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

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Doctoral Thesis Summary

Tomas Bata University in Zlín

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Faculty of Management and Economics

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

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ABSTRACT

The study used the Cobb-Douglas production function to evaluate the cost-effectiveness and profitability of sustainable coffee production in four of the largest coffee-growing provinces in Vietnam. By analyzing data from 864 farming households, the study compared the performance of sustainable and conventional coffee growers. The results showed that contrary to initial predictions, sustainable coffee production was more efficient than traditional methods. Important factors affecting yields include farm size, organic fertilizers, and certification. Expanding the planted area contributed to increased yields in both production models. In particular, organic fertilizers increased yields protected the environment, and maintained biodiversity, while inorganic fertilizers (NPK) significantly impacted conventional coffee. Combining these two fertilizers promoted growth and profitability in both farming systems. Furthermore, actual land prices also have significant effects on coffee output. The study confirms that sustainable coffee production is more cost-effective and brings economic and environmental benefits. The research results provide helpful information for coffee growers, local authorities, and policymakers in Vietnam and can be widely applied.

ABSTRAKT

Studie použila produkční funkci Cobb-Douglas k vyhodnocení nákladové efektivity a ziskovosti udržitelné produkce kávy ve čtyřech největších provinciích pěstujících kávu ve Vietnamu. Analýzou údajů z 864 zemědělských domácností studie porovnávala výkonnost udržitelných a konvenčních pěstitelů kávy. Výsledky ukázaly, že na rozdíl od původních předpovědí byla udržitelná produkce kávy efektivnější než tradiční metody. Důležité faktory ovlivňující výnosy zahrnují velikost farmy, používání organických hnojiv a certifikaci. Rozšiřování plochy osázené kávovníky přispělo ke zvýšení výnosů v obou produkčních modelech. Zejména organická hnojiva nejen zvyšovala výnosy, ale také chránila životní prostředí a udržovala biologickou rozmanitost, zatímco anorganická hnojiva (NPK) měla významný dopad na konvenční pěstování kávy. Kombinace těchto dvou druhů hnojiv podpořila růst a ziskovost v obou zemědělských systémech. Dále skutečné ceny půdy měly významný vliv na produkci kávy. Studie potvrzuje, že udržitelná produkce kávy je nákladově efektivnější a přináší ekonomické i environmentální výhody. Výsledky výzkumu poskytují užitečné informace pěstitelům kávy, místním úřadům a tvůrcům politik ve Vietnamu a mohou být široce aplikovány.

1. INTRODUCTION

1.1. Coffee production situation

Coffee is one of the most consumed agricultural commodities globally, facing significant environmental, social, and economic challenges within the framework of sustainable development (Rubio-Jovel, 2023). Sustainable production certification is critical for addressing these challenges, enhancing product value, and encouraging environmentally friendly practices while improving farmers' livelihoods (d'Albertas et al., 2023; Blackmore et al., 2012). Certified coffee often achieves higher market prices and aligns with growing consumer demand for sustainable and health-conscious products (Astuti et al., 2015; Lee et al., 2012). Vietnam, the world's second-largest coffee exporter after Brazil, contributed 14.2% of global coffee exports in 2021, primarily Robusta coffee. However, the Vietnamese coffee industry faces environmental issues, including soil degradation due to chemical fertilizers and groundwater depletion from unsustainable irrigation practices (D'haeze et al., 2005; Matissek et al., 2012). Despite these challenges, only 10% of Vietnam's coffee production is certified sustainable, raising questions about certification's effectiveness and economic benefits (Tadesse et al., 2014). Additionally, fluctuating global coffee prices and unsustainable farming methods driven by competition exacerbate financial pressures on farmers (Marsh, 2007).

This study focuses on sustainable growth in Vietnam's coffee sector, analyzing data from 1,500 coffee producers in Dak Lak, Lam Dong, Dak Nong, and Gia Lai during 2013–2020. The research highlights the need for sustainable policies to address key challenges and contribute to the Sustainable Development Goals for responsible agriculture and consumption.

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

Vietnam is the world's second-largest coffee producer and exporter, following Brazil, with green coffee exports reaching 24.92 million bags (1.5 million tons) in 2021–2022 and projected to increase to 30.93 million bags in 2022–2023 (USDA, 2022). Despite production challenges, Vietnam benefits from favorable weather conditions, stable cultivation activities, and high-yield, pest-resistant varieties. However, rising production costs, especially fertilizers (70% increase compared to 2020–2021), and fluctuating coffee prices have pushed farmers toward using organic alternatives, impacting yields (USDA, 2022).

Domestically, coffee consumption has surged due to post-COVID-19 recovery and increased demand for instant coffee. In 2022, coffee exports rose significantly, with volume increasing by 13.8% and value by 32%, totaling $4 billion. The European Union (EU) remains Vietnam's largest market, accounting for 39% of total exports, supported by tariff benefits from the EVFTA. However, rising EU sustainability standards, including bans on deforestation-linked products, present new challenges for exporters. While Vietnam's coffee exports show strong growth, competition from Brazil and Indonesia, rising production costs, and domestic price fluctuations pose hurdles. In the 2021–2022 crop year, domestic coffee prices rose by 25%, with productivity reaching 28.2 tons per hectare, the highest since 2005. Vietnam's coffee sector, with its potential for sustainable growth, is integral to global coffee production trends.

1.3. Research gaps

Sustainability attributes are gaining popularity among coffee consumers, with customers willing to pay more for organic certifications, particularly from emerging markets (Van Loo et al., 2015; Basu & Hicks, 2008). However, contradictions exist in the literature regarding the benefits of certification. While some studies argue certification improves biodiversity (Hardt et al., 2015) and environmental protection (Ibanez & Blackman, 2016), others suggest it has minimal economic benefits for farmers, generating lower yields compared to conventional methods (Bolwig et al., 2009; Chiputwa et al., 2015; Lyngbæk et al., 2001). Additionally, sustainable coffee practices often produce mixed results for environmental outcomes, with limited evidence supporting their broader impacts (Castro-Tanzi et al., 2012).

In Vietnam, the world's second-largest coffee producer, many farmers rely on low-price liquidation strategies instead of adopting certifications due to the high costs and restrictions associated with sustainability standards (Basu & Hicks, 2008). This approach exacerbates environmental degradation and soil depletion (Ho, 2018). Furthermore, the small, fragmented farm sizes in Vietnam complicate comparisons between the economic efficiency of certified and non-certified farms, creating a need for empirical evidence to support this distinction.

Although some studies focus on coffee production in Vietnam, most are limited to areas like Dak Lak (Amarasinghe et al., 2015; Nguyen & Sarker, 2018). Fewer studies cover multiple provinces, such as Lam Dong, Dak Lak, and Gia Lai (Ho, 2018; Le et al., 2020). This study addresses this gap by including data from all four central coffee-producing provinces, offering a more comprehensive view of production efficiency. Additionally, this research is the first to explore how real estate prices impact coffee production in Vietnam, aiming to provide evidence-based recommendations for government agencies to mitigate the effects of rising real estate costs.

1.4. Research problem, Research question and research objective

Vietnam is a leading global coffee producer, yet its export value per ton remains below the global average. While sustainable certification is increasingly recognized for its potential to enhance coffee value and secure long-term industry production (VICOFA), its practical application in Vietnam lacks large-scale analysis. Previous studies, such as Ho (2018) and Viet et al. (2019), highlight technical, socioeconomic, and geographic factors influencing coffee production but fail to address the broader scope of sustainability across certified and non-certified farmers. Indirect factors like real estate prices and macroeconomic conditions, such as inflation rates and average economic profit per hectare, are also underexplored in their impact on production yield.

Research question:

This study examines technical inefficiencies and compares the financial gains of certified sustainable and non-certified coffee production. It introduces a novel perspective of land prices on crop productivity while investigating the factors influencing productivity and efficiency. The research explores three key questions:

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

RQ2: How do several factors (e.g., 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 (e.g., real estate price (PRE), total value of coffee exports (EXP), average production (AVY), and inflation rate (INF)) influence the production yield?

Research Objectives:

To address these questions, the study sets the following objectives:

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

RO2: To evaluate the impact of demographic and farming process factors (e.g., AGE, EDU, ITC, AAM) on technical inefficiencies in coffee production.

RO3: To assess the influence of external factors (e.g., PRE, EXP, AVY, INF) on production output for certified and non-certified households.

This approach provides insights into the comparative advantages of certified versus non-certified coffee production and the broader economic factors impacting the industry.

1.5. 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 processl is summarized in figure 1.1.

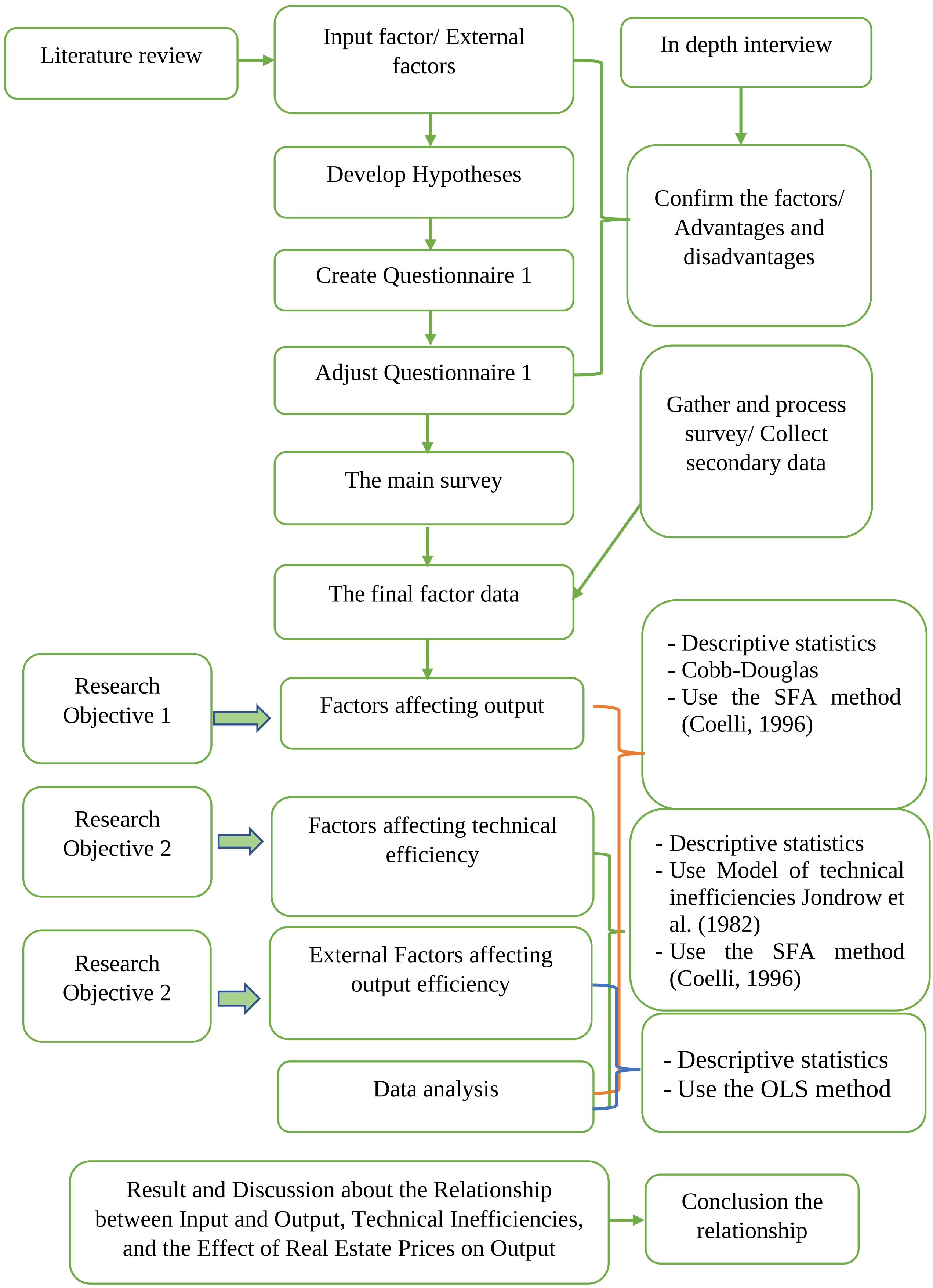

Figure 1.1: Research process. Source: The author's work

2. LITERATURE REVIEW

2.1. Theoretical basis

Theory of Cost and Production Function

The production function, a cornerstone of neoclassical economics, distinguishes allocative efficiency and marginal productivity, focusing on optimal input use to achieve technical efficiency (Fuss, 2017). Its development stems from foundational works by Hotelling (1932, 1935) and Shephard (1953). The widely used Cobb-Douglas production function (Cobb & Douglas, 1928) models the relationship between capital, labor, and output, with parameters determining returns to scale. The function simplifies analysis but excludes inefficiencies like waste and energy use (Greer, 2022).

Theory of Efficiency

Efficiency measures include technical (TE), allocative, and economic efficiency. TE assesses a farm's ability to maximize output with given inputs, while allocative efficiency examines cost-effective input combinations (Farrell, 1957). These efficiencies collectively form economic efficiency (Ndirangu et al., 2017). Scale, cost, and profit efficiencies further expand efficiency analysis (Färe et al., 1985; Berger & Mester, 1997).

Sustainable Development

Sustainable development seeks to meet current needs without compromising future generations' abilities (WCED, 1987). Emerging in the 1970s, it integrates economic, social, and environmental pillars, emphasizing resource conservation and equitable growth (Mebratu, 1998). The 1992 Rio de Janeiro Agreement formalized these pillars, promoting harmonious development for economic efficiency, social equity, and environmental protection.

Sustainability in Coffee Production

Sustainable coffee integrates environmental, social, and economic principles, balancing productivity with resource conservation and equitable social progress. Certification systems, such as those by the Smithsonian Migratory Bird Center (SMBC) and NAFTA's Commission for Environmental Cooperation (CEC), ensure compliance with sustainability standards (Alvarado-Herrera et al., 2017). These practices enhance resource efficiency, mitigate environmental harm, and improve producers' livelihoods.

2.2. Literature review

2.2.1. Current research on variables that affect sustainable agriculture products

The coffee industry, critical in developing countries, has been extensively studied for its environmental, economic, and social sustainability (Chiputwa et al., 2015; Giuliani et al., 2017; Luong & Tauer, 2006). Research highlights the effectiveness of sustainability certification programs and their benefits to farmers (Barham & Weber, 2012; Samper & Quiñones-Ruiz, 2017), though some studies note challenges like inadequate data for predicting organic market outcomes (Giovannucci & Koekoek, 2007).

Key Variables Influencing Sustainability:

Technical factors: Modern technology adoption enhances productivity and efficiency (Castro-Tanzi et al., 2012), but environmental challenges like soil degradation and water quality persist (Ali & Byerlee, 2002; Zulfiqar & Thapa, 2017).

Economic Factors: Sustainable practices like fair trade provide higher revenue but may have initial productivity trade-offs (Kilian et al., 2006). Cost-saving techniques, such as the Alternate Wetting and Drying (AWD) irrigation system, boost productivity and revenue (Kürschner et al., 2010; Lampayan et al., 2015).

Social factors: Household size impacts sustainable agricultural culture (Jarosz, 2000), while socioeconomic attributes like education, experience, and farm size influence output efficiency (Binam et al., 2003). Female-headed households often report lower productivity (Ogada & Nyangena, 2015).

Environmental factors: Certification reduces chemical fertilizer use and enhances environmental conservation (Ibanez & Blackman, 2016). However, inappropriate chemical use, such as excessive fertilizers, jeopardizes long-term sustainability (Castro-Tanzi et al., 2012).

Challenges in Sustainable Agriculture:

Soil nutrient retention, water conservation, and climate change remain critical (Haggar & Schepp, 2012). Pesticides and inorganic fertilizers pose long-term risks to ecosystems and human health, calling for increased adoption of organic alternatives (Shattar et al., 2016).

Sustainable agricultural practices improve environmental outcomes and productivity but require balancing economic, social, and environmental dimensions. Certification and technology adoption are critical for long-term viability despite challenges in data availability and implementation costs (Blackman & Naranjo, 2012; Darnall & Sides, 2008).

2.2.2. Outlook of global conventional coffee and certified coffee production

Coffee is a globally significant crop, particularly in countries like Ecuador, where it plays a critical role in foreign exchange generation (ICO, 2011[1]; COFENAC, 2011). However, improper agricultural practices, such as excessive use of inorganic fertilizers, lead to nutrient loss and environmental degradation (Capa Mora, 2015). While transitioning to organic farming has the potential to reduce greenhouse gas emissions and improve sustainability, the higher costs associated with organic inputs create barriers for farmers (Kilian et al., 2006). Sustainable coffee production offers benefits such as higher revenue opportunities and long-term environmental advantages, yet rising input costs and price volatility remain significant challenges

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

(Lyngbæk et al., 2001; Vossen, 2005). Moreover, financial barriers and risks of poverty exacerbation further hinder the scalability of organic certification programs (Valkila, 2014).

Farm size, household size, gender, and education level are key sociodemographic factors influencing production efficiency, with larger farms generally achieving better outcomes (Amara et al., 1999; Bravo-Ureta & Rieger, 1991; Adesina & Djato, 1997). Farmer education and participation in associations enhance productivity by improving access to resources and market opportunities (Binam et al., 2003; Wollni & Brümmer, 2012). However, sustainable coffee growers, particularly in Vietnam, face challenges such as soil degradation, fluctuating market prices, and ecological pressures, which hinder productivity gains (D’haeze et al., 2005; Ho et al., 2018). In addition, certification programs often fail to align with sales improvements, reducing their appeal for farmers (Giovannucci, 2001).

Despite these challenges, sustainable coffee production can improve efficiency and living standards when effectively implemented. This study aims to bridge gaps in the literature by analyzing variables affecting certified and non-certified coffee growers in Vietnam. By providing evidence-based recommendations to optimize resource use and comply with sustainability requirements, the research seeks to support the Government, coffee experts, and farmers in maximizing benefits while promoting sustainable growth.

Although studies have highlighted the economic benefits of sustainable coffee production, such as higher revenues from fair trade and organic coffee, there is a significant gap in understanding its detailed cost structure, including profits and long-term economic impacts, particularly for Vietnamese coffee farmers. The effectiveness of certification programs also varies and requires more thorough investigation, especially in Vietnam. Comparative studies providing empirical evidence on productivity, economic benefits, and sustainability differences between certified and non-certified coffee farmers are needed. These studies should also consider the impact on both small- and large-scale farmers' productivity and economic sustainability.

Most research on Vietnamese coffee production focuses on specific areas like Dak Lak (Amarasinghe et al., 2015; N. Dzung, 2013; Maskell et al., 2021) and Lam Dong (Le et al., 2020), with few addressing Dak Nong, a significant coffee-producing province. Furthermore, environmental challenges such as soil degradation, water conservation, and climate change require targeted research to develop effective solutions. Previous studies have overlooked advanced methods' effectiveness and the unexplored relationship between real estate prices and coffee output, which this study uniquely addresses.

2.3. Conceptual framework and hypothesis

Based on the theory of Cost Theory and Production Function and Technical Efficiency, a research gap, the author builds a research framework (Figure 2) 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.

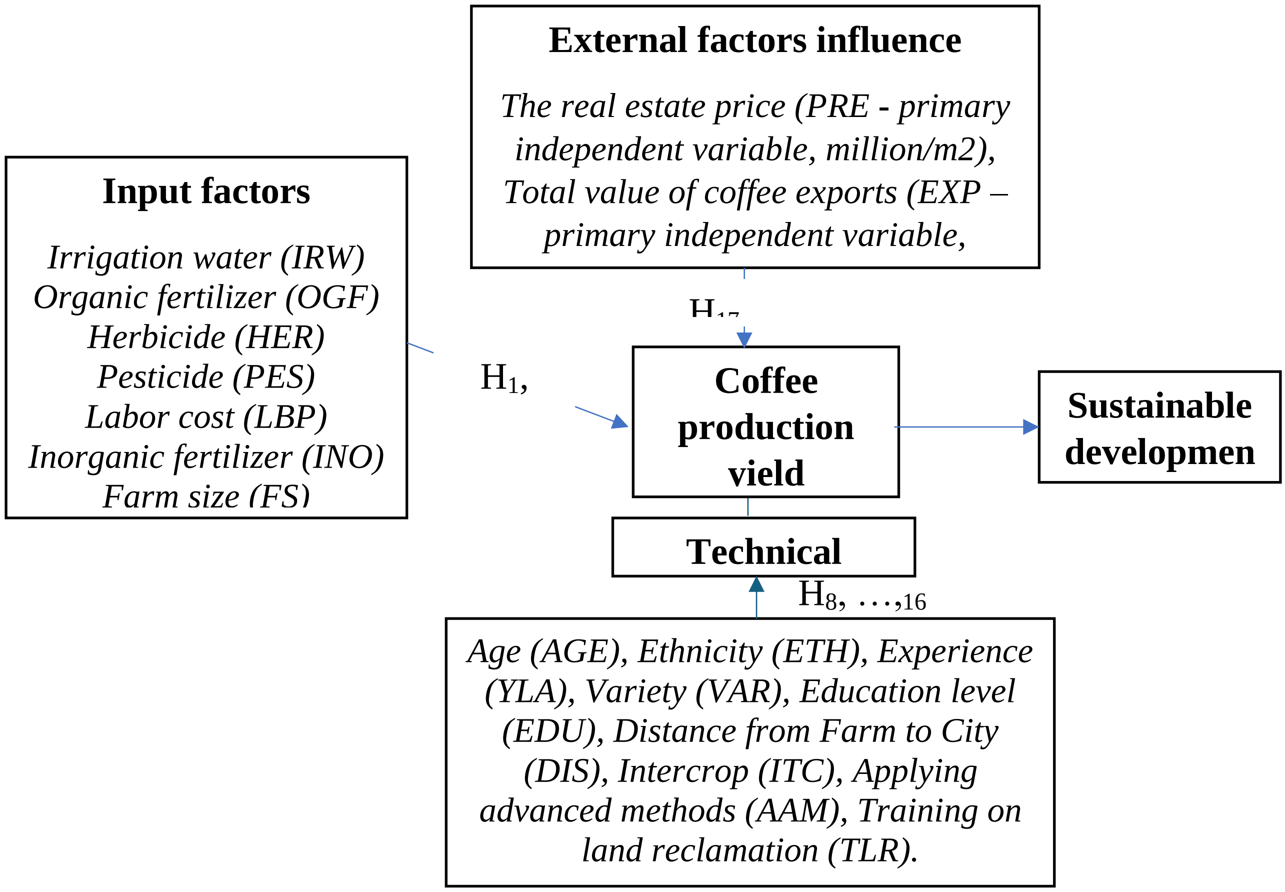

Figure 2.1: Conceptual framework. Source: The author's work

The hypothesis are prosed in the detail as follows:

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.

H3: Pesticides have a positive effect on coffee yield.

H4: Herbicides have a positive effect on coffee yield

H_5: Irrigation water quantity has a negative relationship with coffee yield.

H_6: High labor costs have a positive impact on coffee yield.

H_7: Farm size is positively connected to coffee yield.

H_8: Intercropping has adverse effects on technical inefficiency

H_9: New coffee variety diversity has a negative impact on technical inefficiency

H_{10}: Experience of farmers negatively correlates with technical inefficiency

H_{11}: The education of farmers negatively correlates with technical inefficiency.

H_{12}: Kinh ethnicity farmers negatively correlate with technical inefficiency.

H_{13}: Technical inefficiency has a positive relationship with age.

H_{14}: Applying advanced methods (breeding improvement, mechanization) negatively affects technical inefficiency.

H_{15}: Farmers participating in soil improvement training will help reduce the negative impact of technical inefficiency.

H_{16}: Distance from the farm to the city positively affects technical inefficiency.

H_{17}, H_{18}: The average production and total value of coffee exports positively correlate with coffee yield.

H_{19}, H_{20}: The price of real estate and the inflation rate are negatively correlated with coffee yield.

3. DATA AND METHODOLOGY

3.1. Data

This study uses primary and secondary data to analyze coffee cultivation in Vietnam. Secondary data were obtained from agencies like the General Statistics Office and the Vietnam Coffee and Cocoa Association. Primary data were collected via questionnaires distributed to 1,500 households in Lam Dong, Dak Lak, Dak Nong, and Gia Lai, covering resources, cultivation practices, costs, and credit use. Interviews with 8 local officials and 8 farmers provided additional insights.

Farmers were grouped into certified and non-certified categories. Using the G-power tool, the minimum sample size was set at 250 with a power of 0.95 and a significance level of 0.05. The survey yielded 846 valid responses: 564 from conventional farmers and 282 from certified sustainable farmers.

3.2. Methodology

3.2.1. Quanlitative method

Qualitative research, as defined by Hennink et al. (2020), explores opinions and socio-environmental characteristics flexibly and cost-effectively but is limited by small sample sizes and subjective responses. In this study, qualitative analysis was used as a secondary method to refine questionnaires and gain insights into coffee production and export challenges. Interviews were conducted with eight experienced coffee farmers (two per province) and eight local officials (two per province).

Interviews were arranged via email or direct invitation and conducted in person or through digital platforms like Zoom to ensure flexibility. Each session lasted about an hour, with summaries shared with participants within a week to build trust. Data were coded and analyzed using tools like Word and Excel, applying case comparison techniques (Braun & Clarke, 2006; Yin, 1994). This approach provided focused, actionable insights while maintaining the quality of responses, regardless of the interview environment (Gruber et al., 2008).

3.2.2. Quanlitative results

This qualitative study explored coffee farmers' challenges, sustainable practices, and production dynamics to refine a survey questionnaire for quantitative research. Interviews were conducted with 16 participants (eight experienced farmers and eight local officials) across four provinces: Lam Dong, Dak Lak, Dak Nong, and Gia Lai.

Key findings include:

Farm characteristics: Farmers, with over 10 years of experience, primarily cultivate Robusta coffee due to suitable climate and terrain, though some also grow Arabica and intercrop with other plants like avocado and durian to diversify income.

Climate and geographical challenges: Coffee production is heavily impacted by weather, such as prolonged droughts or heavy rains during harvest, as well as transportation difficulties in mountainous terrains.

Fertilizer use and sustainable practices: Farmers increasingly adopt organic methods to meet sustainability standards, though some report lower yields and high investment costs. Many express concerns about maintaining stable income from organic coffee sales as more farmers enter the market.

Production challenges: Farmers face significant hurdles, including climate change, pests, fluctuating coffee prices, and high input costs. Intermediaries in the supply chain reduce farmers' profits.

Sustainability efforts: Some farmers adopt organic fertilizers, biodiversity conservation, and efficient irrigation, and partner with organizations to gain sustainability certification. However, achieving certification is resource-intensive and requires governmental support.

Advice for new farmers: Experienced farmers recommend understanding the growing process, climate challenges, and participating in support programs to achieve certification.

Feedback on the questionnaire: Farmers and officials found the questionnaire comprehensive but suggested reducing the number of seasons assessed (from 5 to 3) and conducting surveys in person to improve response rates and data accuracy. Questionnaire language was simplified to suit the educational levels of respondents.

3.2.3. Quantitative method

This study employs Stochastic Frontier Analysis (SFA) to assess production efficiency among certified and non-certified coffee farmers, offering advantages over Data Envelopment Analysis (DEA). While DEA is widely used for measuring performance, it is sensitive to errors and cannot simultaneously evaluate efficiency and the factors influencing it (Charnes et al., 1978; Dutta et al., 2022). In contrast, SFA accounts for random errors and inefficiencies in production models, making it a more robust approach (Battese & Coelli, 1995).

The SFA model estimates coffee yield (tons/hectare) based on independent variables such as farm size, organic and inorganic fertilizers, irrigation water, and labor costs. Random errors (v_i) capture uncontrollable factors like weather, while inefficiency errors (uiu_iui) measure deviations from maximum productivity (Coelli et al., 1996). Technical Efficiency (TE) is calculated as the ratio of actual to potential productivity, where u = 0 indicates full efficiency, and $u_i > 0$ indicates inefficiency. Factors such as age, education, crop variety, and farming practices influencing inefficiency are analyzed through a multivariate regression model.

The model also incorporates external variables impacting coffee yield, including real estate prices, coffee export value, average production, inflation rate, and farm size as a control variable. By integrating production technology, environmental conditions, and socio-economic factors, the SFA approach provides a comprehensive understanding of productivity and efficiency in coffee farming.

Key Formulas:

The following is a description of the stochastic frontier production function utilized to calculate the overall yield of coffee farmers:

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

The technical inefficient is:

$$|U_i| = \delta_0 + \delta_1 Independent + W_i$$

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

$$Y_i = \alpha_0 + \alpha_1 q_1 + \alpha_2 q_2 + ... + \alpha_6 q_6 + v_I$$

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

4.1. Demographic characteristics

This study surveyed 1,500 coffee-farming households across four provinces in Vietnam (Lam Dong, Dak Lak, Dak Nong, and Gia Lai), yielding 846 valid responses: 564 from non-certified households and 282 from certified households. The demographic analysis highlights several key characteristics:

Age distribution: Farmers' ages range from 28 to 86 years, with an average of 55.63 years. Most farmers are between 50–59 years old (42.67%), followed by those over 60 (31.91%). Younger farmers under 40 represent only 3.2%.

Ethnicity: Although the Central Highlands are ethnically diverse, Kinh households dominate the sample, accounting for 96.2% of respondents across all provinces. Lam Dong has the highest number of Kinh households (283), while Dak Nong recorded no other ethnic groups.

Gender: Most household heads are male due to cultural norms and the physical demands of farming. Male-headed households account for 97.2% of the sample, with Lam Dong having the highest number of male household heads (283).

Education levels: Educational attainment is generally low, with 54.6% of respondents not completing high school. Lam Dong stands out, with 5.8% of household heads holding university degrees, which could enhance access to innovative farming methods.

Household size: Family sizes range from 1 to 10 members, with an average of 4.57 individuals. Most households consist of 4–5 members (66.55%), followed by those with 5–7 members (19.03%). Family size significantly influences labor availability for farming activities.

4.2. Economic characteristics of coffee farming

Among the surveyed coffee-farming households, 66.66% lacked sustainability certification, while 33.33% achieved certification, with 4C being the most prevalent (244 households), followed by UTZ (31 households). Certification rates remained static during COVID-19 but rose post-pandemic, increasing from 222 households in 2020–2021 to 282 in 2021–2022. Certified households accounted for 61.82% of the total 8,124.2 tons of unprocessed green coffee produced in 2021–2022, with Gia Lai recording the highest average output (12.5 tons/season). Certified farms consistently outperformed non-certified ones, with notable yields in Lam Dong (18.3 tons), Gia Lai (19.1 tons), and Dak Nong (18.9 tons). Farm sizes varied from 0.4 to 16 hectares, with larger certified farms contributing significantly to higher yields, such as Lam Dong’s 16-hectare certified farm and Gia Lai’s 10-hectare certified farm.

Regarding inputs, certified households demonstrated better resource efficiency. They used slightly less water than non-certified farms, averaging 1,692–1,944 m^3/hectare per crop, with advanced irrigation methods like drip irrigation being more common among certified households. Fertilizer usage revealed significant contrasts; certified households used less inorganic fertilizer, promoting sustainable practices, while organic fertilizer usage ranged from 1,376 kg to 2,180 kg/hectare across provinces. Herbicide and pesticide applications remained consistent (1–3 liters/hectare per crop), though certified households showed slightly higher usage, raising questions about their pest management strategies. Labor costs varied significantly, with Lam Dong reporting the highest average of 9.86 million VND/hectare per crop, largely due to labor outsourcing necessitated by family composition.

Most households (77.19%) cultivated older coffee varieties, with limited experimentation (19.27%) with new varieties, particularly among certified farms. Intercropping was practiced by 44.44% of households, with durian and macadamia being the most common crops. Dak Lak led in intercropping (19.74%), while households with smaller plots or coffee as their primary crop were less likely to intercrop. Certified households showed greater adoption of advanced farming methods (48.35%) and higher participation in land reclamation training programs (72.93%), particularly in Lam Dong and Gia Lai. These findings underscore the economic and production benefits of certification while highlighting the role of sustainable practices in enhancing productivity and efficiency.

4.3. Test the factor

The study undertook a thorough examination of the relationships between variables and tested for multicollinearity to ensure the reliability of the research model. First, a Pearson correlation coefficient analysis was conducted to assess the linear relationships between nine independent variables — farm size (FS), organic fertilizer (OGF), inorganic fertilizer (INO), pesticides (PES), labor cost (LBP), years of farming experience (YLA), distance to market (DIS), irrigation water (IRW), and herbicide usage (HER) — and the dependent variable, output (OPU). The analysis revealed significant linear relationships ($p < 0.05$) for most variables except IRW, HER, and AGE, indicating no significant correlation for the latter.

When two independent variables show no correlation ($p > 0.05$), multicollinearity is unlikely. Conversely, correlated variables ($p < 0.05$) with absolute correlation coefficients exceeding 0.7 signal potential multicollinearity. No variables in this dataset exhibited such high correlations, alleviating concerns about multicollinearity.

To further confirm, a multicollinearity test using Variance Inflation Factor (VIF) was performed. All VIF values ranged below 5, with an average of 1.73, indicating no multicollinearity among the variables. The absence of multicollinearity validates the inclusion of all variables in the regression model, ensuring the robustness of the analysis. Consequently, the study retained all variables for further regression operations, highlighting their appropriateness for the research framework.

4.4. Research results

This study investigates the factors influencing coffee productivity and technical efficiency (TE) among farmers in four Vietnamese provinces using the Cobb-Douglas production function model and Stochastic Frontier Analysis (SFA). The research examines input factors such as irrigation water (IRW), organic fertilizers (OGF), inorganic fertilizers (INO), herbicides (HER), pesticides (PES), and labor cost (LBP). It also considers demographic and operational attributes, including age (AGE), ethnicity (ETH), education level (EDU), coffee variety (VAR), and distance from farms to urban areas (DIS).

Table 1: Summary of research results

Hypothesis	**OPU**	**General**	**Non-Certificate**	**Rem-arks**	**Certifi-cate**	**Rem-arks**
	Frontier					
H_{1a}, H_{1b}	**OGF**	-0.0307	-0.1095*	✓	0.2393	⊘
H_{2a}, H_{2b}	**INO**	-0.7307***	0.3378**	✓	-0.0378*	✓
H_3	**PES**	0.0719**	0.0807***	✓	-0.01	⊘
H_4	**HER**	-0.0084	-0.0158	⊘	-0.0438	⊘
H_5	**IRW**	0.0195	0.0956**	×	-0.1051*	✓
H_6	**LBP**	0.3652***	0.0051	⊘	-0.0564	⊘
H_7	**FS**	0.9200***	0.9824***	✓	0.9323***	✓
	Technical inefficiency					
H_8	**ITC**	-0.149***	-0.7371**	✓	1.6639	⊘
H_9	**VAR**	0.2709***	0.3354	⊘	-0.9097*	✓
H_{10}	**YLA**	-0.2347***	-0.3825**	✓	-3.7554**	✓

H_{11}	**EDU**	0.0135	0.1024	⊘	1.3400*	✗
H_{12}	**ETH**	-0.5514***	-1.0677**	✓	-7.1989**	✓
H_{13}	**AGE**	0.0398	0.6844	⊘	-4.4278**	✗
H_{14}	**AAM**	-0.7671***	-0.711	⊘	-0.2269	⊘
H_{15}	**TLR**	0.122**	0.5537	⊘	-0.2655	⊘
H_{16}	**DIS**	0.1659***	0.5241***	✓	0.4326*	✓

Source: The author's works

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.

4.4.1. General research results without grouping

The findings reveal that farm size (FS) and labor costs (LBP) significantly enhance coffee productivity, contributing to increases of 0.92 and 0.3652 units per unit increase, respectively, with high statistical significance. Pesticides (PES) also positively influence yield, while inorganic fertilizers (INO) demonstrate a significant negative effect, suggesting issues with application practices. In contrast, irrigation water, organic fertilizers, and herbicides show no statistically significant impact on productivity. These results underscore the importance of optimizing input usage to improve yields effectively.

$$\begin{aligned} \mathrm{OPU}_{General} &= 1.7818 + 0.9200 \times \mathrm{FS} - 0.7303 \times \mathrm{INO} + 0.0719 \times \mathrm{PES} \\ &+ 0.3652 \times \mathrm{LBP} \end{aligned}$$

The computed Lambda value of 1.4678, exceeding 1, confirms the appropriateness of the random frontier model for the cross-sectional data used. Parameters Sigma_u (0.3205) and Sigma_V (0.2183) further validate the model's robustness. The analysis highlights that technical inefficiencies in coffee production are influenced by various factors, including the precise execution of technical practices such as tree planting to reduce wind effects, proper shading, weeding, pruning, tub construction, irrigation, and timely fertilization and pest control. These practices significantly enhance coffee growth.

Additionally, factors like training participation, adoption of advanced methods, choice of coffee variety, and proximity to urban centers also shape the technical efficiency (TE) landscape. These findings underscore the importance of skill development, advanced practices, and informed decision-making to address inefficiencies and improve coffee production outcomes.

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

The analysis identifies key demographic and operational factors influencing technical efficiency (TE) in coffee production. Ethnicity (ETH), coffee-growing experience (YLA), intercropping (ITC), and the application of advanced methods

(AAM) significantly reduce inefficiencies, while coffee variety (VAR), distance from farm to city (DIS), and participation in land reclamation training (TLR) are linked to increased inefficiencies. Age (AGE) and education level (EDU) show no significant impact on TE. The findings highlight the importance of targeted interventions and practices to optimize efficiency, with an average TE ratio of 51.4%, indicating room for improvement in coffee farming efficiency.

Table 2: Overall technical efficiency percentage

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

Source: The author's works

4.4.2. The research result for non-certificated group

The analysis focuses on the subset of non-certified coffee farmers, encompassing 564 households, and reveals several key findings. Farm size (FS), irrigation water (IRW), and pesticides (PES) show a positive and significant association with coffee yield at the 99% confidence level, while inorganic fertilizer (INO) is significant at the 5% level. Conversely, organic fertilizer (OGF) negatively affects productivity at the 10% significance level. However, herbicide (HER) and labor cost (LBP) lack conclusive evidence to influence productivity. The estimated model suggests that increasing FS, IRW, INO, and PES by one unit enhances productivity, while OGF reduces it.

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

$$\mathrm{OPU}_{Noncertificate} = -1.3011 + 0.9824 \times \mathrm{FS} + 0.0956 \times \mathrm{IRW} - 0.1095 \times \mathrm{OGF} + 0.3378 \times \mathrm{INO} + 0.0807 \times \mathrm{PES}$$

Technical inefficiencies are significantly reduced by factors such as ethnicity (ETH), coffee-growing experience (YLA), and intercropping (ITC), while greater distances from farms to cities (DIS) contribute to higher inefficiencies. Variables like age (AGE), coffee variety (VAR), advanced methods (AAM), and land reclamation training (TLR) show no significant relationship with technical inefficiency.

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

The average technical efficiency (TE) among non-certified farmers is relatively high at 75.72%, surpassing the overall TE of 51.4% across all coffee-growing households. This indicates that non-certified farmers have considerable room for improvement in reducing inefficiencies, with targeted interventions focusing on the significant factors identified in the analysis.

Table 3: 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

4.4.3. The research results for certificated group

The analysis of certified coffee farmers, based on 282 observations, highlights key factors influencing productivity and technical efficiency. Farm size (FS) and organic fertilizer (OGF) positively and significantly affect coffee yield, while irrigation water (IRW) exhibits a negative relationship. Conversely, no significant impact is observed for inorganic fertilizer (INO), herbicide (HER), pesticides (PES), and labor cost (LBP). The regression results confirm the robustness of the model with Lambda > 1, sigma_u = 0.3004, and sigma_v = 0.2351.

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

Technical inefficiencies are significantly associated with age (AGE), ethnicity (ETH), coffee-growing experience (YLA), and coffee variety (VAR). AGE, ETH, and YLA inversely correlate with inefficiencies, indicating higher efficiency with older, experienced farmers from ethnic groups involved in coffee production. However, VAR, education level (EDU), and distance from farm to city (DIS) are positively correlated with inefficiency, suggesting challenges in adopting new varieties and overcoming logistical constraints.

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

Despite these dynamics, the certified group demonstrates a high average technical efficiency (TE) of 96.17%, underscoring the benefits of sustainable practices. This efficiency significantly surpasses the non-certified group, emphasizing the efficacy of certification and sustainable farming methods in enhancing productivity.

Table 4: 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

4.4.4. The distribution of technical efficiency by group

Table 5: 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 5 shows a clear difference in technical efficiency between the two groups of farmers: the Certificate and the non-certified group. In the group without certificates, most farmers (88.48%) achieved technical efficiency below 90%, with the majority concentrated at 80%to 90%(40.43%). In contrast, the group with certificates shows outstanding technical efficiency, with 94.33% of farmers having an effective 90% or more. This is also reflected in the average performance when the group with a certificate reaches an average of 96.17%, significantly higher than 75.72% of the group without certificates. At the same time, the dispersion of technical efficiency in the group without certificates is also more significant, with a standard deviation of 14.96%, compared to 10.26% of the group with a certificate. For details of the dispersion level, see Figures 3 and 4.

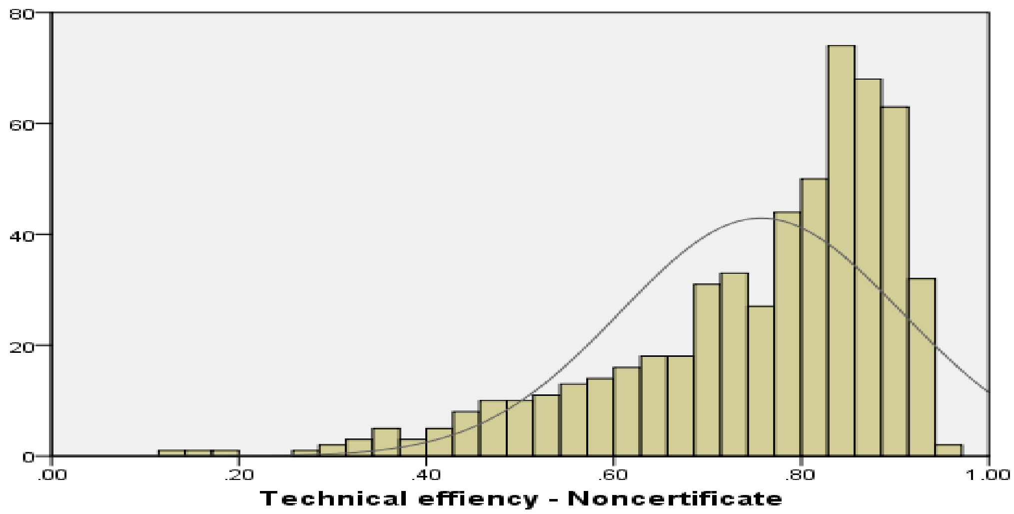

Figure 4.1: Distribution of the technical efficiency situation of all non-certified research households
Source: computed by SPSS

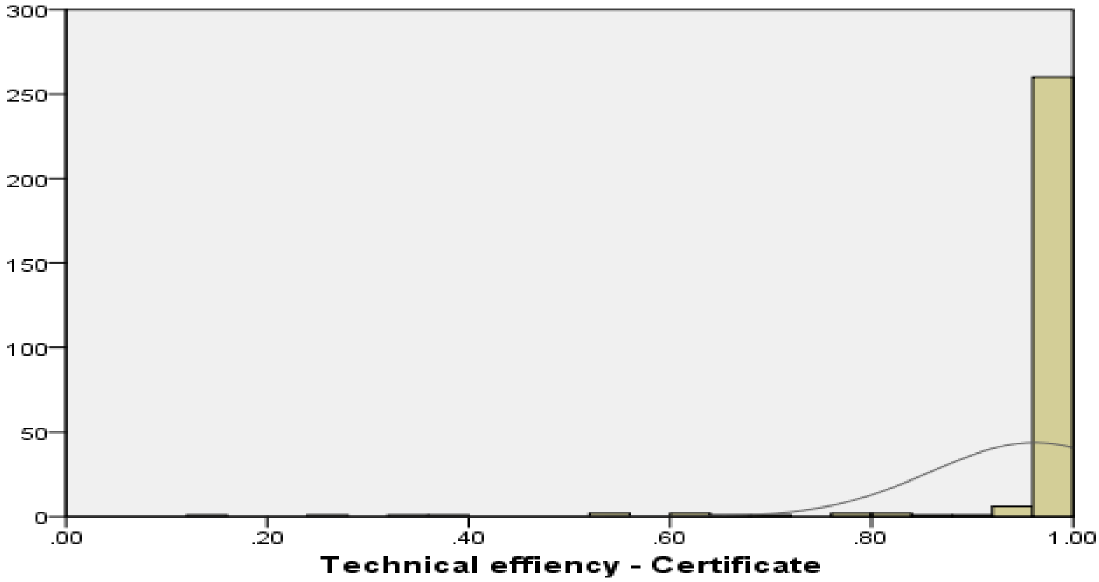

Figure 4.2: Distribute the technical efficiency status of all certified research households. Source: Computed by SPSS

4.4.5. Research results of external variables

In recent times, Vietnam has witnessed a rapid amplification in land prices, significantly impacting agricultural production. The escalating export of coffee to various countries globally not only stimulates the coffee farming sector but has also established a pronounced connection between land prices and export capabilities, exerting a substantial influence on overall production output. Specifically, a 1-unit increase in productivity per hectare (AVY) is associated with a significant increase of 11.82 units in production, while changes in land price (PRE) and export output (EXP) yield nuanced effects. Remarkably, a 1-unit increase in land price (PRE) results in a corresponding rise of 1.8867 units of the overall production, whereas a 1-unit increase in export output (EXP) leads to a curtailment of 0.566 units of the overall production. Furthermore, the variable controlling farm area (FS) describes statistical significance at 5%, whereas inflation (INF) lacks ample evidence to justify its impact.

Table 6: OLS model regression results with the dependent variable of general output

Hypothesis	PRD	Coef.	P >t	Remarks
H_{17}	**AVY**	11.81691	0.013	✓
H_{18}	**EXP**	1.886718	0.085	✓
H_{19}	**PRE**	-0.566132	0.018	✓
H_{20}	**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

5.1. Economic efficiency

Productivity hinges on several critical factors in coffee production, including inorganic fertilizer, organic fertilizer, land area, herbicide, pesticide, and labor cost. The first factor, farm size, emerges as an important determinant. It affects the yield of both sustainable and conventional coffee. The results are consistent with Minh et al. (2016;) and Sharma et al. (2016). The concept of returns to scale is noteworthy (Sharma et al., 2016). Beyond farm areas, organic fertilizer is a pivotal factor in sustainable coffee production. Increased application of organic fertilizer of certified output has demonstrated favorable environmental outcomes (Ibanez & Blackman, 2016).

Moreover, certified production sustainability is linked to enhanced biodiversity conservation (Hardt et al., 2015) and improved biodiversity (Philpott et al., 2008), emphasizing the positive ecological impact of organic fertilizer. Familiar sources of organic fertilizer include livestock manure, compost, green crop residues, farm waste, and compost from natural systems and production system raw materials, in line with research by Dikinya & Mufwanzala (2010) and Satyanarayana et al. (2002). The growing emphasis on sustainable agriculture underscores the need for affordable, readily available, and renewable methods to supply crops with nutrients (Nyalemegbe et al., 2010; Zafar et al., 2011). Utilizing and repurposing organic matter has become crucial in meeting this demand, particularly for export markets relying on responsibly produced commodities like coffee. Enhancing the moisture-holding capacity of organic matter in the soil is an important function of organic fertilizers. It is recognized as an adaptive strategy for climate change (Abd El-Kader et al., 2010). However, research indicates that while compost is beneficial for preserving soil organic matter and supplying nutrients to coffee systems, it may fall short of achieving optimal output levels and balancing nutrient flow to the crop (Stockdale et al., 2002). Like organic fertilizer, conventional production, which has a detrimental impact on soil health, is explored in the context of research by Mignouna et al. (2015), highlighting the importance of correct application rates to mitigate adverse effects on crop output (Chemura, 2014).

Inorganic fertilizers, specifically NPK fertilizers, exert an essential influence. Studies reveal that the collective use of organic and inorganic fertilizers yields similar production growth and economic advantages across various agricultural conditions (Nyalemegbe et al., 2010; Reganold et al., 2001). Hung Anh et al. (2019) have highlighted that the judicious application of NPK fertilizer contributes to cost savings for farmers in terms of labor expenses. Previous research, such as studies by Capa Mora (2015) and Castro-Tanzi et al. (2012), signifies the beneficial impact of fertilizer in enhancing crop yields. Moreover, pesticide utilization positively affects overall productivity in conventional coffee production. However, the influence of pesticides on sustainable coffee alone lacks adequate proof to ascertain its strength or weakness. Prior studies (Khan et al., 2010; Ngango & Kim, 2019) similarly conclude that pesticides contribute to increased productivity.

Nevertheless, this factor does not significantly impact coffee output yields. Similarly, while lacking a clear impact within each target group, labor costs positively correlate in the broader research context. It is noteworthy that sustainable coffee production, despite a marginal difference in production efficiency, proves more cost-effective and profitable than conventional coffee, as observed in studies by Hung Anh et al. (2019) and Tran et al. (2021).

5.2. Determinants of technical efficiency

The literature currently in publication indicates that several demographic factors, including farmer age (Binam et al., 2003; Dessale, 2019; Kamau et al., 2017; Sriboonchitta & Wiboonpongse, 2014); education (Dessale, 2019; Ho et al., 2018; Tun & Kang, 2015); and ethnicity (Gaitán-Cremaschi et al., 2018; Ho et al., 2018), may have an impact on farming efficiency. Furthermore, household size (Bati et al., 2017; Binam et al., 2003; Okoruwa et al., 2006) and agricultural experience (Sriboonchitta & Wiboonpongse, 2014). In a traditional farming system, age emerges as a factor that negatively impacts 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 scholarship, 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.

The recent increase in land prices in Vietnam has significantly affected the agricultural environment concerning coffee production. Meanwhile, the increasing demand for Vietnamese coffee worldwide has led to the establishment of many more coffee farms. The intricate interplay between land prices, export capacity, and coffee production output constitutes a focal point of inquiry in this study, demonstrated as follows:

Land prices and coffee production: The nexus between escalating land prices and coffee production is dimensional and crucial. The ascent in land prices subjects farmers to heightened economic pressures, impeding their ability to expand or sustain existing coffee farms. The consequential effect of inflated land prices is the potential contraction of the total coffee land area available for acquisition. The pragmatic implication of this trend leads to an imminent threat to the sustainability of the coffee-growing industry, particularly for small-scale farmers. This assertion is corroborated by the findings of Maundu & Karugu (2018), who propose that the diminution in coffee production has profoundly impacted the Kiambu District, where the traditional large-scale coffee farms have undergone relocation to the real estate sector in response to the urban expansion originating from Nairobi city.

Export capacity: Increasing coffee export capacity closely relates to heightened coffee production. This rationale is underpinned by the exigencies of catching the international market's demands through substantial exports, thereby fostering incentives for coffee-growing households to persist in coffee cultivation and contemplate expansion. The congruent results by Arfah (2020) advocate a positive relationship between coffee output, the world price index, and coffee exports in Uganda. The additional findings indicate that variables such as coffee yield per hectare and farm area emerge as influential determinants augmenting overall output.

6. CONTRIBUTIONS

6.1. Theoretical Contributions

This study makes an important contribution to the theory of sustainable agricultural production, especially in the coffee sector, through the application of the Cobb-Douglas production function model and stochastic frontier analysis (SFA). These methods help to measure technical efficiency and analyze the differences between traditional and sustainable farming methods.

Comparison of farming methods: Farmers applying sustainable models achieved higher technical efficiency (96.17%) than traditional farmers (75.72%). This result is consistent with international studies Poudel (2012) but also contradicts some studies such as Hung Anh et al. (2019), emphasizing the important role of local context in determining technical efficiency.

Optimizing input use: Sustainable practices can improve technical efficiency by up to 24.28% for conventional farmers and 3.83% for sustainable farmers, reinforcing findings from previous studies (Tamirat & Tadele, 2023).

The role of fertilizers: Organic fertilizers improve efficiency and protect the environment, but need to be properly combined with inorganic fertilizers to optimize productivity, consistent with previous research (Hung Anh et al., 2019).

Socio-economic and demographic factors: Older, experienced farmers achieve higher technical efficiency, while ethnicity (Kinh dominance in the coffee industry) also significantly affects production efficiency.

Impact of external factors: Rising land prices put great pressure on farmers, limiting their ability to expand production, similar to findings in Kenya (Maundu & Karugu, 2018). Expanding export markets helps increase productivity and develop the coffee industry, consistent with the study of Arfah (2020).

6.2. Practical Contributions

This study analyzes the factors affecting sustainable coffee production in Vietnam and provides practical contributions to improve and develop the coffee industry. Key findings include:

- Technical efficiency and profitability of sustainable production: Sustainable coffee production achieved significantly higher technical efficiency (96.17%) than the traditional method (75.72%). This shows that the application of sustainable production helps reduce input costs and increase profits by up to 24.28%, improving farmers' livelihoods.
- The role of organic fertilizers: Organic fertilizers not only increase productivity but also protect the environment, improve soil health and maintain ecosystems. Policies that encourage farmers to switch from chemical fertilizers to organic fertilizers through training and financial support can reduce environmental pollution and improve the quality of coffee products.
- Technical training for farmers: Technical efficiency depends on technology, farming methods, and demographic characteristics such as age, education, and experience of farmers. Training programs should focus on water management, use of organic fertilizers, application of modern technology, and sustainable farming to improve production efficiency.
- Addressing the challenge of high land prices: High land prices negatively affect the production capacity and motivation of farmers, especially smallholders, to adopt sustainable production. Financial support policies, subsidies, or tax exemptions can help reduce the burden and facilitate farmers to expand production.
- Export strategy and supply chain management: Improving infrastructure, reducing transaction costs, and providing market information will help farmers access international markets more easily. This will not only increase income but also promote sustainable economic development of the country.
- Intercropping: Intercropping with crops such as pepper or avocado helps optimize land use and increase biodiversity. Raising awareness and providing technical support to farmers on the economic and environmental benefits of intercropping is essential.
- Modern agricultural technology: Smart irrigation systems and soil sensing technology can improve production efficiency and sustainability. Financial support for technology investment will encourage farmers to adopt modern production methods.
- Stakeholder collaboration: Collaboration between farmers, coffee processors, investors and the government will facilitate knowledge and experience sharing and promote new business opportunities in the coffee industry.
- Research and development (R&D): Investing in research and development of climate-resistant coffee varieties and sustainable farming methods will help increase productivity and reduce environmental impacts, promoting sustainable coffee development.

The practical contributions of this research not only help improve farmers' lives but also promote the sustainable development of the Vietnamese coffee industry in the context of climate change and current global challenges.

7. CONCLUSION

Research on the cost-effectiveness and profitability of sustainable coffee production, utilizing the Cobb-Douglas production function and comparing the efficiency of sustainable and traditional coffee farmers in Vietnam, offers insights into challenges and opportunities for stakeholders, including coffee farmers, local authorities, and the government. The study examines technical efficiency, economic factors, and external influences shaping the dynamics of coffee production. TE Analysis reveals notable disparities in technical efficiency between certified sustainable coffee farmers and their conventional counterparts, contrary to the initial hypothesis. The outcomes demonstrate that sustainable coffee farmers surpass traditional farmers, with average technical efficiency rates of 96.17% and 75.72%, respectively. This implies a potential productivity increase of 3.83% for sustainable coffee farmers and 24.28% for conventional farmers through improved practices. This finding underscores the substantial productivity gains achievable through sustainable coffee farming practices, contrasting with previous studies in different regions.

Economic factors affect coffee production, including land area, organic fertilizer usage, and certification. Larger land areas positively influence coffee yield for sustainable and traditional farming methods. Organic fertilizer enhances productivity and contributes positively to environmental sustainability, particularly in certified sustainable coffee farming. Sustainable practices, including certification, are connected to better biodiversity conservation and overall ecological well-being. In contrast, using inorganic fertilizers, such as NPK, notably impacts conventional coffee farming. Still, combining organic and inorganic fertilizers effectively boosts growth rates and economic returns for both farming categories. As a remark, sustainable coffee farming practices signify a more cost-effective benchmark, although they do not remarkably impact production efficiency. The investigation into external factors elucidates the direct relationship between land prices, coffee demand, and production levels. As land prices rise, economic pressures on coffee farmers intensify, potentially leading to reduced farm sizes and a decline in sustainable coffee farming. This underscores the close-knit relationship between land prices, exports, and production.

In conclusion, achieving sustainable coffee production poses a formidable challenge for coffee growers and local governments. The study accentuates sustainable practices' positive impact on coffee production efficiency and environmental sustainability, particularly organic fertilizer and certifications. The author advocates specific implications, including the active promotion of sustainable farming methods, economic support mechanisms for farmers facing rising land prices, diversification strategies, and the application of advanced agricultural technologies.

Limitations and Directions for Future Research

Although this study has mentioned new factors and tried to expand the scope of research, the author still admits that more profound research is needed to understand better the impact of external factors on coffee production in different regions, such as climate change and government regulations. Besides, the author recommends conducting regular surveys at least every three years to be more comprehensive and reliable. Furthermore, future research can compare Vietnam and the world's largest coffee exporting countries to see differences in cultivation and applied techniques. This will help draw comparable and reliable conclusions, thereby providing recommendations and measures to improve coffee production efficiency in the future.

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