, the author employs the Cobb-Douglas production function model. The assessment includes measuring TE levels achieved by the cultivating households, with the SFA method used within the framework of this study.

This research focuses on an in-depth analysis of the influence exerted on specific coffee productivity by input factors, constituting a significant portion of total investment costs. These factors encompass Irrigation water (IRW), Organic fertilizer (OGF), Inorganic fertilizer (INO), Herbicide (HER), Pesticide (PES), and Labor cost (LBP), with the output factor being coffee yield (OPU). Additionally, factors pertinent to technical efficiency are scrutinized, incorporating demographic attributes such as Age (AGE), Ethnicity (ETH), Education level (EDU), Coffee growing experience (YLA), Coffee variety (VAR), Distance from farm to city (DIS), Intercropping (ITC), Application of advanced methods (AAM), and Land reclamation training (TLR). The deliberate focus on these factors facilitates a nuanced exploration of the intricate dynamics shaping coffee productivity within the investigated households.

Table 4.9: Regression results of productivity and TE function models

OPU	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Frontier						
FS	0.9200	0.0262	35.13	0.0000	0.8687	0.9713
IRW	0.0195	0.0487	0.40	0.6890	-0.0760	0.1149
OGF	-0.0307	0.0754	-0.41	0.6840	-0.1785	0.1171
INO	-0.7307	0.1267	-5.77	0.0000	-0.9791	-0.4823
HER	-0.0084	0.0317	-0.26	0.7910	-0.0704	0.0537
PES	0.0719	0.0323	2.23	0.0260	0.0087	0.1351
LBP	0.3652	0.0405	9.03	0.0000	0.2859	0.4445
_cons	1.7818	1.1662	1.53	0.1270	-0.5039	4.0675
Mu						
AGE	0.0398	0.0902	0.44	0.6590	-0.1369	0.2166
ETH	-0.5514	0.0855	-6.45	0.0000	-0.7190	-0.3837
YLA	-0.2347	0.0423	-5.55	0.0000	-0.3175	-0.1518
VAR	0.2709	0.0406	6.67	0.0000	0.1913	0.3505
EDU	0.0135	0.0219	0.62	0.5370	-0.0294	0.0565
DIS	0.1659	0.0243	6.81	0.0000	0.1182	0.2136
ITC	-0.1490	0.0493	-3.02	0.0020	-0.2456	-0.0525
AAM	-0.7671	0.0901	-8.51	0.0000	-0.9438	-0.5905
TLR	0.1220	0.0576	2.12	0.0340	0.0090	0.2349
_cons	1.4565	0.3993	3.65	0.0000	0.6738	2.2391
Usigma						

_cons	-2.2760	0.1700	-13.39	0.0000	-2.6091	-1.9429
Vsigma						
_cons	-3.0436	0.2894	-10.52	0.0000	-3.6107	-2.4764
sigma_u	0.3205	0.0272	11.77	0.0000	0.2713	0.3785
sigma_v	0.2183	0.0316	6.91	0.0000	0.1644	0.2899
lambda	1.4678	0.0565	25.96	0.0000	1.3570	1.5786

Source: computed by Stata

Table 4.9 showcases the research findings derived from the initial model, which incorporates aggregate data to comprehensively evaluate the four provinces and cities within the study area. The recorded results reveal that certain variables - specifically, coffee garden area (FS), inorganic fertilizer (INO), pesticides (PES), and labor cost (LBP) - demonstrate statistical significance in their association with coffee yield (OPU). Conversely, the volume of irrigation water (IRW), organic fertilizer (OGF), and herbicide (HER) fails to exhibit a statistically significant impact on output productivity. The following equation encapsulates the ensuing marginal production model results.

$$OPU_{General} = 1.7818 + 0.9200 \times FS - 0.7303 \times INO + 0.0719 \times PES + 0.3652 \times LBP$$

The analysis reveals that a unit increase in planted area (FS) and labor cost (LBP) contributes to the rise of approximately 0.92 units and 0.3652 units in output, respectively, at the 1% significance level. Similarly, one-unit increases in pesticide application yield a statistically significant output increase of 0.0719 units with a 95% confidence level. On the other hand, a one-unit increment in organic fertilizer (OGF) presents a potential risk, resulting in a decrease of output of 0.2347 units at the 1% significance level. This phenomenon is attributed to the current lower-than-optimal investment levels in households compared to technical requirements. A strategic fertilizer and pesticide investment enhancement and adherence to correct technical procedures can elevate productivity. In coffee cultivation, timely fertilization is pivotal for robust plant growth and optimal yield. Untimely fertilization can disrupt flowering timing, subsequently impacting the yield in the following year.

Moreover, the computed Lambda value of 1.4678, exceeding 1, aligns with the requisites of the random frontier model with cross-sectional data. Additionally, the estimated parameters Sigma_u and Sigma_v stand at 0.3205 and 0.2183, respectively, consolidating the robustness of the model. The presented table underlines the dynamic nature of technical inefficiency in pepper gardens, which is influenced by many factors. The accurate execution of technical requirements in the production process significantly affects technical inefficiencies at various significance levels. In the context of coffee production, the meticulous adherence to and proper implementation of technical production requisites—such as strategically planting trees to mitigate wind effects, providing suitable shading for coffee, meticulous weeding in cultivation

gardens, constructing tubs, employing effective pruning techniques, adhering to appropriate watering practices, and understanding the optimal periods for fertilization and pest elimination—significantly impacts the developmental trajectory of coffee growth. These issues are linked to the awareness and knowledge acquisition of caretakers responsible for tending to eggplant gardens. Furthermore, active participation in training activities, the application of advanced methods, the selective coffee variety, and the farm's proximity to urban centers all contribute to shaping the TE landscape. The technical inefficiency model can be succinctly expressed as follows:

$$\begin{aligned} \text{MU}_{General} = & 1.4565 - 0.5514 \times \text{ETH} - 0.2347 \times \text{YLA} + 0.2709 \times \text{VAR} \\ & + 0.1659 \times \text{DIS} - 0.1490 \times \text{ITC} - 0.7671 \times \text{AAM} \\ & + 0.1220 \times \text{TLR} \end{aligned}$$

A comprehensive analysis of demographic and operational factors in coffee production has yielded important insights into inefficiencies in production techniques. First, ethnicity (ETH), coffee growing experience (YLA), and intercropping (ITC) variables showed significant inverse relationships with technical inefficiencies, reaching a high level of statistical significance (1%). This suggests that ethnic farmers with long-term coffee growing experience and appropriate intercropping practices are more efficient. These results support the argument that a deeper understanding of crops and biodiversity management strategies can contribute to improved production efficiency. In addition, coffee variety (VAR) and distance from farm to city (DIS) also significantly impacted inefficiencies, with similar significance levels. Using appropriate coffee varieties affects product quality and creates opportunities to improve technical efficiency. However, the extended distance from the farm to the city is a significant obstacle, increasing transportation costs and reducing market access, negatively affecting technical efficiency. Notably, participation in training on land improvement (TLR) also contributes to lowering inefficiency, reaching a significance level of 5%, indicating the importance of providing training programs to improve farmers' skills and knowledge. In contrast, age (AGE) and education level (EDU) do not provide enough evidence to confirm a significant relationship with technical inefficiency. This may reflect the diversity in education and awareness levels among farmers and the uneven impact of accumulated experience by age.

The average total technical efficiency (TE) ratio was 0.514, or 51.4%, indicating that farmers, on average, were only achieving half of their optimal potential in production management. This highlights considerable potential to improve technical efficiency through targeted support strategies, including training programs and infrastructure improvements to bridge geographic distances. These findings shed light on the importance of demographic and operational factors and provide a basis for designing appropriate policy interventions to improve coffee production efficiency.

Table 4.10: Overall technical efficiency percentage

Variable	Obs	Mean	Std.Dev	Min	Max
TE	846	0.5139484	0.1835988	0.093082	0.921797

Source: computed by Stata

The results of the extended analysis focusing on the non-certified farmers provide insights into the factors affecting coffee productivity, as depicted in Table 4.11. Farm area (FS), Pesticide (PES), and irrigation water (IRW) were found to have a significant positive relationship with coffee productivity, reaching a high statistical significance level of 99%. It means that these factors play a key role in improving productivity. Larger farm areas facilitate the adoption of large-scale farming methods, while effective pest control helps protect crops from pests. In particular, irrigation water was one of the most important factors, highlighting the importance of a stable water source in agricultural production. Inorganic fertilizer (INO) also showed a significant positive relationship with productivity at the 5% significance level, confirming the important role of this factor in providing necessary nutrients for crops. However, organic fertilizer (OGF) showed a negative association with yield at the 10% significance level. This suggests that although organic fertilizers have long-term benefits for soil health, in the short term, yield performance may be affected by rapid nutrient depletion compared to inorganic fertilizers. This result requires further analysis to clarify the potential limiting factors of organic fertilizers in the current production context. In addition, herbicides (HER) and labor costs (LBP) did not show a clear statistical association with yield. This may reflect differences in the use or efficiency of these factors among farmers, requiring more detailed studies to determine their potential impact.

The statistical model also produced remarkable results with $\Lambda = 2.8504$ exceeding 1, indicating the appropriateness of the random frontier model to the cross-sectional data. The values of Σ_u (0.5635) and Σ_v (0.1977) reinforced the model's reliability, indicating its strong explanatory power on coffee yield variation. The conclusions from this analysis emphasize the important role of factors such as farm size, pest control, and irrigation water, and they also open up opportunities for optimizing fertilizer use, especially considering the combination of organic and inorganic fertilizers for higher yield efficiency.

Table 4.11: Regression results for the non-certified group

OPU	Coef.	Std. Err.	z	P > z	[95% Conf. Interval]	
Frontier						
FS	0.9824	0.0336	29.27	0.0000	0.9166	1.0481
IRW	0.0956	0.0489	1.96	0.0500	-0.0002	0.1914
OGF	-0.1095	0.0659	-1.66	0.0970	-0.2386	0.0196

INO	0.3378	0.1636	2.06	0.0390	0.0172	0.6584
HER	-0.0158	0.0264	-0.60	0.5500	-0.0675	0.0360
PES	0.0807	0.0273	2.95	0.0030	0.0272	0.1342
LBP	0.0051	0.0469	0.11	0.9140	-0.0869	0.0971
_cons	-1.3011	1.3140	-0.99	0.3220	-3.8765	1.2742
Mu						
AGE	0.6844	0.4652	1.47	0.1410	-0.2273	1.5962
ETH	-1.0677	0.4455	-2.40	0.0170	-1.9410	-0.1945
YLA	-0.3825	0.1823	-2.10	0.0360	-0.7398	-0.0251
VAR	0.3354	0.3454	0.97	0.3310	-0.3415	1.0124
EDU	0.1024	0.1039	0.99	0.3240	-0.1011	0.3060
DIS	0.5241	0.1913	2.74	0.0060	0.1491	0.8990
ITC	-0.7371	0.3651	-2.02	0.0430	-1.4526	-0.0215
AAM	-0.7110	0.7328	-0.97	0.3320	-2.1472	0.7252
TLR	0.5537	0.3521	1.57	0.1160	-0.1364	1.2437
_cons	-2.6833	2.1940	-1.22	0.2210	-6.9836	1.6169
Usigma						
_cons	-1.1473	0.3999	-2.87	0.0040	-1.9311	-0.3635
Vsigma						
_cons	-3.2422	0.1594	-20.33	0.0000	-3.5547	-2.9297
sigma_u	0.5635	0.1127	5.00	0.0000	0.3808	0.8338
sigma_v	0.1977	0.0158	12.54	0.0000	0.1691	0.2311
lambda	2.8504	0.1101	25.89	0.0000	2.6346	3.0662

Source: Computed by Stata

The author has the output and input data result equation as follows:

$$\begin{aligned}
 OPU_{Noncertificate} &= -1.3011 + 0.9824 \times FS + 0.0956 \times IRW - 0.1095 \times OGF \\
 &+ 0.3378 \times INO + 0.0807 \times PES
 \end{aligned}$$

The analysis of the non-certified farmers shows a mixed picture of technical inefficiency and its influencing factors. Among the 564 surveyed households, factors such as ethnicity (ETH), coffee growing experience (YLA), and intercropping (ITC) were found to have a positive impact on reducing technical inefficiency, with statistical significance at the 5% confidence level. This suggests that ethnic diversity and long-term experience, as well as intercropping practices, can play a significant supporting role in improving production efficiency. These findings confirm the important role of socio-economic factors and suggest that sustainable farming practices can bring concrete benefits to agricultural productivity. In contrast, distance from farm to city (DIS) emerged as a negative factor contributing to increased technical inefficiency, reaching high statistical significance at the 99% confidence

level. This reflects that transportation costs and difficulties in accessing markets or supporting resources may be significant barriers to performance for this group of farmers. However, other factors such as age (AGE), coffee variety (VAR), adoption of advanced farming practices (AAM), and participation in land improvement training (TLR) did not show a clear relationship with technical efficiency, suggesting that further research is needed to determine their potential impact.

In addition, the average technical efficiency of the non-certified group of farmers was 75.72%, which is relatively satisfactory and exceeds the average of all 846 coffee-growing households in the four provinces studied. This result suggests that despite being uncertified, this group of farmers is still relatively efficient, but there is still potential for improvement. To optimize performance, focusing on factors such as geographic proximity, technical training, and infrastructure support may be key in strategies to improve productivity and sustainability for this group. More details are presented in Table 4.12, which provides a comprehensive view of the technical efficiency of non-certified coffee-growing households.

$$MU_{General} = -2.6833 - 1.0677 \times ETH - 0.3825 \times YLA + 0.5241 \times DIS - 0.7371 \times ITC$$

Table 4.12: Technical efficiency ratio for non-certified groups

Variable	Obs	Mean	Std.Dev	Min	Max
TE-Non-Cer	564	0.7572	0.1496301	0.12845	0.9553606

Source: computed by Stata

Like the group of certified coffee farmers, the author obtained the results in the table.

Table 4.13: Regression results for the certified group

OPU	Coef.	Std. Err.	z	P>z	[95% Conf. Interval]	
Frontier						
FS	0.9323	0.0263	35.45	0.0000	0.8808	0.9839
IRW	-0.1051	0.0589	-1.78	0.0750	-0.2206	0.0104
OGF	0.2393	0.1395	1.72	0.0860	-0.0342	0.5128
INO	-0.0378	0.1590	-0.24	0.8120	-0.3495	0.2738
HER	-0.0438	0.0519	-0.85	0.3980	-0.1455	0.0578
PES	-0.0100	0.0532	-0.19	0.8500	-0.1144	0.0943
LBP	-0.0564	0.0555	-1.02	0.3100	-0.1652	0.0525
_cons	2.4955	1.2334	2.02	0.0430	0.0780	4.9130
Mu						
AGE	-4.4278	1.7642	-2.51	0.0120	-7.8855	-0.9700

ETH	-7.1989	3.4560	-2.08	0.0370	-13.9725	-0.4252
YLA	-3.7554	1.5802	-2.38	0.0170	-6.8525	-0.6583
VAR	-0.9097	0.5075	-1.79	0.0730	-1.9044	0.0850
EDU	1.3400	0.7449	1.80	0.0720	-0.1201	2.8000
DIS	0.4326	0.2427	1.78	0.0750	-0.0430	0.9082
ITC	1.6639	1.2576	1.32	0.1860	-0.8010	4.1287
AAM	-0.2269	6.1049	-0.04	0.9700	-12.1923	11.7385
TLR	-0.2655	0.4930	-0.54	0.5900	-1.2317	0.7007
_cons	25.1947	10.4138	2.42	0.0160	4.7839	45.6054
Usigma						
_cons	-2.4056	1.0157	-2.37	0.0180	-4.3962	-0.4149
Vsigma						
_cons	-2.8958	0.0890	-32.54	0.0000	-3.0703	-2.7214
sigma_u	0.3004	0.1525	1.97	0.0490	0.1110	0.8127
sigma_v	0.2351	0.0105	22.47	0.0000	0.2154	0.2565
lambda	1.2778	0.1553	8.23	0.0000	0.9733	1.5823

Source: computed by Stata

The model shows the relationship between input and output in the certified group as follows:

$$OPU_{Noncertificate} = 2.4955 + 0.9323 \times FS - 0.1051 \times IRW + 0.2393 \times OGF$$

Analyzing factors affecting coffee production yield provides important information on the relationship between input variables and technical efficiency. Among the variables tested, only three input variables were statistically significant. Farm area (FS) and organic fertilizer (OGF) positively correlated with yield. This reflects that expanding cultivated land can bring about economies of scale due to a larger production scale. At the same time, the use of organic fertilizer not only improves soil fertility but also facilitates sustainable development. The result is consistent with previous studies such as Ibanez & Blackman (2016), which emphasized the positive impact of organic fertilizer on sustainable agricultural production.

In contrast, irrigation water (IRW) showed an inverse relationship with yield, which could be explained by inefficient or excessive use of irrigation water, which wastes resources and negatively affects crop growth. The result raises important questions about optimizing irrigation water use in coffee production, especially regarding climate change and increasing water resource pressure. Other input variables such as inorganic fertilizers (INO), herbicides (HER), pesticides (PES), and labor costs (LBP) did not reach statistical significance, indicating that there is insufficient evidence to confirm their significant impact on yield. It could reflect the heterogeneity in farmers' use or management of these factors.

Furthermore, the result of the technical efficiency (TE) test, with an average value of 96.17%, emphasizes the optimal level of production management of the surveyed farmers. However, inefficiencies still exist and are associated with several factors such as age (AGE), ethnicity (ETH), coffee growing experience (YLA), and coffee variety (VAR). Reducing inefficiencies positively correlates with education level (EDU) and distance from farm to city (DIS), indicating the need for improved education and infrastructure to support production efficiency. The Lambda condition exceeding 1, together with σ_u (0.3004) and σ_v (0.2351) values, strengthens the model's validity, confirming the applicability of the stochastic frontier analysis method in this study.

$$MU_{General} = 25.1947 - 4.4278 \times AGE - 7.1989 \times ETH - 3.7554 \times YLA - 0.9097 \times VAR + 1.3400 \times EDU + 0.4326 \times DIS$$

Table 4.14: Percentage of technical efficiency for certified groups

Variable	Obs	Mean	Std.Dev	Min	Max
TE-Cer	282	0.961661	0.1026	0.121	0.9922675

Source: computed by Stata

Table 4.15: Shows the distribution of technical efficiency by group.

Categories	Non-Certificate		Certificate	
	Farmer	%	Farmer	%
< 40	17	3.01%	4	1.42%
40 ≤ TE < 50	27	4.79%	0	0.00%
50 ≤ TE < 60	40	7.09%	2	0.71%
60 ≤ TE < 70	68	12.06%	3	1.06%
70 ≤ TE < 80	119	21.10%	3	1.06%
80 ≤ TE < 90	228	40.43%	4	1.42%
90 ≤ TE	65	11.52%	266	94.33%
Total	564	100%	282	100%
Min		12.85%		12.10%
Max		95.34%		99.23%
Mean		75.72%		96.17%
Std. dev		14.96%		10.26%

Source: The author's works

Table 4.15 shows that the certified and non-certified farmer groups differed significantly regarding technical efficiency. According to the results, 88.48% of the non-certified group is mainly concentrated at the technical efficiency level below 90%. Of these, the most significant proportion is 80% to 90%, accounting for 40.43%. This reflects a considerable limitation in optimizing the non-certified group's

production inputs and farming techniques. In contrast, the certified group shows outstanding efficiency, with up to 94.33% of farmers achieving efficiency above 90%. This is a positive sign, demonstrating the important role of certification programs in improving production capacity. The average efficiency between the two groups also shows a significant difference. With an average efficiency of 96.17%, the certified group outperformed the non-certified group by a considerable margin (75.72%). This supports the claim that certification programs enhance technical proficiency and aid in production resource and input optimization. Furthermore, the two groups have a notable difference in technical efficiency. The standard deviation in the non-certified group was 14.96%, suggesting that farmers' use of farming techniques differed significantly.

Meanwhile, the certified group had a standard deviation of only 10.26%, demonstrating greater consistency in production capacity. Figures 4.3 and 4.4 provide further details on the dispersion of technical efficiency between the two groups. These results highlight the practical benefits of participating in certification programs and confirm the importance of widely implementing these programs to improve production capacity and sustainability in the coffee industry.

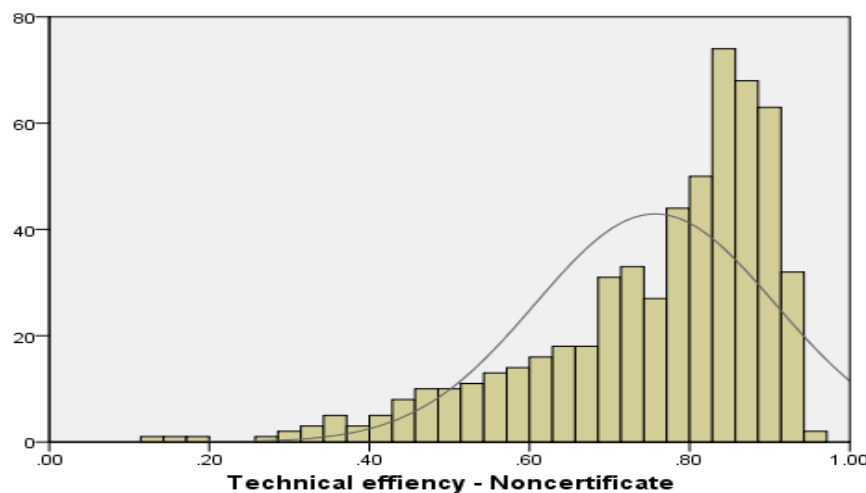
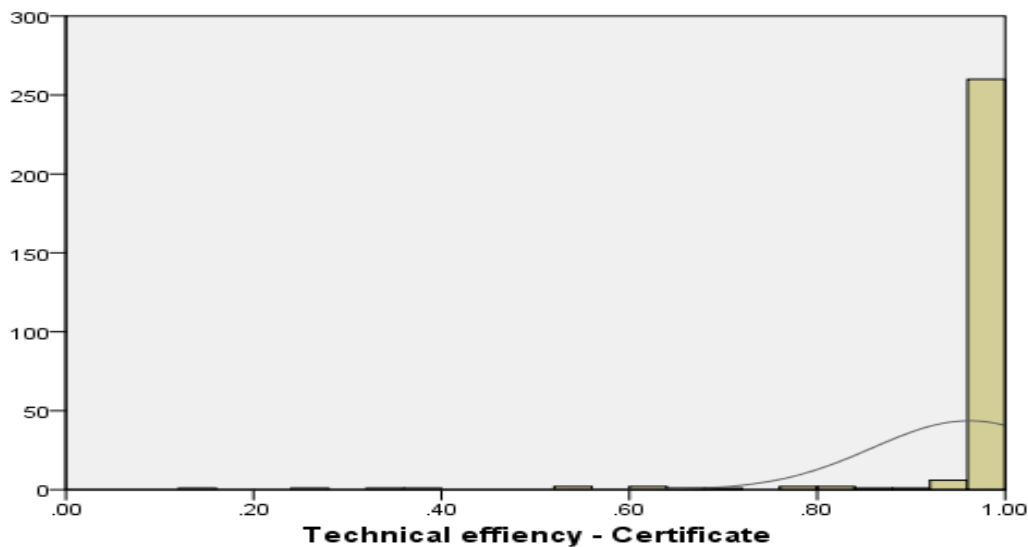


Fig. 4.3: Distribution of the technical efficiency situation of all non-certified research households

Source: computed by SPSS



*Fig. 4.4: Distribute the technical efficiency status of all certified research households.
Source: Computed by SPSS*

In the context of rapidly increasing land prices in Vietnam, the study results show important links between land prices, coffee productivity, and export volume. Coffee productivity (AVY) is a significant determinant of production output, with a 1 unit increase in yield per hectare resulting in a substantial increase of 11.82 units of overall output. This confirms the central role of productivity enhancement measures such as improved farming techniques, optimized resource management, and efficient fertilizer use in boosting production output, especially under increasing pressure on land prices. However, land prices (PRE) present a more complex picture. Although each unit increase in land prices leads to a rise of 1.8867 units of overall output, this may suggest that farmers with larger farms can use economies of scale to maximize returns from their land area. At the same time, rising land prices may also spur investments in modern technology and improved management to optimize production on limited land. However, high land price pressures may reduce small-scale farmers' access to land, making it difficult to maintain efficient production.

In contrast, export output (EXP) negatively impacts overall production output, with each unit increase in export output leading to a 0.566 unit decrease in overall production. This may reflect additional costs associated with expanding international markets, such as transportation costs, higher quality control requirements, or competitive pressures in global markets. This impact may also result from the shift of resources from domestic production to meet export requirements, leading to a decline in overall output. The results also highlight the role of farm size (FS) as an important factor affecting coffee production, with statistical significance at the 5% level. According to earlier research on economies of scale, farmers who own larger farms are more inclined to use cutting-edge farming techniques and technology in order to maximize productivity.

In contrast, the inflation variable (INF) did not significantly impact, suggesting that macroeconomic factors may not directly affect coffee production but mainly through intermediate factors such as input prices or transportation costs. This result clearly shows the multidimensional relationships between economic, environmental, and export factors. It highlights the need to carefully consider strategies to alleviate pressure from land prices, improve productivity, and sustainably promote export production.

Table 4.16: OLS model regression results with the dependent variable of general output

Hypothesis	PRD	Coef.	P >t	Remarks
H₁₇	AVY	11.81691	0.013	✓
H₁₈	EXP	1.886718	0.085	✓
H₁₉	PRE	-0.566132	0.018	✓
H₂₀	INF	-3.203485	0.301	⊙
	FS*	-4.98546	0.013	
	_cons	74.94574	0.016	

*Note: ✓ is sufficient evidence to accept the influence that is recorded the corresponding hypothesis; ⊙ is not enough evidence to confirm that the influence has been recorded the corresponding hypothesis; * FS is control variable;*

Source: Computed by Stata

5. DISCUSSION

The author synthesizes the research results on hypotheses related to production efficiency and technical inefficiency, comparing the groups with and without certification in the table 4.17. The tested hypotheses include many factors affecting production efficiency (Frontier) and technical inefficiency (Technical inefficiency).

Table 4.17: Summary of research results

Hypot hesis	OPU	General	Non- Certificate	Remark s	Certifica te	Remar ks
Frontier						
H_{1a}, H_{1b}	OGF	-0.0307	-0.1095*	✓	0.2393	⊖
H_{2a}, H_{2b}	INO	-0.7307***	0.3378**	✓	-0.0378*	✓
H₃	PES	0.0719**	0.0807***	✓	-0.01	⊖
H₄	HER	-0.0084	-0.0158	⊖	-0.0438	⊖
H₅	IRW	0.0195	0.0956**	✗	-0.1051*	✓
H₆	LBP	0.3652***	0.0051	⊖	-0.0564	⊖
H₇	FS	0.9200***	0.9824***	✓	0.9323***	✓
Technical inefficiency						
H₈	ITC	-0.149***	-0.7371**	✓	1.6639	⊖
H₉	VAR	0.2709***	0.3354	⊖	-0.9097*	✓
H₁₀	YLA	-0.2347***	-0.3825**	✓	-3.7554**	✓
H₁₁	EDU	0.0135	0.1024	⊖	1.3400*	✗
H₁₂	ETH	-0.5514***	-1.0677**	✓	-7.1989**	✓
H₁₃	AGE	0.0398	0.6844	⊖	-4.4278**	✗
H₁₄	AAM	-0.7671***	-0.711	⊖	-0.2269	⊖
H₁₅	TLR	0.122**	0.5537	⊖	-0.2655	⊖
H₁₆	DIS	0.1659***	0.5241***	✓	0.4326*	✓

Notes: ✓ is sufficient evidence to accept the influence recorded in the corresponding hypothesis; ⊖ is not enough evidence to confirm that the influence has been recorded in the corresponding hypothesis; ✗ is the result that does not support the research hypothesis.

Source: The author's works

The research results show that motivating farmers to engage in sustainable coffee production is a significant challenge for coffee growers and local authorities. In the provinces of Lam Dong, Dak Lak, Gia Lai, and Dak Nong, the technical efficiency of conventional and sustainable coffee farming groups is examined using Cobb-Douglas production function analysis and stochastic frontier analysis (SFA).

According to the findings, *sustainable farmers outperform conventional farmers regarding technological efficiency*. The sustainable group's average technical

efficiency was 96.17%, far greater than the traditional group's 75.72%. These results align by Poudel et al. (2015), which showed that organic farmers were more technically efficient than conventional farmers. The findings of Hung Anh et al. (2019), who discovered that traditional farmers were more productive because they used a lot of inputs, are likewise in conflict with the conclusions of this study. *Technical efficiency may be impacted by farming practices and local context. Additionally, the two groups' average technical efficiency levels offer crucial hints regarding the possibility of yield enhancement.*

The conventional group could increase their yield by 24.28% by improving farming practices, while the sustainable group could increase it by 3.83%. *This reflects that, although the sustainable group was more efficient, there were still shortcomings in the production process that needed to be addressed to optimize yields. These results also show a marked difference from studies in other regions of the world. In Jimma Zone, Southwestern Ethiopia, the average technical efficiency level was 82.63% (Tamirat & Tadele, 2023), similar to 82% in Rwanda (Ngango & Kim, 2019). Studies in Costa Rica (Wollni & Brümmer, 2012) and Kenya (Kamau et al., 2017) also showed higher average technical efficiency levels than those achieved by the traditional group in Vietnam. These differences suggest that technical efficiency depends on farming methods and geographical, cultural, and support system contexts.* The study results highlight the importance of adapting farming practices and policies to local conditions to improve technical efficiency. Policymakers and farmers need a more comprehensive approach, including training and financial support, to unlock the potential for productivity improvements while ensuring sustainability in coffee production.

5.1. Economic efficiency

Farm size emerged as an important determinant in shaping coffee production productivity. Large farms can reduce input costs and maximize production efficiency by utilizing economies of scale. This study's results align with earlier research by Minh et al. (2016;) and Sharma et al. (2016) which showed that larger farms can significantly increase output by making better use of their tools. Additionally, according to Sharma et al. (2016), the idea of returns to scale implies that as farm area grows, producers can raise output capacity, apply sustainable farming methods more widely, and invest in more advanced technologies. However, expansion is complex for small farms, especially in high land prices. This limitation affects productivity and makes it difficult for small-scale farmers to remain competitive. Challenges related to farm size require intervention from supportive policies, such as providing preferential loans or subsidies to help small-scale farmers expand their cultivated area. At the same time, establishing cooperative models among small farms can facilitate farmers sharing resources and adopting modern technology, thereby increasing productivity and ensuring long-term sustainability.

Organic fertilizers are central to sustainable coffee production, improving productivity and bringing many environmental benefits. Ibanez & Blackman (2016)

have shown that using organic fertilizers can significantly enhance soil quality while minimizing negative impacts on the ecosystem. Hardt et al. (2015) and Philpott et al. (2008) also emphasized that organic fertilizers contribute to biodiversity conservation and improve soil moisture retention, an important factor in increasing climate change. Familiar sources of organic fertilizers such as manure, green crop residues, and farm waste not only provide nutrients but also help maintain soil structure, creating favorable conditions for sustainable coffee growth (Dikinya & Mufwanzala, 2010); Satyanarayana et al., 2002). However, using organic fertilizers also faces several challenges, including limited nutrient balance and high transportation costs for remote production areas. Stockdale et al. (2002) pointed out that organic fertilizers, although improving soil quality, may not achieve optimal yield levels when not combined with inorganic fertilizers. Therefore, a judicious use strategy of organic and inorganic fertilizers is required to balance productivity and sustainability.

Inorganic fertilizers, especially NPK, are considered indispensable in promoting coffee productivity. Nyalemegbe et al. (2010) and Reganold et al. (2001) have shown that combining organic and inorganic fertilizers brings outstanding productivity and economic efficiency benefits. Hung Anh et al. (2019) emphasized that the rational application of NPK fertilizers increases yield and helps reduce labor costs, highlighting the role of inorganic fertilizers in supporting farmers to optimize production costs. However, using inorganic fertilizers must also be strictly controlled to minimize environmental negative impacts, such as soil and groundwater pollution. Pesticides have been shown to positively affect productivity in conventional coffee production, thanks to their ability to control pests and diseases effectively. Khan et al. (2010) and Ngango & Kim (2019) have confirmed that the use of pesticides can increase crop yields, especially in large-scale farming systems. However, pesticide use needs to be carefully evaluated in sustainable coffee production. Overusing pesticides can seriously affect the environment and public health, especially when proper management practices are lacking. This calls for training programs to raise farmers' awareness of the safe and effective use of pesticides and the development of biological alternatives.

Although not directly related to yield, labor costs are positively correlated with coffee production's economic efficiency. Sustainable coffee production often requires more manual labor to implement environmentally friendly farming practices. However, Hung Anh et al. (2019) and Tran et al. (2021) showed that despite higher labor costs, sustainable coffee production is still more profitable than conventional methods due to the product's added value. Investing in labor training and applying modern technology can help reduce labor costs while improving productivity and product quality. *The study results show that coffee productivity depends on important input factors, including farm size, organic and inorganic fertilizers, pesticides, and labor costs.* Optimizing these factors will not only increase productivity but also ensure the sustainability of coffee production. To achieve this goal, specific support policies are needed, including providing finance to farmers, developing training programs, and promoting research to improve farming methods. In addition,

coordination among stakeholders, from farmers to policymakers, will play an important role in building a sustainable and competitive coffee industry in the international market.

5.2. Determinants of technical efficiency

The literature currently in publication indicates that several demographic factors, including farmer age (Dessale, 2019; Kamau et al., 2017; Sriboonchitta & Wiboonpongse, 2014); education (Dessale, 2019; Ho et al., 2018); and ethnicity (Ho et al., 2018), may have an impact on farming efficiency. Furthermore, household size (Bati et al., 2017; Binam et al., 2003) and agricultural experience (Sriboonchitta & Wiboonpongse, 2014). *In a traditional farming system, age emerges as a factor that negatively impacts the farmers' technical inefficiency. Nonetheless, the older farmers contribute to improved technical efficiencies in production within the sustainable production household group.* This is attributed to their extensive farming experience, accumulated knowledge, and refined skills, leading to more efficient utilization of inputs (Tamirat & Tadele, 2023; Yami et al., 2013). Additionally, the number of years of experience cultivating coffee trees links to a negative effect on inefficiency within the sustainable production group, aligning with findings by Dessale (2019) and Sriboonchitta & Wiboonpongse (2014). However, this perspective contrasts with studies conducted by Hung Anh et al. (2019), Kamau et al. (2017), and Poudel et al. (2015), asserting that older farmers may disregard new production techniques during the coffee industry's transformation.

Furthermore, there is no evident correlation between age and technical inefficiency among non-certificates. The prevalence of Kinh people in coffee farming correlates with higher economic efficiency and excessive productivity in the target groups. The ethnicity variable negatively impacts technical inefficiencies. The finding aligns with previous studies (Gaitán-Cremaschi et al., 2018; Ho et al., 2018; Hung Anh et al., 2019). *Low educational attainment and restricted access to contemporary technologies are traits of ethnic minority farmers.* This confirms the first theory, which states that farms owned by ethnic minorities are less suitable for producing coffee effectively. Educational intervention illustrates a positive impact on inefficiencies in sustainable agricultural systems, consistent with earlier research by Wang et al. (1996), which identified a negative connection between technical proficiency and schooling. This raises the possibility of the attribution that individuals with advanced educations engaging in non-agricultural pursuits rely on hired labor for coffee production due to oversight concerns (Bifarin et al., 2010).

Regarding coffee varieties, in general production, a positive association implies that changing coffee varieties increases inefficiency. However, within the sustainable production group, the impact of varieties is negative in terms of inefficiency, supported by Kamau et al. (2017), who found increased technical efficiency with the application of new varieties. A study by Murthy et al. (2009) testing the technical efficiency of new tomato varieties in India observed that farms operated by younger farmers were more efficient. This can potentially explain the general research

suspicion that new varieties contribute to inefficiency, given that most farmers in the author's research provinces are over 40 years old.

Furthermore, the Central Highlands, characterized by its highland terrain, presents rugged landscapes, making travel more challenging than in the plains. Larger farms in this region are often situated farther from urban centers, emphasizing the importance of location factors. This study reveals a positive correlation between distance and inefficiency, indicating that an increase in this gap corresponds to heightened inefficiency. However, it is noteworthy that this influence, while present, is not as statistically significant as other factors impacting technological inefficiency. This result agrees with the findings of Binam et al. (2003). *The conclusion is that technical efficiency decreases with increasing distance between the farm and the main road.* This restriction on closeness makes it more difficult to obtain market information and access input and output markets (Ahmed, 2014). *The considerable distances associated with high transaction costs impede profitability for farmers, restricting their ability to produce market-oriented products* (Alemu et al., 2009).

Cultivating companion crops such as pepper, avocado, and durian alongside coffee plants holds promises of benefits, including enhanced utilization of environmental factors, increased productivity, soil protection, and socio-economic advantages (Ogundari, 2023). Intercropping, defined as the simultaneous cultivation of two or more crops on the same plot of land using distinct row arrangements (Ruthenberg, 1980), is acknowledged for its potential to optimize agricultural outputs. Environmental indicators crucial for assessing eco-certification in coffee production encompass the presence of windbreaks and shade trees (Blackman & Naranjo, 2012). This perspective is supported by Rodríguez et al. (2022), who underscore that incorporating commercial crops like coffee has contributed to agricultural growth in Nepal. Despite the recognized effectiveness of intercropping as a production strategy, the adoption rate among Vietnamese coffee farms remains modest, with only 44.44% practicing this form of crop diversification.

Regarding its impact on technical efficiency, research results within sustainable production fail to provide sufficient evidence to confirm its influence conclusively. However, findings from general and conventional farm research align with the outcomes observed by Ho (2018), suggesting a consistent pattern in the broader context of coffee cultivation practices. Further investigations into the dynamics of intercropping and its implications for technical efficiency in the context of Vietnamese coffee production may yield nuanced insights.

Nonetheless, it is essential to note that the decision to engage in intercropping is multifaceted and influenced by various factors such as farm size, geographic location, and socio-economic considerations. As the agricultural landscape continues to evolve, exploring the potential barriers and incentives for greater adoption of intercropping practices in Vietnamese coffee farms could be a valuable avenue for future research. The implementation of sophisticated methodologies concomitantly yields enhanced technical efficiency. Endeavors to modify irrigation technology and agricultural management practices, exemplified by the transition from conventional sub-basin

irrigation to cutting-edge alternatives, including environmentally sustainable overhead sprinkler systems and root-level drip irrigation with fertilization, are observed (Sakai et al., 2015). *Empirical findings foreground that adopting advanced techniques is pivotal in facilitating technical inefficiencies, particularly in contexts where conventional research approaches fail to delineate distinct subject categories. Regrettably, the subdivision of subjects in this study yields insufficient evidence to elucidate the impact.*

Nevertheless, the accreditation for these findings is apprehended in extant documents, as affirmed by the works of Ho (2018) and Sakai et al. (2015). Furthermore, the imperative issue of training for coffee farmers garners special attention from local authorities, mainly when the shortfall of professional and dedicated agricultural officers designated for land reclamation within the State Ministry of Agriculture is evident. The frequent rotation of such officers, even after participating in targeted soil reclamation training programs, poses challenges that necessitate efficacious resolution. This exigency fosters the need to furnish additional insights for optimizing reclamation initiatives at the farm level. However, the efficacy of training interventions in enhancing technical proficiency among farmers within the author's purview remains a continuously explored subject.

5.3. External factors affect output productivity.

Rising land prices pose a significant challenge to coffee farmers in the study provinces, especially small-scale producers. The economic pressure from rising land prices has forced many farming households to reduce their cultivation areas or switch to other more immediately profitable production forms. This trend threatens to reduce the area of coffee land, affecting the industry's total output and long-term sustainability. This finding is similar to the study by Maundu & Karugu (2018), where rising land prices forced coffee farms in Kiambu County, Kenya, to convert their land use to real estate to cope with urbanization. This poses a pressing issue for the coffee industry in Vietnam: how to balance the maintenance of cultivated areas with local economic development. High land prices create fierce competition for land resources in the study provinces, especially those with rapid urbanization. This affects farmers and increases coffee enterprises' input costs, thereby affecting the entire industry supply chain. Without supportive government policies, such as subsidies or land reform, the coffee industry in these provinces may face a decline in productivity and competitiveness in the future.

Export capacity enhancement is important in improving coffee productivity in the studied provinces. As international market demand for Vietnamese coffee increases, farmers and businesses are encouraged to expand production to meet this demand. Arfah (2020) in Uganda also pointed out that coffee output and the world price index have a positive relationship, with exports being the main production driver. This suggests that if export capacity is improved through effective strategies such as reducing transportation costs and optimizing supply chains, farmers will have more incentives to invest in coffee production. However, in the context of the studied

provinces, export capacity depends not only on output but also on quality and the ability to meet international standards. Provinces such as Lam Dong and Dak Lak, which have favorable natural conditions, need to focus on improving the quality of coffee beans to meet the strict requirements of the international market. This requires support from training and extension programs to improve farmers' awareness and production techniques. The link between land prices and export capacity creates a complex cycle that impacts coffee productivity. Rising land prices may limit the ability to expand cultivated areas, but strong export capacity can compensate by increasing economic value per unit of land. This is especially important in the context of the studied provinces, where agricultural land is shrinking due to urbanization and the development of other industries. Expanding export markets helps farmers increase their income and pressures them to improve production efficiency. Research shows farmers invest more in fertilizers, technology, and land management practices when international coffee prices rise to maximize production. However, suppose land prices continue to rise without support. In that case, many farmers cannot afford to invest in sustainable production methods, leading to an imbalance between market demand and actual production capacity.

The study provinces need to implement specific support policies to mitigate the negative impacts of rising land prices and optimize export capacity. First, local governments can consider land reform initiatives to maintain and protect coffee cultivation areas. Second, developing infrastructure such as transportation and logistics systems will help reduce export costs, thereby increasing the competitiveness of farmers and coffee enterprises. In addition, there should be trade promotion programs and international cooperation to support farmers in accessing new markets. This will enhance export capacity, motivate farmers to apply advanced production methods and improve coffee quality and productivity. The government should also consider subsidies or tax incentives to support farmers in coping with economic pressures from high land prices.

Land prices and export capacity are two important external factors affecting coffee output productivity in the study provinces. The complex interaction between these two factors requires synchronous policies to balance the coffee industry's short-term economic benefits and long-term sustainable development. This study provides practical suggestions for stakeholders to develop appropriate strategies, ensuring stable development and enhancing the position of the Vietnamese coffee industry in the international market.

6. CONTRIBUTION

6.1. Theoretical contributions

This study makes important theoretical contributions to understanding technical efficiency and its determinants in sustainable agricultural production, especially in the coffee sector. The study has expanded the theoretical foundation in agrarian production management by applying the Cobb-Douglas production function and stochastic frontier analysis (SFA), especially in comparing sustainable and conventional farming.

Technical efficiency and sustainable production context

One of the important contributions of the study is the comparison of technical efficiency between households applying sustainable farming methods and conventional farming households. The results indicate that the technical efficiency of sustainable farming households tends to be higher, consistent with the study of Poudel et al. (2015) in Nepal. However, this result contradicts the study of Hung Anh et al. (2019), thereby posing a new research direction on the complexity of measuring technical efficiency in each local context. The study also emphasizes that technical efficiency depends not only on farming methods but also on each region's geographical factors, climate, resource management systems, and technology application capabilities (Coelli et al., 2005). Under favorable natural conditions, sustainable farmers often use land, water, and biological resources to optimize production. Conversely, technical efficiency may decline under adverse conditions due to lack of supporting technology or inadequate infrastructure.

Application of Cobb-Douglas production function and SFA method

The study uses the Cobb-Douglas production function to analyze the relationship between key inputs such as land, labor, fertilizer, and coffee productivity. Applying this method helps quantify the contribution of each input factor, thereby identifying strengths and weaknesses in the production process. In particular, in the context of sustainable production, the Cobb-Douglas function helps clarify the level of optimization of input factors, thereby showing that farmers applying sustainable farming methods tend to use resources more efficiently than traditional methods. The stochastic frontier analysis (SFA) method is also integrated into the study to assess farmers' technical efficiency level. This method not only measures the level of inefficiency but also identifies the factors that influence this level. The study results showed that farmers applying sustainable farming methods achieved higher technical efficiency, confirming the potential for improving production efficiency through environmentally friendly farming methods.

The role of demographic factors

The study also contributes to the literature on the role of demographic factors in technical efficiency in coffee production. The results indicate that the farm household's age and experience significantly impact technical efficiency. Farm households with many years of experience tend to have higher technical efficiency due to better decision-making ability, a deeper understanding of natural conditions

and markets, and the accumulation of knowledge over many years of cultivation. In addition, the education level of the farm household is also an important factor. Farm households with higher education levels can access and apply new farming techniques, improving technical efficiency. They are also more likely to participate in technical assistance programs and use sustainable production methods, creating a foundation for the sustainable development of the coffee industry.

Filling the research gap and expanding the theory of sustainable production

This study provides a detailed theoretical framework for optimizing resources for higher technical efficiency and fills the research gap of previous studies. While many previous studies focused on individual factors affecting coffee production efficiency, this study combines various factors such as farming methods, geographical conditions, farmer education level, and market access, thereby creating a more comprehensive approach (Stockdale et al., 2002). In addition, the study also expands the theoretical foundation by proposing integrated models to further assess the impact of socioeconomic factors on sustainable agricultural production efficiency. This contributes to the expansion of the theory of sustainable production by emphasizing the role of balancing and rationally using resources to minimize waste and optimize output (Stockdale et al., 2002). In summary, the study has made an important contribution to the theoretical foundation of technical efficiency and sustainable production, opening up new research directions on the relationship between economic, demographic and environmental factors in the coffee industry. The research results can be extended and applied to other agricultural fields to improve sustainability and optimize production resources.

6.2. Practical contributions

Comprehensive understanding of factors affecting sustainable coffee production:

This study demonstrates that sustainable coffee production brings economic benefits and contributes to reducing environmental impacts. Cobb-Douglas production function analysis has shown how resource optimization can lead to higher technical efficiency, lower input costs, and increased product value. Reducing chemical fertilizers and applying sustainable farming practices helps maintain soil health and reduce greenhouse gas emissions, meeting international markets' increasingly stringent requirements. This is especially important in the global coffee industry, which is under tremendous pressure from climate change and environmental protection requirements. The research results provide a practical basis for policymakers to develop strategies to support farmers transitioning to sustainable production models. Incentives such as financial support, training, and technical guidance can help farmers ease the transition. At the same time, establishing sustainable production standards and branding green coffee will raise consumer awareness and create more significant incentives for farmers. Vietnam must affirm its position as one of the world's leading coffee exporters while contributing to sustainable economic development.

Sustainable production improves coffee quality and creates a competitive advantage for the product in the international market. Research has shown that

sustainable practices, such as using organic fertilizers and effective water management, increase productivity and help coffee meet high quality and safety standards. This aligns with global consumer trends, where buyers increasingly prioritize sustainably sourced products. Coffee processing and exporting enterprises can use these results to build effective marketing strategies to meet the needs of high-end markets. The analysis from this study helps shape long-term plans for the Vietnamese coffee industry. Combining economic, technical, and policy factors into an overall strategic framework will help the coffee industry develop more steadily and sustainably in the future. For example, investing in research and development of climate-resistant crop varieties and the application of modern technology will increase farmers' adaptability to new challenges. At the same time, building cooperative networks within the industry, from farmers to international organizations, will create an ecosystem that supports sustainable production, ensuring long-term benefits for all stakeholders.

The role of organic fertilizers in sustainable development:

Organic fertilizers are an important factor in improving sustainable production efficiency. This study shows that using organic fertilizers increases coffee yield and improves product quality, helping the product meet demanding market requirements better. Coffee plants grow better under severe soil and weather circumstances when organic fertilizers are used because they add natural nutrients to the soil, improve fertility, and better retain moisture. In light of climate change, encouraging sustainable agriculture production is crucial. To maximize the benefits of organic fertilizers, incentive programs must be implemented on a large scale. These programs can include direct financial support, such as subsidies, or providing free organic fertilizers to farmers during the transition from conventional to sustainable farming. At the same time, intensive training courses on using organic fertilizers effectively should be organized to help farmers understand the long-term benefits and how to optimize this resource. The support of the government and foreign organizations will be crucial in advancing these projects.

Implementing transparent and unambiguous criteria is essential to guaranteeing the efficacy of organic fertilizers. These standards not only provide the quality of fertilizers but also help increase the confidence of farmers and consumers in sustainably produced coffee products. National and international standards can include regulations on nutritional composition, production methods, and fertilizer quality control. This helps create a reliable organic fertilizer distribution system, ensuring farmers can easily access high-quality products. One of the most important benefits of organic fertilizers is reducing environmental pollution. Unlike chemical fertilizers, organic fertilizers cause less soil degradation, water pollution, or greenhouse gas emissions. Widespread use of organic fertilizers will help protect ecosystems and reduce costs associated with pollution treatment. In addition, the use of organic fertilizers also enhances the brand value of Vietnamese coffee in the international market, especially in markets that prioritize organic and environmentally

friendly products. This benefits farmers economically and helps the Vietnamese coffee industry strengthen its position in the global supply chain.

One workable approach that directly supports the achievement of the UN's Sustainable Development Goals (SDGs) is using organic fertilizers in coffee production. It promotes, in particular, SDG 13 (environmental protection), SDG 12 (sustainable production and consumption), and SDG 1 (increasing farmers' quality of life). This study offers a foundation for creating a sustainable agricultural policy in Vietnam by supporting organic fertilizers, which will safeguard the environment and raise farmers' incomes.

Building farmer capacity and providing training:

These initiatives are critical to advancing sustainable farming methods. This study highlights the urgent need for comprehensive training programs by demonstrating that farmers' age and educational attainment substantially impact their ability to embrace modern techniques. Training provides new knowledge and helps farmers understand the value and benefits of sustainable methods, thereby increasing their motivation to adopt them in production. Training programs should be designed to target both young and experienced farmers, taking advantage of the strengths of each group. For young farmers, equipping them with modern knowledge and encouraging them to use advanced technology will promote innovation and creativity in production. Meanwhile, training programs for experienced farmers should focus on combining practical experience with new scientific methods, helping them optimize the farming process. This approach ensures that all farmers have the opportunity to improve their productivity.

The study highlights that integrating modern technologies such as soil sensors, automated irrigation systems, and data analytics into training programs will improve their practical application. These technologies help farmers manage resources more effectively, reduce waste, and optimize yields. For example, soil sensors can provide detailed information on soil moisture and nutrients, assisting farmers to adjust irrigation and fertilizer applications more accurately. Combining scientific knowledge with technology will create a generation of farmers who are ready to face the challenges of the future. Climate change and ever-changing markets require farmers to be highly adaptable. Training programs should include content on risk management, agricultural markets, and business skills development. Not only does it help farmers improve their productivity, it also helps them better cope with environmental changes and price fluctuations. Training focusing on flexibility will increase the ability to maintain sustainability in coffee production.

Another important factor is to build a support network between farmers and agricultural experts. Training programs can be organized through workshops, discussion groups, and online forums, where farmers can share experiences and learn from each other. This network will create a sustainable community where members support each other in applying advanced farming methods while encouraging innovation and continuous improvement in coffee production. Training programs not only improve the individual capacity of farmers but also contribute to the sustainable

development of the Vietnamese coffee industry. By improving knowledge and skills, these programs will create a high-quality agricultural workforce ready to meet the increasing requirements of the international market. It means enhancing the competitiveness of Vietnamese coffee and contributing to sustainable economic development in the context of globalization.

Strengthening stakeholder collaboration:

The study highlights that stakeholder collaboration is a prerequisite and an important enabler for successfully implementing sustainable coffee production. Farmers need support from businesses, investors, and governments in accessing necessary resources, such as technology, knowledge, and finance. Collaboration helps create an ecosystem where shared responsibilities and benefits increase production efficiency and ensure sustainable development goals are effectively implemented. One important aspect is establishing collaboration programs between businesses and farmers to support the adoption of sustainable practices. Coffee processing and exporting companies can provide guidance and resources, such as organic fertilizers or advanced irrigation technology, to help farmers transition from conventional to sustainable farming. At the same time, training programs and workshops among stakeholders can help share knowledge and practical experiences, thereby improving sustainable production capacity within the farming community.

Value chain linkages are a core element in ensuring farmers receive fair product value. Businesses can create transparent cooperation mechanisms that help farmers understand the added value of their products at the processing and export stages. This makes economic incentives for farmers and encourages them to adopt sustainable practices to improve product quality. Strong value chain linkages also contribute to promoting engagement between farmers and other stakeholders in the industry. The government is an important intermediary in establishing policy and regulatory frameworks to encourage cooperation between farmers, businesses, and investors. Incentive policies such as subsidies, tax breaks, or financial support for sustainable cooperative models can help strengthen the relationship between stakeholders.

Furthermore, the government can support the construction of necessary infrastructure, such as warehouses, roads, and logistics systems, to facilitate the transportation and storage of sustainable coffee products. Sustainable cooperative models not only improve farmers' income and livelihoods but also enhance the competitiveness of the Vietnamese coffee industry in the international market. The coffee industry can achieve long-term sustainable development by connecting resources and knowledge from multiple stakeholders while ensuring that economic, social, and environmental goals are balanced. This is an important premise for the Vietnamese coffee industry to meet the challenges of the global market and climate change in the future.

Addressing the Land Price Challenge:

High land prices are becoming one of the biggest challenges for sustainable coffee farmers, mainly small-scale farmers. Land costs account for a large portion of total investment, reducing profitability and the incentive to expand cultivation area. This

directly affects sustainable farming practices, as farmers have difficulty investing in technology, organic fertilizers, or advanced production methods. This study has shown that addressing the land price issue is a key factor in ensuring the sustainable development of the coffee industry in Vietnam.

One of the practical solutions proposed is to implement financial support policies such as land subsidies, tax exemptions, and providing preferential loans specifically for sustainable coffee farmers. Land subsidies can help reduce fixed costs, increasing small-scale farmers' access to land. Tax exemptions or reductions would also ease the financial burden, encouraging farmers to invest in improved practices and expand their cultivation areas. In addition, providing preferential loans at low interest rates would support farmers with additional capital to invest in technology and modern farming methods while increasing the motivation to develop sustainable production. In addition to financial support, the study highlights the importance of developing infrastructure, including transportation systems, warehousing, and logistics services. Modern infrastructure will help farmers reduce transportation, storage, and market access costs, minimizing the impact of high land prices. For example, building direct roads connecting production areas to commercial centers or export ports will optimize transportation costs, helping farmers increase profits. Upgraded warehousing and logistics systems will also help farmers preserve products, thereby improving the quality and value of coffee products in the international market.

Rising land prices also require technical assistance programs to optimize land use efficiency. These programs can guide farmers on using intercropping or crop rotation to maximize productivity on available land. In addition, the application of modern technology, such as soil sensors and intelligent irrigation systems, also helps to increase the efficiency of land resource use, reduce costs, and increase productivity. These technical assistance programs address land prices and contribute to building long-term sustainable coffee production. Effective land management and planning are two of the strategic solutions proposed by the study. The government and relevant agencies need to develop reasonable land use plans, prioritizing the development of sustainable coffee-growing areas. This planning will ensure that land is allocated efficiently, making it easy for farmers to access and use land for sustainable farming purposes. Furthermore, establishing concentrated production areas with fully invested infrastructure will help reduce production costs and create agricultural economic clusters, thereby enhancing the competitiveness of the Vietnamese coffee industry.

Solving the land price problem cannot be successful without cooperation among stakeholders, including the government, businesses, investors, and farmers. The government is important in establishing support policies and investing in infrastructure. Businesses and investors can participate in providing finance, technology, and consumption markets for farmers. At the same time, farmer organizations need to be established and supported to act as intermediaries, helping to connect farmers with resources and development opportunities. This cooperation will create a favorable environment, helping to reduce pressure from land prices and promote the comprehensive development of the coffee industry. This study improves

farmers' economic efficiency by addressing land prices through financial support policies, infrastructure development, effective land management, and enhanced cooperation. It contributes to the sustainable development of Vietnam's coffee industry. These solutions address current challenges and lay the foundation for long-term growth in the context of climate change and volatile global markets.

Promoting export capacity and supply chain management:

Expanding export capacity is a core factor in increasing the value of Vietnam's coffee industry in the context of globalization. The study emphasizes that increasing access to international markets helps farmers increase their income and affirms the position of Vietnamese coffee on the world map. Vietnam is a leading coffee exporter, but challenges such as high transaction costs and lack of market information still hinder optimal development. Therefore, policymakers must develop a focused export strategy to improve product competitiveness in the international market. Transaction costs are one of the significant barriers to increasing export capacity. The study proposes measures to reduce these costs, such as simplifying customs procedures, optimizing export processes, and reducing transportation-related fees. Improving export infrastructure, including upgrading ports, warehouses, and transport networks, will significantly reduce transportation costs and increase efficiency in bringing coffee products to international markets. This will not only facilitate farmers and businesses but also improve the competitiveness of the Vietnamese coffee industry.

Another important factor is providing timely and comprehensive information on international markets to farmers and small businesses. The study recommends the establishment of market information support centers where farmers can access data on prices, demand, and quality standards from significant markets such as the US, EU, and Japan. This will help farmers better understand market requirements and help them plan production accordingly, optimize supply chains, and add value to their products. The study also highlights the role of trade promotion programs in promoting coffee exports. International trade fairs, business-to-business conferences, and collaborations with global partners create new opportunities for farmers and businesses. In addition, bilateral and multilateral trade agreements will open access to new markets while reducing trade barriers. Policymakers should support farmers and companies participating in these international events to find new customers and expand their global networks.

An efficient supply chain is the foundation for ensuring Vietnamese coffee products meet strict international standards. The study emphasizes that the application of advanced supply chain management technologies, such as blockchain, to track product origins will enhance the transparency and reputation of Vietnamese coffee in the international market. In addition, building strong relationships between farmers, processors, and exporters will ensure that the entire supply chain operates efficiently, minimizing waste and optimizing profits. Finally, the study recommends focusing on adding value to exported coffee products. This includes investing in deep processing technology to create higher-value products like instant coffee, coffee capsules, or unique organic products. In addition, building a national brand for Vietnamese coffee

will help enhance product recognition and value in the international market. Combined with supply chain management and trade promotion strategies, this effectively increases value and profit for the entire industry.

The above proposals not only address the current problems of the coffee industry but also create conditions for the industry to develop sustainably and compete more strongly in the international market. By reducing transaction costs, improving infrastructure, and managing the supply chain effectively, the Vietnamese coffee industry can maximize its export potential, increase value, and contribute to the development of the national economy.

Integrating modern technology into production:

An intelligent irrigation system is one of the technologies this study strongly suggests to increase coffee production efficiency. This technique reduces water resource waste and boosts coffee yield by precisely regulating irrigation water according to the crop's requirements. Integrating cutting-edge irrigation technology helps farmers save water and preserve natural resources, which satisfies the requirements of sustainable farming, especially in light of climate change and the increasing threat of water scarcity. Soil sensors provide detailed data on soil moisture, pH, and nutrient levels. This study recommends using soil sensors so farmers can monitor soil conditions in real-time, thereby optimally adjusting fertilizer doses. This improves crop productivity and minimizes excess fertilizer, avoiding environmental pollution. Large-scale deployment of soil sensing technology will help shape an effective land management system, improving the quality of coffee products. The study highlights that investing in modern agricultural machinery, such as automatic coffee pickers and solar dryers, can significantly improve production efficiency. These devices reduce manual labor and enhance coffee beans' quality, ensuring uniformity during harvesting and processing. Using modern machinery saves time, reduces production costs, and improves the competitiveness of Vietnamese coffee in the international market. Integrating technology into coffee production requires significant capital, which many small-scale farmers find challenging. The study recommends financial support programs from the government and international organizations, including preferential loans, subsidies, and tax exemptions for technology investments. These programs reduce financial pressure on farmers and encourage them to adopt advanced production methods, thereby contributing to building a sustainable and modern coffee industry.

Training and raising awareness among farmers is an important factor in ensuring the success of integrating modern technology. The study emphasizes that training programs on using and maintaining new technological equipment and their benefits for sustainable production must be widely implemented. Practical courses, workshops, and manuals can help farmers master the skills to apply technology effectively and sustainably.

In addition to increasing productivity and economic efficiency, modern technology helps minimize adverse environmental impacts. For example, automatic irrigation systems and soil sensors reduce resource waste and limit nutrient leaching into water

sources, minimizing pollution. Applying solar energy in coffee processing also helps reduce greenhouse gas emissions, which aligns with green production standards and international market requirements. These proposals improve production efficiency and contribute to building a more sustainable coffee industry. Integrating modern technology into coffee production addresses current challenges. It creates conditions for the Vietnamese coffee industry to thrive in the future, especially in the context of increasingly complex global competition and climate change.

Encourage intercropping and diversification:

Intercropping is not only a method to improve land use efficiency but also a way to increase farmers' income. Research shows that planting high-value crops such as pepper, avocado, or legumes with coffee can help farmers optimize the yield per acre of land. In addition, the diversity in crop types also minimizes economic risks if coffee prices fluctuate in the market. The application of intercropping, therefore, brings dual economic and environmental benefits, promoting stability and sustainability in agricultural production.

Intercropping is important in improving biodiversity in growing areas, contributing to the balance of ecosystems. The combination of coffee and other crops, such as legumes, provides additional nutrients to the soil and helps control pests naturally, reducing the need for pesticides. This protects the environment and creates a stable ecosystem, thereby increasing the productivity of coffee and intercropping. Another practical benefit of intercropping is to minimize soil erosion in coffee-growing areas on hills or sloping land. Intercropping crops with deep roots, such as pepper or avocado, helps to hold the soil firmly, preventing the leaching of nutrients from the soil. Furthermore, using legumes in intercropping also provides a natural nitrogen source, significantly improving soil quality without requiring large amounts of chemical fertilizers. This is in line with sustainable production goals, minimizing negative impacts on the environment.

The government must implement technical and financial support programs to encourage farmers to adopt intercropping. Agricultural organizations and research institutes can provide expertise in designing optimal intercropping systems, selecting crops suitable for local conditions, and effectively managing resources such as water and soil nutrients. Financial subsidies or tax breaks for farmers who practice intercropping can also provide a strong incentive to invest in this sustainable farming method. One effective way to promote intercropping is to implement pilot models in large coffee-growing areas. These models can clearly illustrate the economic and environmental benefits of intercropping, thereby convincing farmers to adopt it more widely. At the same time, communication programs and agricultural seminars should focus on raising awareness of the benefits of intercropping, emphasizing that this method increases productivity and protects the environment in the long term.

The government and NGOs should work together to develop policies to encourage intercropping, from funding research to supporting practical application. Further research on intercropping crops suitable for Vietnam's climate and soil conditions will help optimize this method. The Vietnamese coffee industry's ability to produce

sustainably can also be increased by encouraging international cooperation to benefit from the experiences of nations like Brazil and Colombia that have successfully used intercropping. By implementing intercropping, Vietnamese coffee may gain a competitive edge in the global market. Coffee products produced from sustainable intercropping systems can meet consumers' increasing demand for environmentally friendly food. Sustainable coffee brands from intercropping systems help increase product value and affirm Vietnam's position in the global coffee industry. Encouraging intercropping is a technical solution and a sustainable development strategy for the Vietnamese coffee industry. The study emphasizes that strong support from policy, finance, and technology is needed for this method to be widely applied. With the economic, environmental, and social benefits intercropping brings, this will be a strategic direction to help the Vietnamese coffee industry develop sustainably in climate change and increasingly fierce market competition.

7. CONCLUSION

7.1 Conclusion

The study on the cost-effectiveness and profitability of sustainable coffee production in Vietnam has provided a comprehensive picture of the differences in economic and technical efficiency between farmers: those applying certified sustainable farming methods and conventional coffee growers. Using the Cobb-Douglas production function, the study quantified the influencing factors and clarified the challenges and opportunities for stakeholders, including coffee growers and local authorities. The analysis results showed a significant difference in technical efficiency (TE), with the average rate of sustainable farmers reaching 96.17%, outperforming the 75.72% of the conventional group. This implies that sustainable farmers can improve their productivity by 3.83%, while the traditional group has the potential to increase by 24.28% if improved practices are applied. This finding contrasts with previous studies in many other regions and confirms the potential of sustainable farming to enhance production efficiency and protect the environment.

One of the important factors mentioned in the study is the role of land area. The results show that larger land areas positively impact productivity for both groups of farmers, suggesting that production scale plays an important role in optimizing production efficiency. In particular, in the context of increasingly fierce market competition, supporting farmers to expand their area or use land more efficiently can create a significant breakthrough in productivity. In addition to land area, fertilizer is a key economic factor affecting production efficiency. Organic fertilizers have been shown to bring outstanding benefits, especially for sustainable farmers, helping to improve productivity while minimizing negative environmental impacts. In contrast, inorganic fertilizers, such as NPK, are more suitable for conventional farming but pose a risk of soil degradation if not properly managed. Combining organic and inorganic fertilizers is considered a balanced strategy that improves yields and optimizes economic returns for both groups of farmers.

In addition, the study highlights the role of sustainability certification in enhancing product value and promoting biodiversity conservation. Certification is a tool to access international markets and helps build a brand reputation for Vietnamese coffee. However, to achieve certification, farmers often face high initial investment costs, requiring substantial support from the government and international organizations. Along with that, external factors such as land prices and market demand also deeply affect coffee production. Rising land prices pose a significant challenge for farmers, mainly small-scale sustainable coffee growers, which can reduce production scale and reduce farming efficiency. The relationship between land prices, output, and exports highlights the need for economic support policies, including controlling land prices and providing preferential loans to farmers. Another challenge identified is the lack of advanced technology and modern farming techniques in many rural areas. Applying new technologies such as smart sensors, automated water management systems, and real-time data analysis can help farmers improve production efficiency

and optimize resources. Technical training programs also play an essential role in improving farmers' skills, helping them grasp and apply sustainable farming methods effectively.

Although sustainable farming brings clear benefits, the study also shows that transitioning from conventional to sustainable agriculture requires a long-term process and comprehensive support. Farmers need to be encouraged through financial support mechanisms, technical training, and raising awareness of the value of sustainability for both the economy and the environment. Local governments must act as intermediaries, connecting farmers with international certification organizations and facilitating their participation in global supply chains. At the same time, national policies must focus on developing rural infrastructure, improving the quality of production support services, and promoting public-private partnerships to address farmers' economic and social challenges.

This study highlights that sustainable coffee production is not only an economic option but also a long-term development strategy, meeting the demands of the global market and protecting natural resources. From an environmental perspective, sustainable practices such as using organic fertilizers, biodiversity conservation, and adequate water resource management improve soil quality and ensure a long-term ecosystem for future generations. From an economic perspective, applying sustainable methods helps increase productivity, product competitiveness, and expand export markets. However, close coordination between farmers, authorities, and international organizations is needed to promote comprehensive development. Investment in education, technology, and financial support will be key to helping Vietnam become a leading center for sustainable coffee production in the world. Sustainable coffee production in Vietnam faces many challenges, from pressure on land prices and initial investment costs to a lack of infrastructure and technology. However, the outstanding economic, environmental, and social benefits show that this is an indispensable direction for sustainable development. This study has pointed out specific opportunities and solutions, emphasizing that the Vietnamese coffee industry can make great strides with appropriate support policies, ensuring long-term benefits for farmers and the national economy.

7.2 Limitations and further studies

This study makes significant contributions, but future research needs to address some limitations. First, the study did not consider external factors such as climate change and policy regulations in depth, although these factors strongly influence coffee production. Climate change, with changes in temperature, rainfall, and drought, significantly impacts coffee productivity, especially in sensitive areas such as the Central Highlands. Government support policies such as incentives for sustainable certification or financial support also play an essential role but were not mentioned in detail.

The data in the study are mainly based on surveys at one point in time, limiting the assessment of long-term trends. The author recommends periodic surveys, at least

every three years, to monitor changes in production efficiency and the impact of market factors. This will provide more accurate data to guide appropriate support policies.

The scope of the study is limited to Vietnam and has not been compared with other major coffee-exporting countries such as Brazil, Colombia, or Ethiopia. The differences in production scale, farming techniques, and policies between these countries can provide additional functional comparative perspectives, helping Vietnam learn from experience and improve its production strategy. Furthermore, the study used data mainly from Scopus and Web of Science. Still, it did not consider studies in local languages, leading to the possibility of missing important documents in the global context.

In addition, the study focused on quantitative analysis and did not delve into the social and cultural factors that influence farmers' farming decisions. Farmers' beliefs, psychology, and motivations in transitioning to sustainable production must be considered in future studies. Adding qualitative methods will shed light on these barriers and motivations.

Finally, research has not yet explored the role of technology and innovation in coffee production, such as the application of AI, IoT, or resource management technology. These advances have great potential to improve productivity and protect the environment. Technology integration will be an essential direction for improving coffee production efficiency. In short, future research must expand the scope and incorporate more methods to provide a more comprehensive view and practical applications.

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APPENDIX 1A: Interviewee

No.	Full name	Interviewing date	Place and Organization	Experience/years working in the locality
Local and regional officials				
1	Nguyen Kim Tue Nhi	10.08.2023	Daklak	5 years
2	Nguyen Thanh Binh	16.07.2023	Lamdong	6 years
3	Tran Duc Tho	23.07.2023	Gialai	7 years
4	Nguyen Quang Chinh	23.07.2023	Gialai	6 years
5	Pham Ngoc My	09.08.2023	Daknong	6 years
6	Tran Ngoc Hoa	09.08.2023	Daknong	5 years
7	Ngo Quang Hung	16.07.2023	Lam Dong	8 years
8	Le Cong Thien	10.08.2023	Daklak	5.5 years
Farmers				
9	Hoang Van Long	09.08.2023	Daklak	11 years
10	Tran Huu Truong	07.08.2023	Daknong	10 years
11	Kben	15.07.2023	Lamdong	20 years
12	Pham Tan Sinh	15.07.2023	Lamdong	18 years
13	Dao Huu Tan	22.07.2023	Gialai	14 years
14	Vo Van Linh	08.08.2023	Daknong	12 years
15	Ma van Hung	09.08.2023	Daklak	16 years
16	Vu Thi Xuan	23.07.2023	Gialai	12 years

APPENDIX 1B: Interviewee

1. Introduce yourself and your farm.

- Name information
- Farm area
- Total number of years growing coffee
- Whether the farm has achieved certification or not

2. What is the main type of coffee tree you grow?

- The farm mainly grows Arabica/Robusta coffee. But Arabica coffee is grown less than Robusta because the altitude conditions suitable for Arabica are only met in a few areas, so the growing area is very small.

- Currently, most of the interviewed households do not intend to use new varieties because the farm is not too large, and applying new varieties requires a long waiting time, affecting the farm's economy. Mainly, use old and high-yielding varieties.
- Coffee is grown intercropped with other plants such as persimmon, maccadamia, durian, jackfruit, pepper, avocado, grapefruit, and lemon. Among them are Durian and Maccadamia. Ranging from 20 to 300 durian trees and 50 to 500 Maccadamia trees (depending on each household and land area).

3. What are the climatic and topographic conditions in your coffee-growing area?

- Last season's hot weather lasted a little longer, causing a serious decrease in water resources for crops in the Central Highlands. However, in the 2021–2022 season, the weather from the beginning of the season until now has been relatively favorable. The rainy season comes early, unlike previous years during the irrigation period, ensuring enough water for coffee plants. But during the current harvest period, provinces such as Gia Lai, Kon Tum, and Dak Lak have a lot of rain, with large amounts of rain, which will affect the quality of coffee in the crop year. While farmers' processing conditions (drying) are still very limited.

4. Do you use organic coffee growing methods or inorganic fertilizers and chemicals?

- The farm has applied organic and certified coffee growing methods, and we limit the use of inorganic fertilizers to the maximum extent possible to meet the regulations of the certification organization.
- The farm has been using organic fertilizer for a long time, so the nutrients in the soil have partly recovered, and the productivity of the last crop was also better.
- The farm has only just applied organic, so I haven't seen any good results yet. Productivity seems to be decreasing, so I'm also considering whether to continue pursuing the goal of achieving sustainable certification or not because I'm worried about The money from selling coffee is not enough to cover other costs, and in the future, when there are numerous families producing organic coffee, the selling price of this coffee will not be as good as expected. My family's main occupation is growing coffee, and we rely on this coffee farm for all our living expenses.

5. What challenges do you face when growing coffee in this region?

- We often encounter challenges such as climate change, pests, and fluctuating coffee prices. This sometimes affects our output and profits.
- The coffee supply chain still has to go through chain of intermediaries, logistics costs are increasingly high, and the added value from coffee beans is even more difficult for farmers who directly produce coffee, which is small and fragmented.
- Besides, the Central Highlands are a highland area; the terrain is quite rugged, and travel is more difficult than in the plains. Larger farms are often farther away from the city.
- Due to rising prices of input materials (gasoline, fertilizer, labor, etc.), farmers' investment in coffee trees has decreased. Fertilizer costs have increased by 70%

compared to the 2020–2021 crop, while coffee purchasing prices at the garden have not increased in the last 6 months of 2022.

- Find harvest workers because most young workers in the area go to big cities to work. When highly educated young people return, they do not accept manual work such as harvesting or tending coffee.

Currently, many farms that I know have achieved sustainability certifications, but for me, it is difficult for my farm to meet the strict regulations from the issuing organization.

- The issue of training for coffee farmers is also a matter of great concern for local authorities when there is a lack of specialized agricultural extension officers assigned to land reclamation at the State Ministry of Agriculture who are regularly rotated. Agricultural extension officers, even after attending specific soil reclamation training programs, need to be effectively remediated to provide additional information for reclamation programs at the farm level.

6. How do you manage sustainability issues in coffee growing?

- We take measures to protect the environment, maintain biodiversity, and focus on sustainable tree planting. Take advantage of available organic fertilizer to regenerate soil. I also research how to increase productivity by applying certain techniques in irrigation and pest prevention.
- I also cooperate with social organizations and participate in organizations that support some farmers who have not yet achieved certification to achieve certification like me and ensure sustainability in coffee growing.
- It can be said that farming households to pursue sustainable production is a difficult process for coffee farmers themselves and local authorities.

7. Do you have any plans or goals for the future of your farm and coffee production?

- I look forward to expanding production and improving the quality of our coffee. We (a group of coffee growers around my farm) also plan to cooperate with partners to increase product value and improve income.
- Currently, we are often pressured by prices due to the thick layers of intermediaries, so I hope we will find a way or local officials will have a good plan to avoid going through too many intermediaries.

8. Based on your experience, do you have any advice or messages for people interested in coffee farming or this career?

- I advise people interested in growing coffee to learn carefully about the process and how to adapt to climate change. Currently, the climate is changing erratically, unlike before; if the old planting method is maintained, there will not be high productivity.
- The trend is that young people think too simply about growing crops, so more and more young people leave the city to return to the garden to start a business but do not achieve the desired results because growing coffee is not simple and requires investment and experience.

- The current trend is organic coffee, so coffee growers who have not yet achieved certification should participate.

9. In the near future, I will conduct a survey of a large number of coffee-growing households in several areas. However, I do not have much experience in growing coffee, so I have created a questionnaire. Please look at it and give me feedback.

- Reducing the season because I myself have annual records but cannot complete this questionnaire.

- It's quite detailed and complete, but I'm not sure the people surveyed can fill it out completely.

- Most people are not good at technology; you should go directly to the household instead of sending a link.

Note: But the author still keeps the detailed questionnaire in the hope of getting more information, reducing it from 5 seasons to 3 season

APPENDIX 1C: Questionnaire

Household survey

Date..... Month/2022

General information

Full name:

What is the gender of respondent?	<input type="radio"/> Male	Is the respondent household's head?	<input type="radio"/> Yes
	<input type="radio"/> Female		<input type="radio"/> No
What is the marital status of the respondent?	<input type="radio"/> Married		
	<input type="radio"/> Single		
	<input type="radio"/> Widow(er)		
What is your and your partner's age?	Respondent	Husband / Wife	
	
What is your and your partner's ethnicity?	<input type="radio"/> Kinh	<input type="radio"/> Kinh	
	<input type="radio"/> Other, please specify	<input type="radio"/> Other, please specify	
	
		<input type="radio"/> N/a	
What is the name of the village you live in?			
What is the name of the commune you live in?			
Education level of the respondent	<input type="radio"/> None	<input type="radio"/> None	
	<input type="radio"/> Primary school not finished	<input type="radio"/> Primary school not finished	

	<input type="radio"/> Primary school finished	<input type="radio"/> Primary school finished
	<input type="radio"/> Secondary school not finished	<input type="radio"/> Secondary school not finished
	<input type="radio"/> Secondary school finished	<input type="radio"/> Secondary school finished
	<input type="radio"/> High school not finished	<input type="radio"/> High school not finished
	<input type="radio"/> High school finished	<input type="radio"/> High school finished
	<input type="radio"/> More advanced	<input type="radio"/> More advanced
		<input type="radio"/> N/A
If not, what is relationship of respondent to household head?	<input type="radio"/> Wife	
	<input type="radio"/> Husband	
	<input type="radio"/> Daughter	
	<input type="radio"/> Son	
	<input type="radio"/> Other relative	
	<input type="radio"/> Other, specify	
	
How many people in your family?	.....
How many children (<18 years) do you have?	.....
To what extent are you/family dependent on coffee farming? (%)	.....
Is there any child who had to stop schooling?	.....

And how many of them went/ have been to school?	.....
Does your child(ren) have to undertake farming activities	<input type="radio"/> No <input type="radio"/> Yes
How many years have you been active in coffee farming?	.....
Are you member of any coffee related organization, program or project, if so, which?	

	Crop year 2021/2022
Cooperative	<input type="radio"/> No <input type="radio"/> Yes
Farmers union	<input type="radio"/> No <input type="radio"/> Yes
Research project	<input type="radio"/> No <input type="radio"/> Yes
Training project	<input type="radio"/> No <input type="radio"/> Yes
Certification project	<input type="radio"/> No <input type="radio"/> Yes
Other, specify:	<input type="radio"/> No <input type="radio"/> Yes
Did/do you need credit to cover the costs of coffee production?	<input type="radio"/> No <input type="radio"/> Yes <input type="radio"/> N/A
	<input type="radio"/> Owner

In crop years, what type of ownership did you have of the farm?	<input type="radio"/> Rent or lease
	<input type="radio"/> State land
	<input type="radio"/> Other, specify

Producing information

	Crop year 2019/2020	Crop year 2020/2021	Crop year 2021/2022
Capital investment in coffee production	.....(millions )	.....(millions )	.....(millions)
How long is the return on investment?	.....(days)	.....(days)	.....(days)
What was/is the size of your farm in ha?	.....(ha)	.....(ha)	.....(ha)
What was/ is the size of your farm in ha for different types of coffee?	Robusta .....(ha)	Robusta .....(ha)	Robusta .....(ha)
	Arabica .....(ha)	Arabica .....(ha)	Arabica .....(ha)
	Others .....(ha)	Others .....(ha)	Others .....(ha)
How much dried bean coffee in Mt did you produce?	.....(tons)	.....(tons)	.....(tons)
Did/do you use shade trees in your coffee field(s)?	<input type="radio"/> No <input type="radio"/> In some of my fields <input type="radio"/> In all of my fields	<input type="radio"/> No <input type="radio"/> In some of my fields <input type="radio"/> In all of my fields	<input type="radio"/> No <input type="radio"/> In some of my fields <input type="radio"/> In all of my fields
Did/do you use windbreaks in your coffee field(s)?	<input type="radio"/> No <input type="radio"/> In some of my fields <input type="radio"/> In all of my fields	<input type="radio"/> No <input type="radio"/> In some of my fields <input type="radio"/> In all of my fields	<input type="radio"/> No <input type="radio"/> In some of my fields <input type="radio"/> In all of my fields
Anti-erosion	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes

What is the main type of irrigation that you used?	<input type="radio"/> Flooding <input type="radio"/> Dripping <input type="radio"/> Sprinkling <input type="radio"/> (N/A)	<input type="radio"/> Flooding <input type="radio"/> Dripping <input type="radio"/> Sprinkling <input type="radio"/> (N/A)	<input type="radio"/> Flooding <input type="radio"/> Dripping <input type="radio"/> Sprinkling <input type="radio"/> (N/A)
What is the total amount of incoming water for a crop?	.....(m2)	.....(m2)	.....(m2)
What is the estimated total cost of watering the coffee	.....(millions)	.....(millions)	.....(millions)
Did/do you have access to electricity at the farm house?	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
How much chemical fertiliser of which type did you apply on your coffee planted area during the last season?	Crop year 2019/2020	Crop year 2020/2021	Crop year 2021/2022
Urea	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of Urea?	.....(vnd/kg)	.....(vnd/kg)	.....(vnd/kg)
Sulphate Ammonium (SA)	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of SA?	.....(vnd/kg)	.....(vnd/kg)	.....(vnd/kg)
Phosphorus	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of Phosphorus?	.....(vnd/kg)	.....(vnd/kg)	.....(vnd/kg)

Potassium	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of Potassium?	.....(vnd/kg) )	.....(vnd/kg) )	.....(vnd/kg) kg)
NPK	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of NPK?	.....(vnd/kg) )	.....(vnd/kg) )	.....(vnd/kg) kg)
Other, specify: (..... .....)	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of the above fertiliser?	.....(vnd/kg) )	.....(vnd/kg) )	.....(vnd/kg) kg)
Other, specify: (..... .....)	.....(kg)	.....(kg)	.....(kg)
What was the average price per kilogram of the above fertiliser?	.....(vnd/kg) )	.....(vnd/kg) )	.....(vnd/kg) kg)
Did you apply compost, mulch or organic manure during the last crop year?	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
How much did you apply	.....(tons)	.....(tons)	.....(tons)

How much did you spend for these organic fertilisers?	.....VND O N/A	.....VND O N/A	.....VND O N/A
Did you use insecticides?	O No O Yes	O No O Yes	O No O Yes
What is the amount of insecticides applied?	.....(litter/kg)	.....(litter/kg)	.....(litter/kg)
How much did you spend on insecticides during the last season?	.....VND O N/A	.....VND O N/A	.....VND O N/A
What are common brands of the insecticides (indicate 3 brands)?	..... ..... ..... ..... .....	..... ..... ..... ..... .....	..... ..... ..... ..... .....
Did you use herbicide?	O No O Yes	O No O Yes	O No O Yes
What is the amount of herbicides applied?	.....(litter/kg)	.....(litter/kg)	.....(litter/kg)
How much did you spend on herbicides during the last season?	.....VND O N/A	.....VND O N/A	.....VND O N/A
How much did you spend on herbicides during the last season?	..... ..... ..... ..... .....	..... ..... ..... ..... .....	..... ..... ..... ..... .....

Did you use fungicides?	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
What is the amount of fungicides applied?	.....(litter/kg)	.....(litter/kg)	.....(litter/kg)
How much did you spend on fungicides during the last season?	.....VND <input type="radio"/> N/A	.....VND <input type="radio"/> N/A	.....VND <input type="radio"/> N/A
What are common brands of the fungicides (indicate 3 brands)?	..... ..... ..... ..... .....	..... ..... ..... ..... .....	..... ..... ..... ..... .....
Applying advanced methods (breeding improvement, mechanization)	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
During last season, did you use credit?	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
How much money did you borrow last season?	.....VND	.....VND	.....VND
How much interest did you pay on that loan?	.....VND	.....VND	.....VND

<p>If so, what was/is the main source of credit for you?</p>	<p> <input type="radio"/> Bank <input type="radio"/> People's Credit Fund <input type="radio"/> Collector <input type="radio"/> Exporter <input type="radio"/> Projects from social organisations <input type="radio"/> Family <input type="radio"/> Friends <input type="radio"/> Other, please specify <hr/> <input type="radio"/> N/A </p>	<p> <input type="radio"/> Bank <input type="radio"/> People's Credit Fund <input type="radio"/> Collector <input type="radio"/> Exporter <input type="radio"/> Projects from social organisations <input type="radio"/> Family <input type="radio"/> Friends <input type="radio"/> Other, please specify <hr/> <input type="radio"/> N/A </p>	<p> <input type="radio"/> Bank <input type="radio"/> People's Credit Fund <input type="radio"/> Collector <input type="radio"/> Exporter <input type="radio"/> Projects from social organisations <input type="radio"/> Family <input type="radio"/> Friends <input type="radio"/> Other, please specify <hr/> <input type="radio"/> N/A </p>
<p>During last season, did you use hired labour?</p>	<p> <input type="radio"/> No <input type="radio"/> Yes </p>	<p> <input type="radio"/> No <input type="radio"/> Yes </p>	<p> <input type="radio"/> No <input type="radio"/> Yes </p>
<p>How many man-days did you and your family members spend on your coffee production?</p>	<p>.....days</p>	<p>.....days</p>	<p>.....days</p>
<p>How many man-days did you exchange with other farmers or you relatives?</p>	<p>.....days</p>	<p>.....days</p>	<p>.....days</p>
<p>How many man-days did you exchange with other farmers or you relatives?</p>	<p>.....days</p>	<p>.....days</p>	<p>.....days</p>

How much money per man-day did you pay for hired labour?	.....VND	.....VND	.....VND
How much did you spent last season on the following the warehouse facilities?	.....VND	.....VND	.....VND
How much did you spent last season on the following the renting machines?	.....VND	.....VND	.....VND
How much did you spent last season on the following the transportation?	.....VND	.....VND	.....VND
How much did you spent last season on the following thess drying costs?	.....VND	.....VND	.....VND
Other production cost, please specify:	.....VND	.....VND	.....VND
Are you certified, please specify:	<input type="radio"/> No <input type="radio"/> Yes,	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
When did you get certified?	.....month/ year		
Can you indicate if certification has led to additional costs in cash, and how much per season?	.....VND <input type="radio"/> N/A	.....VND <input type="radio"/> N/A	.....VND <input type="radio"/> N/A

Are you certified by other certification, please specify:	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
When did you get certified?	.....month/ year		
Could you indicate if the certification has led to additional costs in cash, and how much per season?	.....VND <input type="radio"/> N/A	.....VND <input type="radio"/> N/A	.....VND <input type="radio"/> N/A
Attending agronomy trainings	.....days <input type="radio"/> N/A	.....days <input type="radio"/> N/A	.....days <input type="radio"/> N/A
Training on land reclamation	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes	<input type="radio"/> No <input type="radio"/> Yes
Irrigation method	<input type="radio"/> Tap water <input type="radio"/> Water from wells <input type="radio"/> Other, please specify	<input type="radio"/> Tap water <input type="radio"/> Water from wells <input type="radio"/> Other, please specify	
Amount of irrigation water per hectare	.....m ³	.....m ³	.....m ³

Sales information	Crop year 2019/2020	Crop year 2020/2021	Crop year 2021/2022
Average price per unit (VND/kg)			
Total revenue (VND)			

Institutional environment

Did you attend agronomy trainings provided by following organisations?	Crop year 2019/2020	Crop year 2020/2021	Crop year 2021/2022
Extension services	O No O Yes	O No O Yes	O No O Yes

LIST OF PUBLICATIONS OF THE AUTHOR

Journal Publications:

- An, Tran Van Nguyen and Nhan, Do Thi Thanh and Novak, Petr (2022). BUSINESS STRATEGY DURING COVID PANDEMIC EVENT: SURVIVAL PLANS OF INSTANT COFFEE MANUFACTURERS IN VIETNAM. Vol 25, issue No 2, 18 pages, ISN 2081-7452, 10.17512/pjms.2022.25.2.23
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Proceedings:

- An, Tran Van Nguyen (2021). Sustainable Development Practices against Contemporary Urbanization toward the Effectiveness of Ho Chi Minh City. Proceeding: Value Co-creation in Crisis Vol 2 page 115-121, Peradeniya University International Management Research Sessions, ISSN 2714-1403.
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- An, Tran Van Nguyen and Thao, Phuong Do and Tuan, Bach Le (2022). DIVIDEND POLICY AND INVESTMENT OPPORTUNITY: EVIDENCE FROM VIETNAMESE LISTED FIRMS. Conference: International Conference on Blockchain and Advanced Financial Management 2022 1st Edition, Organization: Ton Duc Thang University, Ho Chi Minh City, Vietnam.

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- Logistics Executive at Sucafina Group Switzerland in Coffee sector.

Academic/ Research interests

Knowledge Management, SMEs Business, Corporate Business, Business model analysis, Coffee industry, Research Statistics, Sustainable development, Agricultural sector.

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**Factors affecting sustainable production with Economic growth in
Coffee Industry: Evidence from Vietnam**

Faktory ovlivňující udržitelnou produkci s ekonomickým růstem v kávovém
průmyslu: Studie z Vietnamu

Doctoral Thesis

Published by: Tomas Bata University in Zlín,
nám. T. G. Masaryka 5555, 760 01 Zlín.

Edition: 5pcs

Typesetting by: An Tran Van Nguyen

This publication has not undergone any proofreading or editorial review.

Publication year: 2025