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EU deforestation regulation and Ethiopian smallholder coffee farmers: Awareness, compliance capacity, and potential impacts

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Abstract

This study provides an empirical assessment of Ethiopian smallholder coffee farmers' preparedness for the European Union Deforestation Regulation (EUDR), examining awareness, compliance capacity, and potential impacts, with particular attention to the role of Voluntary Sustainability Standards (VSS). Conducted in southwestern Ethiopia using a mixed-methods approach—including a survey of 600 households, focus group discussions, key informant interviews, and advanced econometric models (Propensity Score Matching and Endogenous Switching Regression)—the research reveals a significant gap between regulatory awareness and operational compliance capacity. While VSS certification effectively enhances farmer awareness, it yields limited and method-sensitive improvements in the technical and financial capacity required for EUDR's stringent traceability and geolocation mandates. The analysis further identifies an "ecological paradox": farmers in biodiverse, forest-integrated systems face the highest compliance barriers despite having low deforestation footprints. The study concludes that without targeted investments in land governance, digital infrastructure, differentiated support systems, and equitable cost-sharing, the EUDR risks excluding the most vulnerable smallholders, potentially undermining both its environmental goals and rural livelihoods. Success depends on reframing compliance as a shared governance challenge rather than an individual producer burden.

1. Introduction

Global forest ecosystems represent the primary terrestrial defense against the contemporary climate crisis. Functioning as critical carbon sinks, biodiversity refuges, and regulators of global hydrological cycles, forests are indispensable to the stability of the Earth system. Despite their vital importance, these ecosystems are declining at an alarming rate; in 2023 alone, the world lost over 4.7 million hectares of tropical primary forest, driven largely by agricultural expansion and commercial commodity production (World Resources Institute, 2024). Over the past decade, satellite data reveals that tropical forests across 91 countries have consistently lost more than 10 million hectares annually, depleting a carbon stock equivalent to approximately one-third of global historical emissions (Assunção et al., 2025). This trajectory contributes roughly 10–12% of global anthropogenic greenhouse gas emissions, fundamentally threatening the climate pathways established by the Paris Agreement (IPCC, 2023). Emerging literature highlights that this loss is not merely an environmental issue but a systemic risk that amplifies regional warming and destabilizes rural livelihoods (Golbazi et al., 2025). Despite decades of international accords, forest loss persists due to entrenched economic incentives and a mismatch between rising global commodity demand and local land-use pressures (Meyfroidt et al., 2022; Costa et al., 2025).

In response to the inadequacy of voluntary commitments, the European Union Deforestation Regulation (EUDR) - (EU) 2023/1115 represents a landmark shift in global environmental policy. Adopted in June 2023, the EUDR prohibits the placement of key commodities—including coffee—on the EU market unless they are verified as deforestation-free (not associated with forest conversion after December 31, 2020), legally produced, and traceable to their precise plot of origin via geolocation coordinates (European Union, 2023). While proponents view this demand-side regulation as essential for fulfilling climate commitments, critics question its feasibility in smallholder-dominated supply chains where land tenure is complex and digital infrastructure is sparse (Melati & Jintarith, 2024). There is a significant concern that the regulation may externalize

compliance costs onto the most vulnerable producers, effectively creating a non-tariff trade barrier that marginalizes those it intends to protect (Dhingra et al., 2023).

Coffee is among the commodities most directly affected by the EUDR due to its cultivation in ecologically sensitive tropical landscapes and its reliance on millions of smallholder farmers. Ethiopia, the geographical origin of *Coffea arabica* and Africa's largest coffee exporter, finds itself at the epicenter of this regulatory shift. The Ethiopian coffee sector is the backbone of the national economy, supporting over 5 million smallholder households and providing income for 25% of the population through interconnected activities along the coffee value chain (Tefera et al., 2025). Coffee generates up to 35% of Ethiopia's export revenue, with approximately one-third of these earnings derived from EU markets (FAO, 2023). Smallholders, cultivating plots of 0.5–1.0 hectares, account for over 95% of the national output (Worku, 2023).

Coffee production is concentrated in the south and southwest—including the forest-rich zones of Kafa, Sheka and Bench Sheko —where it is embedded within diverse agroforestry systems of high ecological value. These landscapes host globally significant biodiversity, including wild coffee gene pools critical for genetic diversity and long-term climate resilience, and provide essential ecosystem services such as carbon storage and watershed regulation (Schmitt et al., 2010; Tadesse, 2024). However, Ethiopia continues to experience substantial deforestation driven by agricultural expansion, population pressure, and weak regulatory enforcement. Although national restoration efforts have moderated overall loss rates, long-term Landsat-based analyses indicate that southwest Ethiopian coffee landscapes continue to experience forest loss and degradation at rates of around or above 1% per year, driven by land-use change and intensified management practices (Hwang et al., 2020). Concurrently, semi-forest coffee systems—long valued for their biodiversity—are increasingly subject to intensification practices like canopy thinning and understory clearance, which undermine their ecological integrity (Takahashi & Todo, 2016). This persistent environmental fragility elevates the stakes of EUDR implementation considerably.

The interaction between the EUDR's stringent due-diligence requirements and Ethiopia's smallholder-dominated coffee sector creates a profound socio-ecological dilemma. Mandatory plot-level geolocation and rigorous due diligence requirements impose substantial burdens on fragmented value chains, predominantly informal land tenure arrangements, and limited technical and digital capacity among smallholders (FAO, 2024). The European Commission's classification of Ethiopia as a "standard-risk" country, which mandates enhanced due diligence, further intensifies this burden by requiring heightened oversight. Preliminary evidence indicates that awareness of the EUDR among smallholder producers remains limited, while the financial and administrative costs associated with meeting traceability and geolocation requirements constitute a major barrier to compliance (International Trade Centre, 2024). Without targeted intervention, the EUDR risks functioning as a de facto non-tariff barrier, potentially excluding vulnerable producers from EU markets and potentially driving them toward less regulated markets or alternative land uses that accelerate forest conversion—a perverse outcome that would undermine the regulation's primary objective (Tadesse, 2024; Schmitt & de Deus Vidal, 2024).

The EUDR also intersects with an established landscape of Voluntary Sustainability Standards (VSS), including Fairtrade, Organic, and Rainforest Alliance certification. These standards are often assumed to enhance traceability, strengthen cooperative governance, and promote environmental stewardship, potentially positioning certified farmers closer to regulatory compliance. Some VSS protocols already incorporate elements such as geolocation reporting and forest-protection requirements that partially align with the EUDR framework (ISEAL Alliance, 2023). However,

empirical evidence on whether VSS meaningfully facilitate EUDR preparedness remains limited. While certification can improve organisational capacity and environmental awareness (Meemken et al., 2021), it may not ensure compliance with the EUDR's legal precision, particularly regarding historical deforestation baselines and plot-level traceability. There is also a growing concern that certification may create an illusion of compliance, leaving farmers exposed to market exclusion if critical legal and geospatial gaps persist. Furthermore, the cumulative cost of multiple certifications may exacerbate financial burdens on smallholders. A critical investigation is therefore essential to determine the tangible role of VSS in EUDR preparedness, ensuring that leveraging these existing initiatives facilitates compliance without exacerbating producer inequity.

Despite the looming compliance deadlines, empirical evidence on the actual readiness of Ethiopian smallholders remains scarce. This study addresses this gap by providing an empirical assessment of the preparedness of smallholder coffee farmers for the EUDR in southwestern Ethiopia, with particular attention to the moderating role of Voluntary Sustainability Standards (VSS). The research is guided by three primary questions: What is the current level of EUDR awareness and compliance capacity among smallholders, and what are its key determinants? (ii) to what extent does VSS certification influence EUDR awareness and compliance readiness; and (iii) what are the perceived socio-economic and environmental impacts of the EUDR, and which institutional pathways could support a more equitable and effective implementation. By addressing these questions, the study aims to generate policy-relevant evidence to support smallholder-inclusive deforestation-free trade, mitigate unintended market exclusion, and align forest conservation with sustainable rural livelihoods.

2. Literature Review

2.1. The Transnational Governance of Forest Risk: From Voluntary Pledges to Mandatory Due Diligence

The contemporary climate crisis is inextricably linked to the accelerating loss of forest ecosystems, which represent the second-largest source of anthropogenic carbon emissions (Gong et al., 2022). Beyond carbon sequestration, deforestation triggers systemic biophysical disruptions—including altered hydrological cycles and regional warming—that threaten to push tropical biomes toward irreversible tipping points (Armstrong McKay et al., 2022). While the proximate drivers of this loss are primarily agricultural, the underlying causality remains a subject of intense scholarly debate. Current discourse navigates the tension between the "industrial frontier" model, driven by large-scale commodity production (Feurer et al., 2025), and the cumulative impact of smallholder expansion often necessitated by tenure insecurity and poverty (Runyan & Stehm, 2020).

This complexity is compounded by the "embodied" nature of deforestation, where approximately 16% of forest-risk commodities are consumed in international markets, far removed from the point of production (Pendrill et al., 2022). Historically, the global response relied on voluntary corporate social responsibility (CSR) and private certification schemes. However, the persistent failure of these voluntary commitments to decouple supply chains from forest loss—often dismissed as "greenwashing"—has prompted a paradigm shift toward binding regulatory intervention (European Court of Auditors, 2021; Kauffman & Martin, 2021).

The European Union's transition toward mandatory due diligence represents a landmark in transnational environmental governance, yet it has surfaced profound questions regarding

legitimacy and equity. Critics argue that these demand-side measures risk becoming a form of "green protectionism," potentially violating World Trade Organization (WTO) non-discrimination principles by imposing prohibitive compliance costs on developing-country exporters (Marx et al., 2022). Furthermore, there is a significant concern that stringent standards may inadvertently marginalize smallholders who lack the technical capacity for sophisticated traceability, thereby driving supply-chain consolidation and reinforcing neo-colonial power dynamics (Dauvergne, 2022). Consequently, the effectiveness of emerging climate governance depends not only on its environmental stringency but also on its ability to navigate the contested political economy of global trade and domestic sovereignty (Lima, 2021).

2.2. The EUDR: Governance Innovation and the Equity-Efficacy Dilemma

The EU Deforestation Regulation (EUDR; Regulation 2023/1115) represents a paradigm shift in environmental governance, transitioning from the narrow legality-based focus of the EU Timber Regulation (EUTR) to a mandatory "deforestation-free" standard. This framework requires operators to ensure that seven key commodities—coffee, cocoa, soy, palm oil, beef, rubber, and timber—and their derivatives are legally produced and traceable to specific plot-level geolocations. By institutionalizing these requirements, the EUDR aims to overcome the historical limitations of voluntary corporate commitments and third-party certifications, which have frequently been undermined by inconsistent enforcement and fragmented coverage (Lambin et al., 2018).

This regulatory evolution is characterized as a form of "trade-based climate governance," where the EU leverages its market power to export environmental norms and influence land-use practices globally. Proponents argue that the EUDR's emphasis on geolocation and transparency will not only reduce fraud and enhance accountability but also catalyze structural improvements in producer countries. These include the modernization of land-governance systems, accelerated digitalization, and the alignment of global value chains with international biodiversity and climate targets (Cashore & Bernstein 2023).

Despite its transformative potential, the EUDR faces significant criticism regarding its feasibility within complex, smallholder-dominated landscapes. Critics contend that the regulation's technical requirements reflect the operational realities of large-scale industrial plantations rather than the heterogeneous and often informally governed systems of small-scale farmers (Judijanto, 2025). While high-resolution remote sensing has improved the detection of forest disturbances (Hwang et al., 2023), its efficacy is often constrained by incomplete cadastral data, ambiguous land tenure, and the difficulty of monitoring agroforestry mosaics where degradation occurs as gradual canopy thinning rather than clear-cutting (Oliveira et al., 2024).

Furthermore, the implementation of a tiered risk-classification system has raised concerns about the potential stigmatization of producer nations, which could distort trade flows without necessarily improving environmental outcomes (Berning & Sotirov, 2024).). The central tension of the EUDR lies in its potential for unintended consequences: while it may harmonize global monitoring standards, the high cost of compliance risks marginalizing smallholders and incentivizing a shift toward capital-intensive producers. Such a transition could exacerbate rural inequality and trigger "leakage" effects, where deforestation-linked production is simply diverted to less regulated markets rather than being eliminated (Meyfroidt et al., 2022)

2.3. The VSS-EUDR Nexus: Institutional Synergies and Structural Misalignments

The role of Voluntary Sustainability Standards (VSS)—such as Fairtrade, Organic, and Rainforest Alliance—in facilitating compliance with the EU Deforestation Regulation (EUDR) is a subject of significant scholarly contention. While some researchers view VSS as "stepping-stone mechanisms" that foster institutional upgrading, others highlight a fundamental "compliance paradox" where certified status does not guarantee regulatory alignment (Marx et al., 2024).

Institutional Foundations vs. Substantive Impact: Proponents of VSS argue that these schemes provide a vital organizational infrastructure for EUDR readiness. By strengthening cooperative governance, digital record-keeping, and environmental awareness, VSS create a "culture of documentation" that can lower the barriers to formal regulatory compliance (Marx et al., 2022; United Nations Forum on Sustainability Standards, 2022). However, critics distinguish between "procedural compliance" (the act of being certified) and substantive environmental outcomes. Meta-analyses indicate that while VSS often succeed in reducing agrochemical use, their impact on preventing deforestation remains mixed or negligible (Dröge, Verbist, Maertens, & Muys, 2024). A critical temporal gap also exists: the EUDR mandates proof of no deforestation since a 2020 cutoff, whereas many VSS frameworks traditionally focus on current agronomic practices rather than rigorous historical land-use verification (United Nations Forum on Sustainability Standards, 2022).

Technical and Structural Misalignments: A primary obstacle to integrating VSS into EUDR workflows is the discrepancy in traceability requirements. Most certification schemes utilize "mass-balance" models, which allow for the mixing of compliant and non-compliant products during processing to maintain market liquidity (Marx et al., 2024). In contrast, the EUDR demands strict supply chain segregation and precise plot-level geolocation. This misalignment means that a farm may hold a valid sustainability certification yet remain non-compliant under the EUDR due to insufficient geospatial precision or the lack of a fully segregated chain of custody (Jelsma et al., 2023).

Cumulative Burdens and the Research Gap: The intersection of voluntary and mandatory standards also raises concerns regarding "cumulative compliance fatigue" among smallholders. Layering the EUDR's stringent geolocation and legality requirements onto existing VSS audit cycles may overburden the administrative and financial capacity of small-scale producers, potentially deepening rural inequality (Schilling-Vacaflor & Gustafsson, (2024). Consequently, scholars warn against treating VSS as a proxy for regulatory due diligence, as the two systems differ fundamentally in their legal accountability and technical rigor (Cosimo et al., 2024). Given these complexities, there is a pressing need for empirical research to determine whether and how VSS translate into tangible EUDR readiness—a gap this study directly addresses.

2.4. A Cross-Regional Synthesis of EUDR Implementation: Readiness and Exclusion Risk

Emerging evidence from major producing regions indicates that while the EU Deforestation Regulation (EUDR) acts as a catalyst for governance reform, its implementation reveals a systemic gap between national ambitions and on-the-ground readiness. Across Southeast Asia, Latin America, and Africa, three primary constraints—technical data gaps, land-tenure insecurity, and the threat of smallholder marginalization—define the current landscape of compliance.

Technical and Geospatial Constraints: A fundamental barrier across all regions is the lack of precise geospatial data and the institutional capacity to manage it. In Southeast Asia, despite Vietnam's potential for sustainability upgrading in the coffee sector, weak geolocation infrastructure remains a primary bottleneck (Hoang et al., 2025). Similarly, research from Peru and Cameroon highlights how fragmented geospatial data and insufficient technical resources hinder the ability of state institutions to provide the "plot-level" verification required by the EU (Solar et al., 2025; Ten Hove et al., 2025). Even in Brazil, where coffee producers demonstrate relatively high technical readiness, the administrative burden of maintaining these data systems remains a significant hurdle for the broader agricultural sector (Oliveira et al., 2024).

Structural and Legal Hurdles: Land Tenure and Governance: The EUDR's requirement for "legality" documentation has exposed deep-seated vulnerabilities in national land administration. In Indonesia and Côte d'Ivoire, persistent ambiguities in land-tenure security and weak data governance create significant legal risks for exporters of cocoa, rubber, and palm oil (Nasution et al., 2025; Verhegghen et al., 2024). These structural weaknesses suggest that without comprehensive land-administration reforms, compliance will remain elusive. In Ghana, early modeling suggests that the EUDR may fail to achieve its conservation goals unless it is accompanied by fundamental shifts in how forest-fringe land is monitored and governed (Mabica et al., 2025).

The Smallholder Paradox: Inclusion vs. Compliance Costs: The most consistent finding across global studies is the disproportionate risk of exclusion faced by smallholder farmers. In Colombia and Honduras, the high costs of compliance and limited technical assistance threaten to decouple small-scale producers from the EU market (Naranjo et al., 2024; Melo-Velasco et al., 2023). This concern is echoed by industry bodies in Malaysia, who have advocated for enforcement delays to prevent the wholesale exclusion of smallholders from the palm oil and rubber supply chains (Malaysian Palm Oil Council, 2024). Consequently, a "compliance divide" is emerging: while well-capitalized large-scale enterprises may successfully pivot to meet EUDR standards, the lack of targeted support for smallholders could lead to unintended social consequences and the redirection of "non-compliant" commodities to less regulated markets.

2.5. The Ethiopian Coffee Frontier: Structural Bottlenecks and the Smallholder Inclusion Gap

Ethiopia occupies a unique yet precarious position within the EUDR framework. As the genetic home of *Coffea arabica*, its production is defined by high-biodiversity agroforestry systems—ranging from garden to forest coffee—managed by approximately five million smallholders (FAO, 2018). However, the very features that make Ethiopian coffee ecologically valuable also present formidable barriers to regulatory compliance.

Structural Fragmentation and Traceability Hurdles: The Ethiopian coffee sector is characterized by "multi-nodal" value chains where coffee from thousands of plots—most smaller than two hectares—is aggregated through complex networks of intermediaries and cooperatives (Minten et al., 2019). This structural fragmentation leads to significant "lot mixing," which directly conflicts with the EUDR's requirement for strict plot-level traceability (Ponte, 2022). Furthermore, the physical nature of Ethiopian coffee systems complicates verification; in forest and semi-forest landscapes, distinguishing between sustainable harvesting and forest degradation via remote sensing requires a level of geospatial resolution and contextual expertise that is currently lacking (FAO, 2018).

Institutional and Tenure Constraints: Compliance is further hampered by a misalignment between national land governance and EUDR mandates. Ethiopia's reliance on customary land boundaries and its limited cadastral coverage make the precise geolocation and "legality" verification of millions of tiny plots an administrative paradox (Tefera et al., 2025). While cooperatives are often viewed as the primary vehicle for data aggregation, preliminary assessments suggest they suffer from uneven digital infrastructure and a lack of technical capacity to manage the rigorous data-management demands of the regulation (Getaw et al., 2024).

The Risk of Market Bifurcation: The intersection of low farmer awareness and high compliance costs creates a significant risk of socio-economic marginalization. Early evidence suggests a looming "bifurcated market": well-resourced farmers or those in elite cooperatives may maintain EU access, while the most vulnerable households—constrained by land insecurity and digital illiteracy—are pushed toward lower-value, non-regulated markets (Tefera et al., 2025). This potential for exclusion is particularly acute for households already facing systemic barriers to extension services and credit (Gallemore et al., 2025).

The Research Gap: While these preliminary studies provide a macro-level overview of the institutional and technical challenges facing Ethiopia, they remain largely speculative or descriptive. There is currently a critical lack of systematic, household-level empirical evidence regarding how individual smallholders perceive the EUDR, their actual capacity to meet its technical requirements, and the extent to which participation in Voluntary Sustainability Standards (VSS) might moderate these impacts. This study addresses this gap by providing a granular analysis of farmer-level readiness and the institutional mechanisms that may either facilitate inclusion or exacerbate marginalization.

3. Methodology

3.1. Study Area

The study was conducted in southwestern Ethiopia, a region of strategic importance for both national coffee production and the implementation of the EU Deforestation Regulation (EUDR). The broader area contributes approximately half of Ethiopia's total coffee output and is characterized by diverse production systems, including garden (50%), semi-forest (35%), forest (10%), and plantation coffee (5%) (Arai et al., 2023). The research focused specifically on the Southwestern region's zones of Kafa, Sheka, and Sheko (Bench Maji), which host most of the country's last remaining montane rainforests and are recognized as UNESCO Biosphere Reserves. These landscapes are globally significant for harbouring the center of origin and genetic diversity of *Coffea arabica*, including the iconic "Mother Tree," believed to be one of the oldest living Arabica trees.

Coffee cultivation in these zones is deeply intertwined with natural forest ecosystems, particularly through semi-forest and forest coffee systems formalized through community-based Participatory Forest Management (PFM) initiatives covering approximately 1.5 million hectares of forest coffee areas (European Forest Institute, 2025) that provide critical biodiversity and ecosystem service benefits. The coffee value chain in this region reflects both traditional and modern elements. Approximately 45% of coffee is marketed through primary cooperatives and cooperative unions while private collectors and processors handle the remainder (Minten et al., 2018). This cooperative structure has been instrumental in implementing sustainability certifications mostly Fairtrade, Organic (EU/USDA), Rainforest Alliance) that now cover approximately 25% of exports,

providing institutional experience relevant to EUDR compliance. The selection of these zones was therefore purposive, reflecting their ecological importance, the prevalence of forest-based coffee systems, and their relevance for assessing potential regulatory implications under the EUDR.

3.2. Research Design and Data Collection

A convergent mixed-methods design was employed to holistically assess EUDR awareness, compliance capacity, and perceived impacts among smallholder coffee farmers. This approach facilitated data triangulation, enhancing the robustness and validity of the findings.

3.2.1. Sampling Design

A multi-stage, stratified random sampling strategy was employed to ensure balanced representation across major coffee production systems (garden, semi-forest, and forest coffee) and certification categories, including Fairtrade, Organic, and Rainforest Alliance schemes.

In the first stage, woredas were selected purposively in consultation with the Regional Bureau of Agriculture and the Coffee, Tea and Spices Authority to capture variation in forest cover, coffee production systems, and the presence of Voluntary Sustainability Standards (VSS). This resulted in the inclusion of Gimbo, Gwata, and Decha woredas in Kafa Zone, Debub Bench in Sheko Zone, and Andracha in Sheka Zone. The purposive selection was intended to ensure policy relevance and variation in certification exposure rather than statistical representativeness at the national level.

In the second stage, coffee producer cooperatives within each selected woreda—including those participating in Participatory Forest Management (PFM)—were identified and stratified by certification status (certified vs. non-certified). Cooperatives served primarily as sampling frames through which certified and non-certified households could be accessed. In the final stage, individual coffee-producing households were randomly selected from cooperative membership lists using probability proportional to cooperative size. In total, 600 households were surveyed.

Although certification opportunities and information channels are often organized through cooperative structures, the empirical analysis is conducted at the household level. The econometric models exploit within-sample variation in certification status and household characteristics rather than cooperative-level treatment assignment. Because detailed cooperative-level covariates (e.g., management quality, financial capacity, or institutional performance indicators) were not available, the models do not include cooperative fixed effects. Consequently, inference relies on household-level variation, and the identification strategies (PSM and ESR) primarily address selection at the individual-farmer level.

While this design allows rigorous comparison between certified and non-certified households within the sampled cooperatives, unobserved cooperative-level characteristics cannot be entirely ruled out. This limitation is acknowledged when interpreting statistical precision and causal inference.

3.2.2. Quantitative Survey Design and Data Collection

The quantitative survey instrument was designed to capture detailed information on (i) farmers' awareness and understanding of the EUDR, (ii) their technical, financial, and institutional capacity

to meet EUDR compliance requirements, (iii) perceived and potential economic, social, and environmental implications, and (iv) the moderating role of VSS participation in enhancing EUDR preparedness.

Questionnaire development and quantitative data collection followed a rigorous, multi-step process designed to maximize reliability and contextual accuracy. The instrument was informed by qualitative findings and existing literature, particularly regarding traceability requirements, due-diligence processes, land-use documentation, and certification mechanisms. To minimize measurement error, best practices in survey design were applied, including careful refinement of wording, logical sequencing of questions, and clear formatting. Enumerators were recruited based on their educational background, proficiency in local languages, and demonstrated motivation, and subsequently received intensive training on survey content, interviewing standards, and research ethics. The questionnaire was pre-tested with a small group of households to assess clarity, contextual relevance, and internal consistency, leading to further refinement before the main fieldwork. Data collection was closely supervised by the research team, involving real-time checks for completeness, accuracy, and logical coherence. Any inconsistencies or missing information were promptly addressed through follow-up visits and verification procedures to ensure the integrity of the final dataset.

3.2.3. Qualitative Data Collection and Stakeholder Engagement

Qualitative data collection involved multiple Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) across the selected woredas. FGDs were conducted with smallholder farmers, cooperative leaders, and local agricultural extension workers to explore collective perceptions of the EUDR, anticipated challenges in meeting its requirements, and suggestions for institutional or policy support.

KIIs were undertaken with a wide range of stakeholders, including officials from federal ministries and agencies, regional and local government bureaus, coffee unions and exporters, and NGOs and development organizations engaged in coffee value chains, forest governance, and environmental conservation. These interviews provided insights into policy and market preparedness, existing institutional support mechanisms, and broader governance challenges associated with EUDR implementation.

To complement the primary data, secondary data on forest cover, land-use change, and coffee production trends were obtained from government reports and institutional databases. These datasets supported contextualization of the empirical results and triangulation of findings across data sources.

3.3. Analytical Methods

This study employed a combination of econometric and qualitative analytical techniques to address the three research questions. The analytical framework was organised around (i) modelling farmers' awareness and compliance capacity regarding the EUDR, (ii) estimating the impact of Voluntary Sustainability Standards (VSS) on these outcomes, and (iii) assessing the perceived socio-economic and environmental implications of the regulation.

3.3.1. Variables and Measurement

Two composite outcome variables were constructed to measure farmers' preparedness for the EU Deforestation Regulation (EUDR): an EUDR Awareness Index and an EUDR Compliance Capacity Index. EUDR awareness was measured using nine Likert-scale items assessing farmers' understanding of the regulation's objectives, scope, deforestation cut-off requirements, export implications, documentation obligations, geolocation specifications, and access to relevant information. All items were recorded on a five-point scale ranging from very low to very high. The indicators demonstrated satisfactory internal consistency and were aggregated using standardized averages to construct a continuous Awareness Index.

Compliance capacity was conceptualized as a multidimensional construct reflecting farmers' ability to meet the regulatory, technical, and institutional requirements of the EUDR. The Compliance Capacity Index integrates four complementary dimensions:

- Compliance Evidence, capturing the ability to demonstrate deforestation-free production and knowledge of plot establishment year and related legal documentation.
- Technical Capacity, including record-keeping practices, mapping/GPS ability, and traceability systems necessary for plot-level verification.
- Support Systems, reflecting access to sustainability-related services and cooperative or buyer support mechanisms.
- Operational Feasibility, indicating ability to manage compliance-related costs, and capacity to adapt production practices where required.

All compliance indicators were measured on comparable five-point Likert scales and aggregated using standardized averages to form a continuous composite index. The multidimensional specification reflects the regulatory architecture of the EUDR, which requires simultaneous fulfillment of documentation, geolocation, traceability, institutional support, and operational feasibility conditions. Internal consistency diagnostics confirmed satisfactory reliability of the constructed index.

As robustness checks, alternative indices based on principal component analysis (PCA) were estimated, yielding qualitatively similar results. Additionally, self-reported overall awareness and compliance readiness were collected using five-point ordinal measures to validate the main constructs.

In all causal models, Voluntary Sustainability Standards (VSS) certification was operationalized as a binary treatment variable, defined as participation in one or more recognized certification schemes (including Fairtrade, Organic, Rainforest Alliance, and related standards), coded as 1 for certified farmers and 0 otherwise.

Given the institutional context of Ethiopian coffee marketing, certification is typically mediated through cooperative structures that facilitate compliance with traceability, documentation, and export requirements. Accordingly, the treatment variable captures participation in certified cooperative supply chains rather than the isolated design features of any single certification standard. While individual schemes may differ in specific traceability or land-use requirements, they share core principles of deforestation-free production, documentation, and third-party verification that are central to EUDR-related preparedness, and most of the farmers have multiple certification.

Due to sample size constraints and overlapping scheme participation, scheme-specific effects could not be separately identified. Therefore, the estimated Average Treatment Effect on the Treated (ATT) should be interpreted as the effect of participation in certified-cooperative marketing channels that operate under one or more sustainability standards, rather than the causal impact of a particular certification label in isolation.

An extensive set of demographic, socioeconomic, geographic, and farming characteristics (e.g., age, education, gender, household size, landholding, non-farm participation, coffee farming experience, plot size and characteristics) were included as covariates. For the ESR model, years of cooperative membership served as the instrumental variable, justified by its influence on the likelihood of VSS participation while not directly affecting EUDR-specific awareness or compliance capacity.

3.3.2. Model Specification

A. Determinants of EUDR Awareness and Compliance Capacity of Smallholder Farmers

The choice of econometric models used to identify the determinants of smallholder farmers' awareness of the EU Deforestation Regulation (EUDR) and their capacity to comply was guided by the measurement properties, scale characteristics, and distributional features of the dependent variables. EUDR awareness and compliance capacity were first operationalised through the construction of composite indices—namely, the Awareness Index (AI) and the Compliance Capacity Index (CCI)—each derived as the average of standardized scores from multiple five-point Likert-scale indicators. This aggregation yields an approximately interval-level variable suitable for linear estimation. Consequently, an Ordinary Least Squares (OLS) regression model was selected for its efficiency, straightforward interpretation of coefficients, and consistency in estimating continuous outcomes. This specification was employed following diagnostic tests, which confirmed that the core assumptions of linearity, normality of residuals, and homoscedasticity were substantially met.

OLS Model

$$CCI_i = X_i^{'}\beta + u_i,$$

where CCI_i or AI_i is the continuous compliance capacity index or awareness index (separate model for CCI and AI), X_i is the vector of explanatory variables, and u_i is a zero-mean disturbance term with $E(u_i | X_i) = 0$.
The parameters are estimated by minimizing the sum of squared residuals:

$$\hat{\beta} = \arg \min_{\beta} \sum_{i=1}^{n} (CCI_i - X_i'\beta)^2$$

To assess the robustness of the results to alternative measurement assumptions, an ordered logit model was additionally estimated using farmers' self-reported overall awareness and perceived compliance capacity measured on a five-point Likert scale. Here, the dependent variables were the direct ordered categorical responses capturing overall awareness and perceived compliance capacity, estimated in separate models. While the index assumes approximate interval scaling, the ordered logit model is the appropriate estimator for ordinal outcomes, as it models the cumulative

probability of being at or above each response threshold without imposing restrictive equal-interval assumptions (Wooldridge, 2010).

Ordered Logit Model

Let the latent continuous awareness and perceived compliance capacity variable be (estimated separately)

$$A_i^* = X_i'\beta + \varepsilon_i$$

where A_i^* is unobserved, X_i is a vector of explanatory variables, and ε follows a logistic distribution.

The observed ordered outcome $A_i \in \{1,2,3,4,5\}$ is defined by threshold cut-points μ_j:

$$A_i = j \text{ if } \mu_{j-1} < A_i^* \leq \mu_j$$

The probability of being in category j is

$$P(A_i = j) = \Lambda(\mu_j - X_i'\beta) - \Lambda(\mu_{j-1} - X_i'\beta),$$

where $\Lambda(\cdot)$ is the logistic CDF.

B. Impact of Voluntary Sustainability Standards (VSS) on Awareness and Compliance

We expect participation in Voluntary Sustainability Standards (VSS)—including Fairtrade, Organic, and Rainforest Alliance certification—to influence farmers' readiness for the EUDR through improved training access, strengthened record-keeping systems, enhanced traceability procedures, and greater organizational capacity. Accordingly, we first included VSS participation as a binary explanatory variable in the awareness and compliance capacity models, and we estimated interaction terms between certification status and household characteristics (e.g., education, training access, farming experience) to test potential moderating effects. However, because participation in VSS is not randomly assigned, certified farmers may differ systematically from non-certified farmers in ways that also affect EUDR preparedness, generating potential selection bias (Rosenbaum & Rubin, 1983). To address this concern and support causal interpretation, we employed a rigorous impact-evaluation strategy. As a first step, we applied Propensity Score Matching (PSM), which mitigates selection bias by constructing a counterfactual outcome for certified farmers using non-certified farmers with similar observable characteristics. This matching process ensures comparability across pre-treatment covariates and reduces bias arising from differences in observable attributes (Caliendo & Kopeinig, 2008).

Propensity Score Matching (PSM)

We first estimated the probability of receiving treatment—i.e. VSS certification—conditional on a vector of observed covariates. Formally, for each farmer *i*, the propensity score is defined as:

$$p(X_i) = Pr(D_i = 1 \mid X_i),$$

where $D_i = 1$ denotes VSS-certified status and $D_i = 0$ indicates non-certified farmers. We parameterised the propensity score using a logistic regression model:

$$p(X_i) = \frac{exp(X_i'\alpha)}{1 + exp(X_i'\alpha)},$$

where X_i includes demographic, socioeconomic, and farming characteristics that jointly influence both certification and EUDR readiness (awareness and compliance capacity computed separately). Specifically, the covariate set comprised age, gender, household size, years of education, total landholding, coffee landholding, years of coffee farming, non-farm participation, cooperative membership, distance to markets, and access to extension or sustainability training. Including these variables ensures conditional independence—i.e. treatment assignment is assumed independent of outcomes given X_i—which is the key identifying assumption of PSM.

After estimating the model, we predicted individual propensity scores $\hat{p}_i$ and proceeded to match treated and control farmers based on these probabilities.

Our primary estimand is the Average Treatment Effect on the Treated (ATT), which reflects the causal effect of VSS certification on EUDR awareness or compliance capacity for those farmers who are actually certified. Formally:

$$ATT = E[Y_i(1) - Y_i(0) \mid D_i = 1],$$

where $Y_i(1)$ and $Y_i(0)$ denote potential outcomes under treatment and non-treatment, respectively. Because the counterfactual $Y_i(0)$ for treated farmers is unobserved, PSM replaces it with the matched outcomes of observationally similar non-certified farmers.

To ensure robustness and reduce reliance on any single matching estimator, we implemented three commonly recommended matching algorithms—nearest-neighbour, radius, and kernel matching—each of which constructs counterfactuals using different weighting schemes.

Nearest-Neighbour (NN) Matching: Nearest-neighbour matching pairs each treated farmer with the closest control farmer(s) in terms of estimated propensity scores. For each treated unit *i*, we identified a set of *k* control neighbours $N_k(i)$. The weight assigned to each matched control unit *j* is:

$$w_{ij}^{NN} = \begin{cases} \frac{1}{k}, & \text{if } j \in \mathcal{N}_k(i), \\ 0, & \text{otherwise .} \end{cases}$$

The ATT estimator is then:

$$\widehat{ATT}_{NN} = \frac{1}{N_1} \sum_{i:D_i=1} \left(Y_i - \frac{1}{k} \sum_{j \in \mathcal{N}_k(i)} Y_j \right),$$

where N_1 is the number of treated farmers. We used matching with replacement to minimise bias and implemented both k=2 (primary) and k=3 (robustness) specifications.

Radius (Caliper) Matching: Radius matching restricts matches to controls whose propensity scores lie within a pre-specified caliper (radius) around a treated farmer. A control farmer j is considered a valid match for treated farmer i if:

$$|\hat{P}_j - \hat{P}_i| \leq c,$$

where c denotes the caliper width. The weights for radius matching are:

$$w_{ij}^R = \frac{K_{ij}}{\sum_j : D_j = 0 K_{ij}}, where\, K_{ij} = 1\{|\hat{P}_j - \hat{P}_i| \leq c\}$$

The ATT estimator is:

$$\widehat{ATT}_R = \frac{1}{N_1} \sum_{i:D_i=1} \left(Y_i - \sum_{j:D_j=0} w_{ij}^R Y_j \right).$$

We used a caliper of 0.03 as the main specification and conducted sensitivity checks with alternative calipers.

Kernel Matching: It uses a weighted average of all available control observations, with weights decreasing as the propensity score distance increases. Following standard practice, we applied an Epanechnikov kernel:

$$K(u) = \frac{3}{4}(1-u^2)1(|u| \leq 1),$$

with weights defined as:

$$w_{ij}^K = \frac{K\left(\frac{\hat{p}_j - \hat{p}_i}{h}\right)}{\sum_{l:D_l=0} K\left(\frac{\hat{p}_l - \hat{p}_i}{h}\right)},$$

where h is the bandwidth parameter governing smoothness. The ATT estimator takes the form:

$$\widehat{ATT}_K = \frac{1}{N_1} \sum_{i:D_i=1} \left(Y_i - \sum_{j:D_j=0} w_{ij}^K Y_j \right).$$

We set h=0.08 as the primary bandwidth and checked robustness (sensitivity to the bias–variance trade-off.) using h=0.06 and h=0.13.

Before matching, we assessed the region of common support by examining the distribution of estimated propensity scores for certified and non-certified farmers. Observations falling outside the overlapping region—where no suitable match exists—were trimmed to avoid extrapolation. This step improves the reliability of the counterfactual comparison and ensures that matched farmers are similar in their pre-treatment characteristics.

Diagnostics and Balance Assessment

To verify the quality of matching, we performed a comprehensive set of post-matching diagnostics. First, we evaluated covariate balance by comparing standardized mean differences (SMDs) between treated and matched control groups:

$$SMD = \frac{\bar{X}_T - \bar{X}_C}{\sqrt{(s_T^2 + s_C^2)/2}}$$

Successful matching requires all SMDs to fall below the commonly accepted threshold of |0.10||0.10||0.10|. We also examined variance ratios, conducted paired t-tests, and computed Rubin's B and Rubin's R statistics to evaluate mean and variance balance of the propensity score index. Additionally, we generated kernel density plots of the propensity score distributions pre- and post-matching to visually confirm overlap and improved comparability.

Endogenous Switching Regression (ESR)

To complement our PSM estimator and address endogeneity arising from both observed and unobserved heterogeneity, we estimate an Endogenous Switching Regression (ESR) model. ESR is particularly appropriate in our context because farmers self-select into Voluntary Sustainability Standard (VSS) certification based on characteristics that may also influence their EUDR awareness and compliance capacity. By modelling the certification decision jointly with the outcome process, ESR enables us to obtain bias-corrected estimates and construct internally consistent counterfactuals. We begin by modelling farmers' certification status through a binary selection equation of the form

$$C_i^* = Z_i'\alpha + \eta_i, C_i = \begin{cases} 1 & \text{if } C_i^* > 0 \\ 0 & \text{otherwise} \end{cases}$$

where the latent variable C_i^* captures the underlying propensity to obtain certification, Z_i' is a vector of explanatory variables including the instrumental variable 'Years of cooperative membership', and η_i is the error term. We observe the actual decision as C_i=1 if C_i^*>0 (certified) and C_i=0 otherwise. We estimate this selection equation using a probit model, which yields the predicted probabilities of certification

$$\hat{p}_i = \Phi(Z_i'\hat{\alpha}),$$

from which we compute the regime-specific correction terms required to address non-random selection. In particular, we calculate the Inverse Mills Ratios (IMRs) as

$$\lambda_{1i} = \frac{\phi(Z_i'\hat{\alpha})}{\Phi(Z_i'\hat{\alpha})} \text{ for } C_i = 1,$$
$$\lambda_{0i} = \frac{\phi(Z_i'\hat{\alpha})}{1 - \Phi(Z_i'\hat{\alpha})} \text{ for } C_i = 0,$$

where ϕ (·) and Φ (·) denote the standard normal density and cumulative distribution functions, respectively. These terms allow us to correct for selection bias arising from unobserved characteristics that simultaneously influence certification and outcomes.

Given that farmers face different production and market conditions depending on whether they are certified or not, we specify two outcome equations corresponding to the certified and non-certified regimes. For certified farmers (C_i=1), we specify

$$Y_{1i} = X_i'\beta_1 + \rho_1\sigma_1\lambda_{1i} + \varepsilon_{1i}$$

while for non-certified farmers (C_i=0), the outcome equation is

$$Y_{0i} = X_i'\beta_0 - \rho_0\sigma_0\lambda_{0i} + \varepsilon_{0i}$$

Where Y_k represents either the EUDR Awareness Index or the EUDR Compliance Capacity Index, X_i is a vector of household and farm-level covariates, ε_{ki} are regime-specific disturbance terms with standard deviations σ_k.

The parameters ρ_k are defined as the correlation coefficients between the error term in the selection equation (η_i) and the regime-specific outcome equation errors (ε_{ki}):

$$\rho_k = \frac{\text{Cov}(\varepsilon_{ki}, \eta_i)}{\sigma_k\sigma_\eta}, k \in \{0,1\}$$

where σ_η is the standard deviation of the selection equation error.

Under the assumption of joint normality, the conditional expectations of the regime-specific errors generate the selection correction terms shown above, including the negative sign in the non-certified regime equation.

A statistically significant ρ_k indicates selection on unobservables. The sign of ρ_k reflects the direction of correlation between unobserved determinants of certification and unobserved determinants of the outcome in regime k.

The ESR framework allows computation of expected outcomes under actual and counterfactual regimes:

$$E(Y_{1i} \mid C_i = 1), \quad E(Y_{0i} \mid C_i = 1),$$
$$E(Y_{0i} \mid C_i = 0), \quad E(Y_{1i} \mid C_i = 0)$$

From these expectations, we compute the Average Treatment Effect on the Treated (ATT) and the Average Treatment Effect on the Untreated (ATU). By explicitly modelling the selection mechanism and correcting for non-random sorting, ESR provides treatment-effect estimates that account for both observable and unobservable sources of selection.

A key identification requirement for the Endogenous Switching Regression (ESR) model is the presence of at least one instrumental variable that affects the probability of certification but does not exert an independent effect on the outcome variables, conditional on the included covariates. We use years of cooperative membership as the exclusion variable in the outcome equations.

This choice is grounded in the institutional organization of Ethiopian coffee marketing, where certification opportunities are primarily accessed through cooperative structures (Berihun & Gutema, 2025). Certification is typically initiated, coordinated, and maintained at the cooperative level, implying that farmers with longer membership histories are more likely to be selected into or participate in certification schemes. Empirically, cooperative years is strongly correlated with certification status in the first-stage selection equation, satisfying the relevance condition.

The exclusion restriction requires that, conditional on observable household and farm characteristics (X_i), cooperative membership duration does not directly affect EUDR awareness or compliance capacity. While cooperatives serve as general platforms for information exchange and market coordination, the EUDR is a recent regulatory development. EUDR-specific awareness and compliance requirements—such as geolocation precision, deforestation cut-off verification, and formalized traceability documentation—were not historically embedded in cooperative services prior to certification engagement.

Importantly, in the indexed OLS specifications for both the Awareness and Compliance Capacity indices, years of cooperative membership does not exhibit a statistically significant association with the composite outcomes once certification status and other covariates are controlled for. This suggests that any direct effect of membership duration on the EUDR-specific preparedness measures is limited in magnitude. Although cooperative years shows some association with self-rated compliance in ordered models, such measures may reflect subjective confidence rather than the structured index capturing regulatory-specific dimensions. The absence of significance in the indexed regressions supports the plausibility of the exclusion assumption.

Nevertheless, we acknowledge that the exclusion restriction cannot be tested directly and remains an identifying assumption. Given the institutional role of cooperatives in facilitating certification access rather than independently delivering EUDR-specific infrastructure to non-certified farmers, we interpret the ESR estimates as providing a robustness assessment of potential selection bias rather than as the sole source of causal identification.

Based on this identification strategy, the Average Treatment Effect on the Treated (ATT) derived from the ESR model should be interpreted as conditional on the maintained assumption that cooperative membership duration influences EUDR preparedness primarily through its effect on certification participation.

C. Potential Impacts of the EUDR: Qualitative Analysis

Given the anticipatory nature of assessing the EUDR's effects and its early implementation stage, we complemented our quantitative farmers' perceived potential impact analysis with a qualitative thematic exploration of potential impacts. We conducted Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs), and analyzed the resulting transcripts using an integrated inductive–deductive thematic approach informed by Braun and Clarke's (2006) framework. This allowed us to systematically identify and refine emerging themes related to farmers' perceived economic risks, compliance constraints, institutional readiness, expected market responses, forest-conservation implications, and support requirements.

We then organized these themes to trace the pathways through which the EUDR may shape smallholder livelihoods and coffee-forest systems. By triangulating these qualitative insights with the quantitative findings from our analyses of awareness and compliance capacity, we developed a richer and more holistic interpretation of the regulation's potential consequences. This mixed-methods integration enhanced the interpretive robustness of the findings and informed the development of context-sensitive policy implications for Ethiopia's smallholder coffee sector.

4. Result

The following sections present the empirical findings of the study, beginning with a descriptive profile of the sampled households and their institutional environment, followed by an econometric analysis of the factors influencing EUDR readiness.

4.1. Household Characteristics

The surveyed smallholder coffee households exhibit diverse socio-demographic and livelihood profiles, reflecting the heterogeneous conditions of coffee production in Southwest Ethiopia. These characteristics (Table 1) serve as the baseline for understanding the socio-economic landscape in which EUDR requirements are being introduced.

The average age of household heads is approximately 44 years, representing a mature farming population. However, the sample includes a broad range of ages, from young to elderly respondents, reflecting a mix of generational perspectives, physical capacities, and varying stages of the household life cycle. This age diversity suggests that the farming population possesses a wide spectrum of agricultural experience and potential receptivity to shifting market requirements.

The sample is predominantly male-headed (93%), a structural feature that characterizes the demographic composition of decision-makers in the region's coffee sector. Similarly, marital status data indicate that the majority of respondents are married, pointing toward relatively stable household units. The average household size exceeds six members, with a high maximum value indicating the presence of extended family structures. These figures highlight the demographic pressure on household resources and the potential pool of internal labor available for farm management.

Educational attainment is primarily clustered at the primary level, representing the baseline human capital available within the sampled households. While most respondents possess basic literacy, the limited reach of higher formal education suggests that communication of complex regulatory frameworks may need to account for varying levels of technical and documentative literacy.

Regarding livelihood strategies, only 23% of households participate in non-farm income activities, indicating a high degree of specialization in agricultural production. This reliance on the farm sector is further evidenced by the respondents' extensive experience in coffee cultivation, which averages over 16 years. Such longevity suggests a deep-rooted expertise in traditional coffee systems, though it remains to be seen how this experience interacts with modern, data-intensive regulatory demands.

Finally, households rely heavily on family labor, with an average of nearly five members engaged in farm activities. This internal labor supply is a central component of the smallholder production model in the region, serving as the primary mechanism for managing the labor-intensive requirements of coffee harvesting and post-harvest processing.

In summary, the household characteristics reveal a population with significant farming experience and stable household structures, yet one characterized by low levels of income diversification and formal education—factors that establish the socio-economic context for the subsequent analysis of EUDR readiness.

4.2. Coffee Production Systems

To contextualize the subsequent data on production practices, it is essential to define the three dominant coffee systems within the study sample, as categorized by Ethiopian agricultural typology. Forest coffee refers to coffee growing under natural forest canopies where farmers selectively manage wild coffee stands through thinning and cleaning. Semi-forest coffee is a more intensively managed derivative, where forest is thinned and undergrowth cleared to increase coffee yield, yet the ecosystem remains shaded and semi-wild. Crucially, both forest and semi-forest systems constitute *managed* production within existing ecosystems and are distinct from the harvesting of truly wild, unmanaged coffee. In contrast, garden coffee is cultivated on small plots near homesteads, often with integrated shade trees and more frequent agronomic inputs.

The distribution of coffee production systems among sampled households reveals substantial heterogeneity in land-use practices, ecological exposure, and regulatory vulnerability under the EU Deforestation Regulation (EUDR). These systems are not merely agronomic categories; rather, they reflect differing levels of forest dependence, traceability complexity, and compliance risk.

Approximately 16.95% of sampled households cultivate coffee exclusively under forest systems. These systems are closely embedded within natural or semi-natural forests and are strongly associated with Ethiopia’s biodiversity-rich coffee landscapes. While forest coffee offers significant environmental value, it faces heightened EUDR scrutiny, as demonstrating deforestation-free status requires precise historical land-use evidence and accurate geolocation of production plots. Compliance capacity for forest coffee producers may therefore be constrained by indistinct plot boundaries, customary tenure arrangements, and limited access to mapping and documentation technologies.

The largest share of households (39.2%) rely exclusively on semi-forest coffee systems, which occupy an intermediate position between forest and garden systems in terms of ecological integration and management intensity. Although semi-forest coffee typically involves some degree of forest modification and enrichment planting, it still poses notable EUDR compliance challenges. These are generally less severe than in forest systems but remain substantial, particularly with respect to verifying historical land-use change and ensuring consistent traceability.

By contrast, 29.3% of households operate garden coffee systems only, making this the second most prevalent production modality in the sample. Garden coffee is usually cultivated on long-established plots near homesteads, often with clearer land-use histories and more easily identifiable boundaries. This relative clarity can reduce EUDR compliance complexity, particularly for plot-level documentation, establishment year verification, and supply chain traceability. As a result, garden coffee producers may exhibit comparatively better readiness for EUDR compliance, even in the absence of formal certification.

Importantly, approximately 13% of households operate mixed production systems, combining two of the production systems. Although each specific mixed category represents a relatively small share individually, together they reflect diversified production strategies. While such diversification may enhance livelihood resilience, it substantially increases EUDR compliance complexity, as farmers must document multiple plots with distinct land-use histories, ecological characteristics, and risk profiles. This multiplicity can strain record-keeping capacity and raise transaction costs, particularly for non-certified producers.

Only a very small proportion of households (1.55%) combine all three production systems, suggesting that full diversification across systems is rare, likely due to land constraints and tenure limitations. Nevertheless, these households represent a high-risk group for EUDR non-compliance unless targeted technical and institutional support is provided.

Overall, the predominance of semi-forest and garden coffee systems highlights the dual challenge posed by the EUDR in the Ethiopian context: safeguarding ecologically valuable forest-based coffee landscapes while ensuring that smallholders—particularly those embedded within forest environments—are not disproportionately excluded from regulated export markets due to elevated compliance barriers.

Table 1 Socio-Demographic, Livelihood, and Coffee Production System Characteristics of Sampled Households (N = 600)

Variable	Description	Mean (Std. Dev.)
Household position	Head or spouse of household	1.33 (1.00)
Age of household head (years)	Respondent age	43.53 (12.17)
Gender of household head	1 = Male, 0 = Female	0.93 (0.26)
Marital status	Marital category	2.03 (0.38)
Household size	Number of household members	6.36 (5.29)
Education level	Formal education attained	2.89 (1.06)
Non-farm income participation	1 = Yes, 0 = No	0.23 (0.42)
Coffee farming experience (years)	Years in coffee production	16.42 (6.30)
Family labour availability	Household members engaged in farming	4.71 (2.47)
Forest coffee only	Cultivation exclusively in forest systems	0.16 (0.50)
Semi-forest coffee only	Cultivation exclusively in semi-forest systems	0.39 (0.30)
Garden coffee only	Cultivation exclusively in garden systems	0.29 (0.46)

Forest + semi-forest	Combined forest and semi-forest systems	0.01 (0.04)
Forest + garden	Combined forest and garden systems	0.07 (0.25)
Semi-forest + garden	Combined semi-forest and garden systems	0.05 (0.21)
Forest + semi-forest + garden	All three systems combined	0.02 (0.12)

Notes: Production system variables are binary indicators. Means represent the proportion of households using each system.

4.3. Coffee Farming Practices and Recent Trends

An overview of coffee farming practices and self-reported changes over the past five years is summarized in Table 2. These practices are directly relevant to compliance with the European Union Deforestation Regulation (EUDR), as they reflect land-use management decisions, tree-cover dynamics, and conservation behaviour at the farm level — elements that shape deforestation risk, traceability complexity, and documentation requirements. The descriptive evidence indicates that coffee production in the study area is largely embedded within agroforestry-based systems, reflecting the dominance of forest and semi-forest production alongside homestead garden coffee, with notable heterogeneity in management intensity and conservation practices.

Core practices of land stewardship show system-dependent prevalence. For example, an estimated 60-70% of smallholders rely on natural regeneration (self-sown seedlings) for coffee stand renewal, a practice almost universal in forest and semi-forest systems. In contrast, the intentional planting of coffee seedlings is more common in garden systems, affecting traceability as planted plots can have more definitive establishment dates. The widespread practice of intercropping or maintaining ground cover with companion crops such as bananas, enset, spices, or legumes is reported by over half of all households, a strategy not only enhances microclimate regulation and soil fertility but also reduces pest pressure and can support diversified income streams that enhances food security but may complicate the clear demarcation of the coffee plot boundary for geolocation. About 44% of farmers apply erosion control measures such as contouring, grass strips, or mulching to minimise topsoil loss, indicative of active soil conservation efforts that support long-term land productivity and reduce the need for expansion into forested areas.

The reported shade tree density reflects a predominantly shaded agroforestry context typical of southwest Ethiopia's coffee landscapes. On average, farmers report maintaining 131 shade trees per coffee plot, a figure that—given local reporting conventions and variability in plot size—is best interpreted as a relative indicator of canopy presence rather than a precise per-hectare measure. This level of shade is broadly consistent with evidence from forest and semi-forest coffee systems in the region, where reported shade tree densities commonly range from about 100 to over 200 trees per hectare, and contrasts with the lower densities observed in garden coffee systems elsewhere in Ethiopia. The prevalence of dense canopy cover in the sample indicates production systems that are generally associated with lower deforestation risk under EU regulatory frameworks, although effective documentation of shade management and land-use history remains essential for demonstrating compliance with the EUDR. At the same time, one-third of the households report that canopy thinning is practiced infrequently and primarily as a selective management intervention to regulate shade conditions rather than as systematic tree removal. Such practices are characteristic of coffee grown under natural or semi-natural canopies, where coffee plants gradually replace understory vegetation through controlled thinning and undergrowth management—processes that may nonetheless complicate EUDR land-use verification. Another practice with significant EUDR relevance is coffee stumping (renovation),

practiced by an estimated 30-40% of farmers on a multi-year cycle. If a plot was recently stumped and regenerated after the December 2020 cutoff, it could be misconstrued as deforestation via remote sensing, requiring careful ground-truthing and explanation.

Input-use patterns reveal a mixed sustainability profile across production contexts. A substantial majority of households rely on organic soil fertility management practices such as mulching and composting (71%). The high use of organic soil amendments is underpinned by the widespread collection and application of forest leaf litter, a practice involving an estimated 50% of forest and semi-forest farmers. This directly ties the fertility of those systems to the maintained forest ecosystem, creating a tangible link between conservation and productivity for EUDR justification. The use of organic pest management remains limited (31%). These patterns highlight a partial transition toward low-external-input systems, with implications for both environmental compliance and traceability requirements under the EUDR. The use of improved, bred coffee varieties remains low (estimated at <25% nationwide), meaning most coffee is "heirloom" or local landraces. While beneficial for biodiversity, this complicates the documentation of genetic material, a minor but emerging aspect of full traceability.

Climate exposure during the reference period appears modest, with only 7% of households reporting recent flood or drought shocks. While this suggests that observed management changes are driven more by deliberate farm decisions than by acute climate events, however, the predominantly rain-fed nature of coffee production signals potential vulnerability to future climatic shifts, with implications for long-term sustainability and EUDR risk mitigation strategies.

The lower panel of Table 2 documents perceived changes over the past five years and reveals dynamics with direct relevance to EUDR compliance. On average, households report improvements in coffee yields, quality, and market access, while changes in cultivated coffee area remain moderate, indicating limited expansion into new land and a pattern of intensification within existing plots. This outcome is broadly consistent with EUDR objectives to decouple productivity gains from deforestation. However evidences indicate a growing trend with potential risk - incremental boundary cultivation, where farmers slowly expand garden coffee into adjacent forest margins—a process extremely difficult to monitor via satellite but critical for EUDR enforcement. Reported use of fertiliser and pesticide are less pronounced than improvements in agroecological practices — such as nutrient management, water conservation, shade maintenance, and weed control, indicating a gradual shift toward sustainable intensification across the dominant production systems.

Overall, the evidence suggests that compliance preparedness is inherently linked to production system and farming practice. The common practices of the predominant semi-forest and garden coffee farmers create a mixed profile: strong on organic integration and agroforestry but potentially weak on precise plot demarcation and vulnerable to misinterpretation of standard management practices (thinning, stumping) as deforestation. For the EUDR to be implemented fairly, verification mechanisms must account for these specific Ethiopian farming realities, distinguishing between sustainable agroforestry management and actual forest conversion.

Table 2 Summary of coffee farming practices and recent changes relevant to EUDR

Dimension	Description	Mean (Std. Dev.)
Current farming practices		
Crop diversification	Intercropping / ground cover (1 = yes)	0.57 (0.50)
Soil conservation	Use of erosion control measures (1 = yes)	0.44 (0.50)

Agroforestry structure	Shade trees per plot	131.16 (172.26)
Forest pressure	Shade tree cutting intensity	0.33 (0.48)
Organic soil management	Mulching/composting (1 = yes)	0.71 (0.45)
Input use (low-external)	Use of organic pesticides	0.31 (0.49)
Climate exposure	Exposure to flood or drought	0.07 (0.34)
Changes over the last five years		
Productivity	Change in coffee yield	2.73 (0.61)
Land use	Change in coffee area	2.68 (0.49)
Product quality	Change in coffee quality	2.90 (0.36)
Farm diversification	Change in area for other crops	2.01 (0.78)
Market integration	Change in access to coffee markets	2.73 (0.50)
Input intensification	Change in fertilizer use	1.76 (0.82)
Input intensification	Change in pesticide use	1.67 (0.73)
Agroecological shift	Change in biological management	2.48 (0.68)
Agroecological shift	Change in nutrient management	2.58 (0.62)
Agroecological shift	Change in water management	2.60 (0.57)
Agroforestry dynamics	Change in agroforestry practices	2.57 (0.63)
Forest-friendly systems	Change in shade coffee area	2.52 (0.66)
Land stewardship	Change in erosion control practices	1.98 (0.82)

Notes: Binary variables are coded as 1 = yes, 0 = no. Change variables are based on self-reported trends over the last five years, where 1 = decrease, 2 = no change and 3 = increase. The table highlights farming practices and land-use dynamics most relevant to the EUDR's deforestation-risk assessment, particularly agroforestry management, land expansion, and intensification pathways.

4.4. EUDR Preparedness: Descriptive Evidence

This subsection presents descriptive evidence on smallholder farmers' awareness of the European Union Deforestation Regulation (EUDR) and their perceived capacity to comply with its requirements, for the full sample and disaggregated by certification status. The results point to generally moderate—but uneven—levels of preparedness, with certified households exhibiting systematic advantages in awareness and compliance-related capacities, while notable gaps persist across both certified and non-certified groups.

4.4.1. The Awareness Landscape: Baseline Knowledge of EUDR

Across the full sample of 600 households, awareness of the EUDR is best characterized as partial rather than comprehensive, with most indicators clustering around the neutral midpoint of the Likert scale. Basic awareness dimensions—such as having heard about the regulation, understanding its general purpose, and knowing that coffee is regulated—exhibit mean values slightly above neutrality (Table 3). This suggests that information about the EUDR has begun to diffuse among smallholders, likely through cooperatives, traders, and public discourse.

However, awareness declines sharply for operationally critical dimensions, including documentation requirements, geolocation obligations, and export implications. These elements lie at the core of the EUDR's due diligence framework, and limited understanding at this level poses a serious implementation risk. The predominance of neutral responses indicates that many farmers are neither clearly informed nor completely uninformed. From a regulatory perspective, this "awareness gap" is particularly problematic: farmers with only vague familiarity may underestimate the stringency of compliance requirements, delay preparation, or fail to adopt

preventive measures, thereby risking exclusion from EU markets through inadvertent non-compliance rather than active deforestation.

4.4.2. Baseline Compliance Capacity

A similar pattern emerges for compliance capacity. On average, farmers report moderate and uneven capacity, with notable contrasts between conceptual and practical dimensions (Table 3). Self-assessed ability to demonstrate deforestation-free production and knowledge of plot establishment years score relatively higher, reflecting farmers' confidence in the environmental integrity of their production systems. In contrast, capacities that require verifiable evidence and technical infrastructure—such as record-keeping, GPS/mapping skills, traceability systems, and the ability to manage compliance costs—remain at or below the neutral threshold.

This divergence highlights a critical distinction between being compliant in practice and being able to prove compliance. While many farmers may indeed cultivate coffee under low-deforestation or forest-integrated systems, the EUDR requires documented, plot-level verification. The neutral-to-low overall compliance capacity therefore points to a structural readiness gap that cannot be addressed through regulatory enforcement alone. Without targeted investments in technical assistance, institutional support, and affordable compliance infrastructure, the EUDR risks disproportionately disadvantaging smallholders who are environmentally compliant but administratively constrained.

4.4.3. Awareness and compliance capacity by certification status

Disaggregation by certification status reveals a consistent and statistically significant pattern: certified households exhibit better awareness and stronger perceived compliance capacity across most dimensions (Table 3) compared to noncertified ones. Certified farmers are substantially more likely to have heard about the EUDR, understand its purpose, recognize coffee's regulatory status, and be aware of deforestation cut-off dates. Awareness gaps are particularly pronounced for technical and procedural elements, such as documentation and geolocation requirements—two pillars of EUDR compliance.

These differences are consistent with the informational and institutional role of Voluntary Sustainability Standards (VSS). Certification schemes typically operate through cooperatives and buyer relationships that facilitate training, information dissemination, and exposure to emerging regulatory demands. Certified households are also more likely to report receiving reliable EUDR-related information and feeling well-informed overall, underscoring the importance of embedded institutional channels.

A similar but more nuanced pattern emerges for compliance capacity. Certified households report significantly better capacity in outcome-oriented dimensions, including the ability to demonstrate deforestation-free production, traceability capacity, perceived feasibility of compliance, capacity to manage compliance costs, and ability to adapt farming practices. These attributes are central to navigating the EUDR's due diligence requirements and suggest that certification enhances farmers' confidence and readiness to engage with regulatory change.

However, certification does not eliminate foundational constraints. No statistically significant differences are observed for several basic capacities, including record-keeping, GPS/mapping skills, knowledge of plot establishment year, legal land use documentation, and access to training. These

persistent gaps across both certified and non-certified households point to broader structural limitations—such as weak rural service provision, limited digital infrastructure, and constrained extension systems—that certification alone cannot resolve. Importantly, certified households report significantly higher levels of cooperative or buyer support, reinforcing the role of institutional embeddedness rather than individual capacity as a key mediator of compliance readiness.

The descriptive evidence presented in this subsection provides an initial overview of patterns in EUDR awareness and perceived compliance capacity across certified and non-certified smallholder households. While these comparisons highlight systematic differences associated with certification status, they do not permit causal inference, as observed outcomes may be influenced by underlying household characteristics, selection processes, and other confounding factors. Accordingly, the next subsection examines the determinants of EUDR awareness and compliance capacity, while the subsequent econometric analysis assesses the causal impact of certification by explicitly accounting for observed covariates and potential sources of bias.

Table 3 EUDR Awareness and Compliance Capacity

Dimension	Indicator	Total Sample (N=600)	Non-Certified (N=302)	Certified (N=298)	Mean Diff. & Sig.
Basic Awareness	Heard about EUDR	3.14 (1.39)	2.75 (1.43)	3.53 (1.23)	0.78***
	Understand EUDR purpose	3.18 (1.37)	2.90 (1.44)	3.46 (1.23)	0.56***
	Know coffee regulated	3.25 (1.27)	2.84 (1.29)	3.66 (1.12)	0.81***
Technical Awareness	Understand deforestation cut-off	3.54 (1.18)	3.25 (1.18)	3.83 (1.12)	0.57***
	Understand export implications	3.15 (1.28)	2.96 (1.23)	3.34 (1.30)	0.38***
	Aware of documentation requirements	3.01 (1.31)	2.78 (1.32)	3.24 (1.27)	0.46***
	Know GPS/geolocation requirement	3.00 (1.46)	2.70 (1.47)	3.31 (1.39)	0.61***
Information Access	Received reliable information	2.96 (1.37)	2.81 (1.36)	3.11 (1.37)	0.30**
	Feel well-informed	2.97 (1.34)	2.79 (1.41)	3.15 (1.25)	0.36***
Compliance Evidence	Prove deforestation-free	3.80 (1.21)	3.57 (1.19)	4.03 (1.18)	0.46***
	Knowledge of plot establishment year and legal document	3.78 (1.14)	3.71 (1.10)	3.86 (1.18)	0.14
Technical Capacity	Record-keeping capacity	2.79 (1.31)	2.74 (1.39)	2.84 (1.22)	0.09
	Mapping/GPS ability	2.81 (1.38)	2.76 (1.50)	2.86 (1.24)	0.10
	Traceability capacity	2.87 (1.38)	2.65 (1.44)	3.09 (1.28)	0.44***
Support Systems	Access to sustainability support	3.13 (1.30)	3.12 (1.32)	3.14 (1.29)	0.02
	Cooperative/buyer support	3.01 (1.28)	2.87 (1.32)	3.16 (1.22)	0.29**
Operational Feasibility	Manage compliance costs	2.74 (1.35)	2.61 (1.44)	2.87 (1.23)	0.25**
	Adapt practices	3.35 (1.26)	3.13 (1.34)	3.57 (1.13)	0.44***

Notes: Mean values are shown with standard deviations in parentheses. All indicators measured on comparable scales. Mean differences between certified and non-certified groups tested using t-tests. ** $p < 0.05$, *** $p < 0.01$.*

4.5. Determinants of EUDR Awareness and Compliance Capacity

This subsection examines the determinants of smallholder farmers' awareness of the EUDR and their perceived capacity to comply. To this end, we estimate Ordinary Least Squares (OLS) models using composite index measures of awareness and compliance capacity as continuous outcomes, alongside ordered logit models based on farmers' self-assessed awareness and compliance levels. This dual modelling approach allows us to capture both objective variation in constructed indices

and subjective perceptions, providing a comprehensive assessment of the factors shaping EUDR preparedness at the household level.

4.5.1. Determinants of EUDR Awareness: Certification, Systems, and Structural Factors

The analysis reveals that awareness of the EUDR is shaped by a combination of institutional, production system, and demographic factors, with certification emerging as the most consistent and substantial determinant. As shown in Table 4, certification increases standardized awareness by 0.24 standard deviations (p=0.002) and raises the log-odds of higher self-rated awareness by 0.59 (p=0.003). This finding across both measurement approaches confirms that Voluntary Sustainability Standards (VSS) function as critical channels for regulatory information dissemination, likely through cooperative networks, buyer communications, and certification-related training programs that reach farmers who might otherwise remain outside formal information ecosystems.

Production systems exhibit complex and heterogeneous relationships with awareness levels. Compared to semi-forest systems (the reference category), most alternative systems show significantly lower awareness in the composite index model, with reductions ranging from 0.44 to 0.95 standard deviations (Table 4). However, the ordered logit results reveal more nuanced patterns: while some integrated systems (mixed farming system) show negative coefficients (notably Forest+Semi-forest), garden-only systems show no significant disadvantage in self-rated awareness. This discrepancy suggests that farmers in different production systems may experience distinct information access pathways or perceive their awareness differently relative to their actual knowledge levels. The particularly poor performance of integrated systems across both models highlights the compliance complexity faced by farmers managing multiple cultivation approaches simultaneously, potentially creating information overload or confusion about system-specific requirements.

Structural demographic factors reveal persistent inequalities in awareness distribution. Female-headed households demonstrate substantially lower awareness across both measurement approaches (0.32 SD lower in OLS, p=0.006; 0.69 log-odds lower in ordered logit, p=0.059), indicating that gender-based disparities in information access extend to emerging regulatory knowledge. This gap persists despite controls for education and resources, suggesting structural barriers beyond mere resource differentials. Surprisingly, formal education shows no significant effect on awareness across either model—a finding that challenges conventional human capital assumptions and suggests that EUDR information dissemination operates through channels that bypass traditional education pathways.

Farm scale and economic characteristics demonstrate selective influences on awareness. Coffee area consistently enhances awareness (0.04 SD, p=0.000 in OLS; 0.22 log-odds, p=0.000 in ordered logit), suggesting that larger-scale farmers receive more regulatory information, possibly through greater market integration or buyer attention. The paradoxical effect of nonfarm income—positive in self-ratings (0.81 log-odds, p=0.001) but insignificant in the composite index—may indicate that diversified households feel more informed despite lacking substantive knowledge gains, potentially reflecting confidence derived from broader livelihood security rather than specific EUDR understanding.

4.5.2. Determinants of Compliance Capacity: Experience, Resources, and Perception Gaps

Compliance capacity exhibits distinct determinants from awareness, emphasizing practical experience, resource endowments, and perceptual factors that mediate between knowledge and implementation ability. Certification again demonstrates positive effects, though of more moderate magnitude than for awareness: 0.15 standard deviations (p=0.044) in the composite index and 0.47 log-odds (p=0.014) in self-ratings (Table 5). This suggests that while certification builds awareness effectively, its capacity-building function is more limited—particularly for technical skills like record-keeping and geolocation that showed minimal certification advantages in descriptive analyses.

Production system effects on compliance capacity mirror—but in some cases intensify—the patterns observed for awareness. Semi+Garden and Forest+Garden systems exhibit particularly large deficits (0.87 and 0.58 standard deviation reductions, respectively; $p < 0.001$), while the Forest+Semi system again shows a significant disadvantage in self-rated compliance capacity (−2.50 log-odds; $p < 0.001$). These consistent negative associations across forest-integrated systems suggest that producers operating within forest-based—typically characterized by low environmental footprints—or mixed production systems face compounded compliance challenges. Such disadvantages may stem from diverse documentation requirements, heterogeneous land-use histories, or more complex traceability demands across multiple production modalities.

Demographic determinants reveal both expected and surprising patterns. The gender gap persists for compliance capacity, with female-headed households showing 0.29 SD (p=0.012) and 0.85 log-odds (p=0.025) lower capacity across models. Household size negatively affects self-rated capacity (0.05 log-odds reduction per member, p<0.001) but not measured capacity, suggesting that larger households may perceive greater coordination challenges despite adequate objective resources. Most strikingly, formal education again shows no significant effect—reinforcing that compliance capacity depends more on specific technical skills and institutional support than general educational attainment.

Resource endowments and farm characteristics demonstrate divergent impacts on objective versus perceived capacity. Coffee experience positively influences measured capacity (0.009 SD per year, p=0.041) but shows only marginal effects on self-ratings, suggesting that accumulated practical knowledge enhances actual implementation abilities more than confidence. Conversely, land resources show positive effects on self-rated capacity (0.058 log-odds, p=0.001) but not measured capacity, possibly indicating that land ownership confers confidence without necessarily building specific compliance skills. The paradoxical nonfarm income effect intensifies for compliance: while it substantially reduces measured capacity (0.43 SD, p<0.001), it strongly increases self-rated capacity (1.49 log-odds, p<0.001). This dangerous divergence suggests that economically diversified farmers may overestimate their compliance readiness—a perception gap that could lead to costly implementation failures.

Labor dynamics reveal another instructive divergence: family labor reduces measured awareness but enhances self-rated compliance capacity. This pattern may reflect specialization within households, where labor contributions build practical implementation confidence even as they limit time for information acquisition. Alternatively, it may indicate that hands-on farm experience builds compliance confidence through direct engagement with production systems, even without formal regulatory knowledge.

The consistent methodological divergence between composite index and self-rated measures across both awareness and capacity models suggests that objective assessments and subjective evaluations capture distinct but complementary dimensions of EUDR preparedness. Variables

showing strong effects in both models (certification, gender) likely represent robust determinants with both practical and perceptual dimensions. Those showing divergent effects (nonfarm income, specific production systems) may indicate areas where perceptions decouple from realities—creating either dangerous overconfidence or unnecessary anxiety that could respectively undermine compliance or deter engagement. These distinctions have important implications for intervention design, suggesting that effective EUDR support must address both actual capacity gaps and the perceptual filters through which farmers assess their own readiness.

Table 4 Determinants of EUDR Awareness – OLS and Ordered Logit Results

Determinant	OLS: Awareness Index (Standardized)	Ordered Logit: Self-Rated Awareness (0-5)
Certification Status	0.241***	0.587***
Production System (Base: Semi-forest only)		
Forest-forest only	-0.767***	-0.454*
Garden only	-0.439*	0.245
Forest+Semi-forest	0.117	-4.421***
Semi-forest+Garden	-0.947***	-0.653**
Forest+Garden	-0.826***	-1.004**
All three	-0.771***	-2.417**
Household Characteristics		
Cooperative years	0.003	0.020
Age	0.001	-0.008
Gender	-0.319**	-0.685*
Household size	0.000	-0.077***
Education	-0.009	0.054
Nonfarm income	0.109	0.813***
Farm Characteristics		
Coffee experience	-0.0003	0.004
Total land	0.003	0.035*
Coffee area	0.043***	0.223***
Tree age	0.006	-0.017
Credit access	-0.045	0.087
Family labor	-0.054***	0.077*

Notes: OLS coefficients represent change in standardized awareness index (mean=0, SD=1). Ordered logit coefficients are log-odds ratios. Significance: ***p<0.01, **p<0.05, *p<0.1*

Table 5 Determinants of EUDR Compliance Capacity – OLS and Ordered Logit Results

Determinant	OLS: Compliance Index (Standardized)	Ordered Logit: Self-Rated Compliance (0-5)
Certification Status	0.147**	0.465**
Production System (Base: Semi-forest only)		
Forest only	-0.867***	-0.303
Garden only	-0.460	-0.002
Forest+Semi-forest	0.161	-2.503***
Semi-forest+Garden	-0.872***	-0.922***
Forest+Garden	-0.582***	-1.739***
All three	-0.995***	-1.459
Household Characteristics		

Cooperative years	0.0001	0.030**
Age	0.005*	-0.009
Gender	-0.293**	-0.850**
Household size	-0.004	-0.050***
Education	-0.002	-0.020
Nonfarm income	-0.429***	1.488***
Farm Characteristics		
Coffee experience	0.009**	0.021*
Total land	0.003	0.058***
Coffee area	0.029***	-0.066
Tree age	-0.002	-0.017
Credit access	-0.086	0.046
Family labor	-0.018	0.146***

Notes: OLS coefficients represent change in standardized compliance index (mean=0, SD=1). Ordered logit coefficients are log-odds ratios. Significance: ***p<0.01, **p<0.05, *p<0.1*

4.6. Causal Estimates of Certification Impacts: PSM and ESR Analysis

4.6.1. Propensity Score Matching: Accounting for Observable Selection

4.6.1.1. Empirical Strategy and Balance Diagnostics

We employed Propensity Score Matching (PSM) to estimate the causal effect of coffee certification on EUDR awareness and compliance capacity while addressing observable selection bias. The propensity score model (Table 6) reveals systematic selection into certification: more educated households (β=0.176, p<0.001), those with larger coffee areas (β=0.104, p<0.001), and greater coffee experience (β=0.020, p=0.019) are significantly more likely to certify, while garden ownership substantially reduces certification likelihood (β=-0.684, p<0.001). This systematic selection necessitates rigorous matching to create comparable counterfactuals.

Table 6 Determinants of Certification Adoption (Probit Model)

Variable	Coefficient (SE)
Education	0.176*** (0.051)
Coffee area	0.104*** (0.031)
Coffee experience	0.020** (0.009)
Garden ownership	-0.684*** (0.137)

Model fit: *Pseudo R^2 = 0.098, LR χ^2 = 80.84 (p = 0.000)*

Notes*:* Only statistically significant covariates are presented for parsimony. Standard errors (SE) are in parentheses. Significance levels: *p* < 0.05, **p* < 0.01, ***p* < 0.001.

All three matching algorithms—nearest neighbor (k=2), radius (caliper=0.03), and kernel (bandwidth=0.08)—achieved excellent covariate balance. As shown in Table 7, post-matching pseudo-R^2 values dropped from 0.098 to 0.003-0.004, LR tests became statistically insignificant (p=0.755-0.841), and mean bias was reduced by 77-80% to acceptable levels below 7%. Rubin's B statistics fell below the critical threshold of 25, confirming that remaining imbalances do not

threaten causal inference. These diagnostics validate the matching quality and support the use of PSM for estimating certification effects.

Table 7 Matching Quality Diagnostics

Method	Pseudo R^2	LR χ^2 (p)	Mean Bias	% Reduction	Rubin's B
Unmatched	0.098	80.84 (0.000)	28.9%	-	68.7
Nearest Neighbor	0.004	3.41 (0.755)	6.6%	77.2%	15.5
Radius	0.004	3.10 (0.797)	6.2%	78.5%	14.7
Kernel	0.003	2.74 (0.841)	5.7%	80.3%	13.9

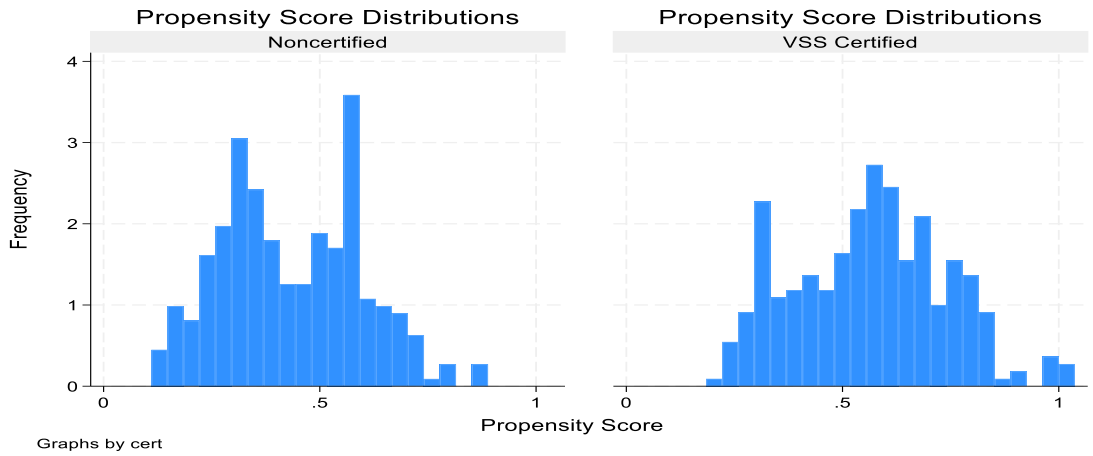

Figure 1 Baseline distribution of propensity scores for certified (treatment) and non-certified (control) households in the full sample.

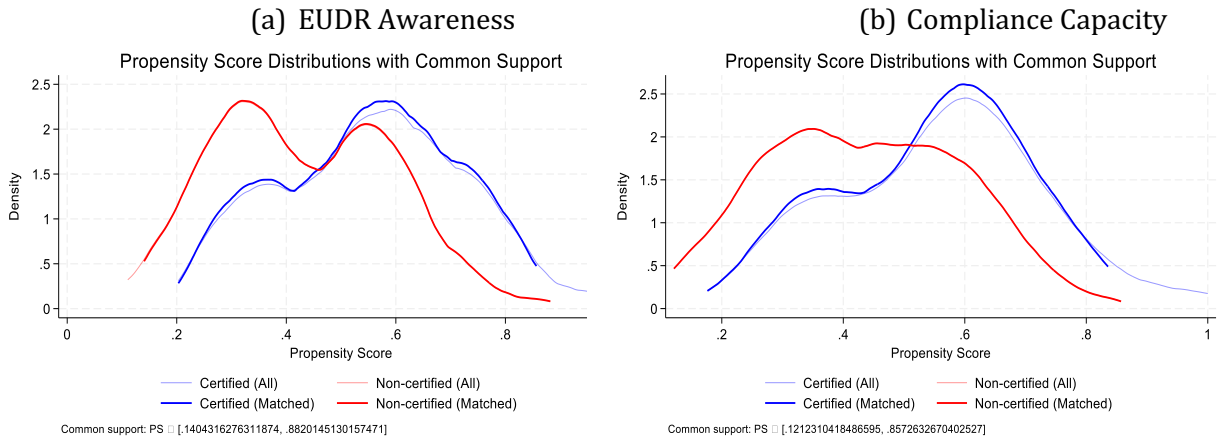

Figure 2 Distribution of estimated propensity scores for certified (treated) and non-certified (control) smallholder coffee farmers, illustrating the region of common support for (a) EUDR awareness and (b) compliance capacity. The substantial overlap between the two groups indicates adequate comparability and supports the validity of the matching procedure used in the PSM analysis.

Notes: The propensity score distributions demonstrate adequate common support. Figure 1 shows the overall overlap between certified and non-certified households in the full sample, demonstrating the fundamental common support necessary for propensity score analysis. More critically, Figure 2 confirms that this overlap is maintained within the matched samples used for estimating the treatment effects on awareness and compliance capacity separately, validating the matching quality for each outcome model.

4.6.1.2. Treatment Effect Estimates

The estimated Average Treatment Effects on the Treated (ATT), obtained using alternative matching algorithms are reported in Table 8. For awareness, certification demonstrates a robust positive effect: certified farmers show 0.28-0.30 standard deviations higher awareness compared to matched non-certified counterparts, with all estimates statistically significant at conventional levels ($p<0.01$). The consistency across matching methods—nearest neighbor (ATT=0.283), radius (0.295), and kernel (0.285)—strengthens confidence in this finding.

In stark contrast, certification shows no statistically significant effect on compliance capacity. ATT estimates range from 0.054 to 0.087 standard deviations, with p-values between 0.238 and 0.509 across methods. This null finding persists despite the strong awareness effect, revealing a critical awareness-compliance disconnect; while certification effectively disseminates regulatory knowledge, it does not translate into measurable improvements in farmers' capacity to implement compliance requirements.

Table 8 PSM Treatment Effect Estimates (ATT)

Outcome	Method	ATT (SE)
Awareness	Nearest Neighbor	0.283*** (0.091)
	Radius	0.295*** (0.080)
	Kernel	0.285*** (0.078)
Compliance	Nearest Neighbor	0.054 (0.082)
	Radius	0.087 (0.074)
	Kernel	0.080 (0.071)

Notes: ATT denotes the Average Treatment Effect on the Treated. Standard errors are in parentheses. Significance levels: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Matching estimates are based on common support. Standard errors are estimated at the household level; given the sampling structure, results should be interpreted with caution regarding potential cooperative-level residual correlation.

While propensity score matching effectively mitigates selection bias arising from observable differences between certified and non-certified households, two important limitations remain. First, PSM cannot address bias stemming from unobserved factors—such as farmer motivation, managerial ability, or social capital—that may simultaneously influence certification uptake and EUDR-related outcomes. Second, standard errors from matching estimators do not fully account for uncertainty associated with propensity score estimation, although this concern is partially alleviated by the consistency of results across multiple matching algorithms. To assess the robustness of the PSM findings and explicitly account for potential endogeneity arising from unobserved selection, we therefore complement the matching analysis with an Endogenous Switching Regression (ESR) framework.

4.6.2. Endogenous Switching Regression: Accounting for Unobservable Selection

The Endogenous Switching Regression (ESR) addresses a critical limitation of PSM by explicitly modeling unobservable selection through correlated error structures between the certification decision and outcome equations. The significant likelihood ratio tests (χ^2=11.12, p=0.0039 for awareness; χ^2=11.50, p=0.0032 for compliance) confirm endogeneity—unobserved factors jointly influence both certification decisions and outcomes—validating the ESR approach. This endogeneity is underpinned by systematic selection into certification, as shown in Table 9: more educated farmers and those with larger coffee areas are more likely to certify. This non-random adoption creates the selection bias that ESR corrects for by simultaneously estimating the selection and outcome processes.

Table 9 Determinants of Certification Adoption – ESR Selection Equation Results

Variable	Awareness Model Coef. (SE)	Compliance Model Coef. (SE)
Cooperative years	0.0190** (0.0074)	0.0571*** (0.0075)
Household age	0.0038 (0.0041)	0.0036 (0.0044)
Education	0.1908*** (0.0488)	0.2250*** (0.0513)
Coffee experience	0.0116 (0.0078)	0.0213** (0.0086)
Coffee area	0.1157*** (0.0267)	0.1208*** (0.0325)
Constant	−1.3781*** (0.3001)	−2.1775*** (0.3199)

Notes: Coefficients are from the ESR selection equations for certification adoption. Standard errors are reported in parentheses. Significance levels: *** p < 0.01, ** p < 0.05. Likelihood ratio tests indicate joint significance of the selection equations at p < 0.001 for both models.

The error-correlation structure reveals distinct selection patterns across the two outcome domains (Table 10). In the ESR framework, ρ_0 and ρ_1 measure the correlation between the unobserved determinants of certification (selection equation) and the unobserved determinants of the outcome in the non-certified and certified regimes, respectively. The sign of ρ therefore captures selection on unobservables relative to the potential outcome in each regime.

For awareness, the strongly negative ρ_1 (−0.972, p < 0.001) indicates negative selection into certification: conditional on observable characteristics, farmers who select into certification tend to have lower unobserved awareness in the certified regime. In other words, absent certification, these farmers would be predicted to exhibit lower awareness relative to observationally similar counterparts. This pattern is consistent with certification participation being associated with farmers who initially face awareness constraints.

By contrast, for compliance capacity, the positive ρ_1 (0.472, p = 0.015) indicates positive selection into certification: conditional on observables, farmers who enter certification tend to possess higher unobserved compliance-related traits in the certified regime. This suggests that certification participation is partly associated with farmers who already have latent characteristics conducive to compliance. Together, these results indicate that selection mechanisms differ across outcome dimensions, reinforcing the importance of accounting for unobserved heterogeneity when estimating treatment effects.

Table 10 ESR Error Correlation Structure

Parameter	Awareness Model	Compliance Model	Interpretation
ρ_0	−0.469*	−0.484***	Negative selection into non-certified regime
ρ_1	−0.972***	0.472**	Opposing selection effects across regimes
σ_0	0.888	0.827	Error variance (non-certified regime)

σ_1	1.037	0.686	Error variance (certified regime)

Notes: ρ_0 and ρ_1 denote the correlations between the selection equation error term and the outcome equation errors for the non-certified and certified regimes, respectively. σ_0 and σ_1 represent the corresponding error variances. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.10.

4.6.3. Comparative Treatment Effect Estimates: PSM versus ESR

Treatment effect estimates were examined using both Propensity Score Matching (PSM) and Endogenous Switching Regression (ESR) to assess the robustness of certification impacts. As shown in the comparative treatment effect estimates (Table 11), for EUDR awareness, PSM yields relatively large effects (0.283–0.295 SD), whereas ESR estimates are substantially smaller (0.098 SD), roughly one-third of the PSM magnitude. This reduction reflects ESR's correction for negative selection bias: by accounting for unobserved factors that reduce innate awareness potential while simultaneously increasing the likelihood of certification, ESR provides more conservative estimates of certification's effect.

In contrast, for compliance capacity, the two methods diverge more markedly. PSM indicates small, statistically insignificant effects (0.054–0.087 SD), whereas ESR identifies a substantial and significant positive effect (0.148 SD, p < 0.001). This reversal occurs because ESR adjusts for positive selection bias—unobserved traits that simultaneously enhance compliance capacity and raise the probability of certification.

Table 11 Comparative Treatment Effect Estimates (PSM vs ESR)

Outcome	Method	Effect Size (SD) [95% CI]
Awareness	PSM (average)	0.287*** [0.224, 0.350]
	ESR	0.098*** [0.072, 0.124]
Compliance	PSM (average)	0.074 [−0.035, 0.183]
	ESR	0.148*** [0.112, 0.184]

Notes: Effect sizes are reported in standard deviation units. Significance levels: *** p < 0.01, ** p < 0.05, * p < 0.10.

Overall, the results reveal both convergence and divergence across estimation strategies. Certification consistently shows positive effects on awareness, although the magnitude varies across methods. For compliance capacity, the estimated impact is more sensitive to unobserved heterogeneity, with the ESR specification producing larger effects than PSM.

The comparison between PSM and ESR is informative in light of the estimated selection patterns. In the ESR model, the sign of ρ reflects selection on unobservables relative to regime-specific potential outcomes. For awareness, the negative ρ_1 indicates that certified farmers would, conditional on observables, have lower unobserved awareness absent treatment. For compliance capacity, the positive ρ_1 suggests that certified farmers possess higher unobserved compliance-related traits.

In this dataset, PSM yields a larger ATT for awareness and a smaller ATT for compliance capacity compared to ESR. These differences should not be interpreted as a general rule linking the sign of selection to the direction of matching bias. Rather, they reflect how ignoring unobserved heterogeneity may affect treatment-effect estimates depending on the underlying selection structure. While PSM adjusts for observable differences, ESR additionally accounts for selection on

unobservables. The joint use of both estimators therefore strengthens the robustness of the causal interpretation.

4.6.4. Synthesis: Interpreting the Comparative Results

The comparative analysis yields two principal interpretive insights. The results suggest a dual role for certification: it functions as a remedial intervention for farmers with lower baseline awareness while acting as a validation mechanism for those already prone to compliance. This divergence in the models indicates that while awareness-focused outcomes are consistent across the sample, compliance capacity gains are concentrated among specific subgroups.

Furthermore, the awareness-compliance disconnect—identified in the PSM but qualified by the ESR—highlights that certification alone may not be the sole determinant of EUDR preparedness. The data suggests that the gap between knowledge and implementation is likely mediated by external factors such as technical skills and financial resources.

Methodologically, the significant correlation parameters in the ESR models (ρ_0 and ρ_1) confirm that unobserved selection bias is empirically relevant. The substantial discrepancy between the PSM and ESR estimates, particularly regarding compliance capacity, demonstrates the sensitivity of these impact results to selection assumptions. Presenting both sets of estimates provides a bounded range of the treatment effect, offering a more robust interpretation of certification's efficacy than either model could provide in isolation.

4.7. Perceived EUDR Impacts: Quantitative Farmers' Perspectives

These descriptive perceptions are interpreted cautiously and are complemented by qualitative evidence in subsequent sections. Table 12 presents descriptive statistics on farmers' perceptions of the potential impacts of the EU Deforestation Regulation (EUDR) on their livelihoods, production practices, and market participation. Overall, the results reveal a mixed and uncertain perception landscape, reflecting both perceived risks and potential opportunities associated with the regulation.

On average, farmers' overall expectation of the EUDR's impact on smallholders (mean = 2.46 on a five-point scale) lies between *not sure* and *no clear effect*. This suggests that, at the aggregate level, the regulation is not yet perceived as a clear development opportunity, but neither is it uniformly viewed as harmful. Such ambivalence is consistent with the early implementation phase of the EUDR, where regulatory requirements are known in broad terms but concrete enforcement mechanisms, timelines, and support arrangements remain uncertain. This uncertainty is further reflected in responses to specific impact channels.

Market access emerges as a central concern. Nearly one unit on the market access loss indicator (mean = 0.98 on a 0–2 scale) indicates that a substantial share of farmers either expect potential exclusion from EU markets or remain unsure about their future access. This concern is reinforced by relatively high levels of anxiety about sales reductions (mean = 2.41 on a five-point concern scale), suggesting moderate to high perceived risk of reduced coffee sales. From an EUDR perspective, this aligns with regulatory logic that non-compliant or unverifiable producers may be excluded from EU supply chains, particularly those lacking geolocation data or deforestation-free proof. These perceptions underscore the risk that EUDR could function as a de facto market barrier for smallholders if compliance support is insufficient.

Expectations regarding buyer support are notably weak. The low mean value for buyer support (0.63 on a 0–2 scale) indicates that many farmers either do not expect buyers to assist with compliance or are uncertain about such support. This finding is critical, as the EUDR places legal responsibility on operators and traders, implicitly assuming some degree of upstream engagement with producers. The perceived absence of buyer support raises concerns about asymmetric burden-sharing, where compliance costs and risks are transferred disproportionately to smallholders.

Cost implications further reinforce this concern. While the average perceived cost increase is not extreme (mean = 1.11 on a 0–2 scale), it indicates that many farmers anticipate higher production or transaction costs associated with EUDR compliance, such as mapping, documentation, or changes in farm practices. At the same time, expectations of compensating price premiums remain modest (mean = 1.29 on a 0–2 scale), suggesting that farmers are uncertain whether higher compliance costs will be offset by better prices. This perceived imbalance between costs and rewards reflects a core tension in EUDR implementation debates: strong environmental conditionality without guaranteed economic incentives may undermine producer buy-in.

Consistent with this, farmers report moderate expectations that EUDR will require changes in farm management (mean = 1.11 on a 0–2 scale). This suggests that compliance is not seen as purely administrative but as potentially requiring substantive adjustments in production practices—an issue that is especially relevant for garden coffee systems and for farmers operating near forest margins. Such anticipated changes may include restrictions on land-use expansion, tree cutting, or input use, all of which carry labor and cost implications.

Despite these concerns, longer-term livelihood expectations are relatively neutral. The mean income outlook over the next 3–5 years (3.02 on a five-point scale) is centered around *no change*, with some optimism present but not dominant. This indicates that, while short-term risks related to market access and compliance costs are salient, farmers have not yet formed strong expectations that the EUDR will fundamentally improve or worsen their livelihoods. This neutrality may reflect limited concrete experience with EUDR enforcement, reinforcing the need to interpret these results alongside qualitative evidence capturing farmers' reasoning, expectations, and conditional optimism or pessimism.

Overall, these descriptive results suggest that farmers perceive the EUDR primarily through uncertainty lens, with market exclusion and compliance costs featuring more prominently than price or income gains. Importantly, these perceptions are likely to be shaped by heterogeneous factors such as certification status, production system, cooperative membership, and access to information—dimensions that are not accounted for in this particular descriptive analysis.

Table 12 Farmer Perceptions of EUDR Impacts

Perception Dimension	Scale Interpretation	Mean Score (Range)	Std. dev.	Key Pattern
Overall EUDR Impact	1=Positive, 2= Unsure 3=No effect, 4= Negative	2.46 (1-4)	1.26	Slight not sure
Market Access Concern	0=No, 1=Yes, 2=Unsure	0.98 (0-2)	0.95	High concern about access loss
Sales Reduction Concern	1=Not concerned to 5=Extremely concerned	2.41 (0-5)	1.19	Moderate concern about sales impact
Buyer Support Expectation	0=No, 1=Yes, 2=Unsure	0.63 (0-2)	0.77	Moderate/low expectation of buyer assistance

Production Cost Increase	0=No, 1=Yes, 2=Unsure	1.11 (0-2)	0.76	Expected cost increases
Price Premium Expectation	0=No, 1=Yes, 2=Unsure	1.29 (0-2)	0.55	Moderate optimism about price benefits
Farm Management Change Need	0=No, 1=Yes, 2=Unsure	1.11 (0-4)	0.82	Anticipation of practice changes
3-5 Year Income Outlook	1=Very negative to 5=Very positive	3.02 (0-5)	0.92	Neutral to slightly positive long-term outlook

Notes: Variables capture farmers' perceived risks and opportunities associated with EUDR implementation. These descriptive perceptions are interpreted cautiously and are complemented by qualitative evidence and econometric results in subsequent sections.

4.8. Qualitative Results: Preparedness, Challenges, and Potential Impacts of EUDR Compliance in Ethiopia

Evidence from key informant interviews (KIIs), focus group discussions (FGDs), and secondary document review reveals a consistent pattern of uneven awareness, preparedness, and compliance capacity for the EUDR across Ethiopia's coffee value chain. While strategic and operational initiatives have been launched at federal and regional levels, qualitative findings indicate that these efforts have not yet translated into adequate readiness among smallholder farmers and primary cooperatives—the actors most directly responsible for plot-level compliance. This qualitative pattern closely mirrors the quantitative results, which show relatively medium or low farmer-level preparedness.

At the national level, KIIs with federal institutions confirm that the EUDR has prompted a series of strategic responses, reflecting growing institutional recognition of the regulation's implications for Ethiopia's coffee exports. These include the formulation of a National Action Plan by the Ethiopian Coffee and Tea Authority (ECTA), the establishment of a national multi-stakeholder taskforce, and intensified bilateral engagements with development partners and EU member states. Operationally, stakeholders report progress in developing a Market Information Management System (MIMS) intended to support supply chain tracking and due diligence. In parallel, pilot initiatives—often led by cooperative unions with support from NGOs and development partners—have begun collecting geolocation data from smallholder farmers, with reported coverage ranging from 30% to 70% in selected pilot zones. These efforts are widely viewed by KII participants as important first steps, but insufficient in scale relative to the regulation's requirements.

The national land certification program is frequently cited in KIIs as a potentially critical asset for EUDR compliance. Since its inception, the program has issued first-level land certificates to approximately 14 million rural households, providing a foundational layer of tenure documentation. However, both KIIs and document review emphasize that its relevance for EUDR compliance is constrained by the slow rollout of second-level, georeferenced certificates. Current estimates suggest that only around 15% of coffee plots possess the precise spatial data required under the regulation, particularly in major coffee-growing regions. This gap significantly limits the effectiveness of traceability and risk assessment efforts.

In forest coffee regions of Southwest Ethiopia, qualitative evidence highlights a striking institutional tension that may be characterized as an emerging ecological paradox. Participatory

Forest Management (PFM) systems constitute a substantial governance infrastructure, covering more than 777,000 hectares and involving approximately 102,895 cooperative members across multiple zones. Document review and Key Informant Interviews (KIIs) with regional forest authorities consistently emphasize that PFM arrangements are designed to conserve natural forest ecosystems through community-based stewardship, collective monitoring, and regulated forest use. In this respect, forest-integrated coffee systems operate within landscapes that are intrinsically aligned with the environmental objectives of the EU Deforestation Regulation (EUDR), often maintaining low deforestation risk and long-standing forest cover.

However, despite this strong ecological alignment, KIIs and Focus Group Discussions (FGDs) reveal significant administrative and institutional constraints that limit these systems' readiness for EUDR compliance. Respondents point to weak inter-sectoral coordination, incomplete regional land administration frameworks, fragmented data systems, and limited integration between forest governance institutions and agricultural traceability mechanisms. As a result, forest-based producers—who are arguably among the lowest deforestation-risk groups—face disproportionately high compliance barriers in meeting geolocation, documentation, and traceability requirements.

Despite these strategic and institutional initiatives, a pronounced implementation gap persists at the farmer and primary cooperative levels. FGDs with smallholder farmers and cooperative members consistently indicate low awareness of the EUDR, limited understanding of its requirements, and minimal exposure to formal training or capacity-building activities. Participants repeatedly emphasize that awareness-raising efforts have largely targeted mid- and upper-level stakeholders—such as unions, government officials, and development partners—leaving frontline actors insufficiently prepared to undertake compliance-related tasks. This disconnect is widely viewed by respondents as one of the most critical bottlenecks in the EUDR implementation process.

Structural characteristics of Ethiopia's smallholder coffee system further exacerbate compliance challenges. KIIs with technical experts and cooperative leaders underscore that extreme land fragmentation—where farmers typically manage three to five separate plots averaging around 0.2 hectares each—renders plot-level traceability logistically complex and financially burdensome. Documented estimates place initial mapping and documentation costs at approximately USD 50–150 per farmer, a figure widely perceived in FGDs as prohibitive given prevailing income levels and the absence of guaranteed price premiums for EUDR-compliant coffee. These structural constraints significantly undermine the feasibility of rapid, large-scale compliance.

Preparedness among cooperatives—the key aggregation and coordination points in the coffee value chain—is similarly uneven. KIIs referencing assessments of cooperative unions indicate that only about half of the reviewed unions are making tangible progress toward EUDR preparedness, including data collection and member registration. Other unions possess basic information but have not initiated practical implementation, while a subset reportedly lacks awareness of the regulation altogether. FGDs with primary cooperatives attribute this unevenness primarily to financial constraints, limited technical capacity, and uncertainty regarding the costs and benefits of compliance. Many cooperatives perceive the EUDR as introducing additional obligations without corresponding economic incentives—though some expect maintained market access—reinforcing skepticism about its financial viability.

These concerns are further compounded by parallel regulatory pressures, particularly changes in other certification requirements. KIIs and FGDs indicate that while existing sustainability

certifications (e.g., Organic, Fairtrade, Rainforest alliance) have built some foundational capacity, they also present new, parallel hurdles associated to costs. KIIs and FGDs report that for example the new European Organic certification framework imposes substantial additional costs and organizational burdens, including certification at the primary cooperative level, a maximum cap of 2,000 members per certificate, expanded sampling requirements, and sharply increased auditor fees, and that according to KII and document review certification costs can reach up to €11,000 per cooperative, a level widely viewed as unsustainable for cooperatives exporting small volumes. Stakeholders emphasize that these cumulative regulatory demands risk excluding smaller cooperatives and exacerbating inequalities within the sector. Those specific burdens amplify the general EUDR-related challenges widely acknowledged by stakeholders: complex supply chain traceability, inadequate digital infrastructure, gaps in deforestation risk assessment documentation, limited technical and financial capacity, and the absence of a fully coordinated national policy framework to mobilize resources and provide clear guidance.

Beyond compliance capacity, FGDs and KIIs provide important insights into the potential socioeconomic and environmental impacts of the EUDR. From a socioeconomic perspective, stakeholders acknowledge the regulation's potential to safeguard access to EU markets, enhance export stability, and reinforce Ethiopia's positioning as a supplier of sustainable coffee. Cooperative leaders and development partners note that existing sustainability certifications already confer competitive advantages, which EUDR alignment could further strengthen. However, FGDs with farmers and primary cooperatives reveal deep concern that rising compliance costs and administrative burdens may outweigh these benefits, particularly in the absence of explicit price premiums, potentially reducing net incomes and increasing vulnerability among smaller producers.

Participants also discuss potential labor and social implications. KIIs suggest that EUDR implementation could create new employment opportunities related to geospatial mapping, data management, and traceability services, especially if these functions are decentralized. At the same time, FGDs caution that without sustained training and institutional support, compliance requirements may instead translate into additional unpaid labor and administrative pressure for farmers and cooperative staff, rather than meaningful skill development.

Environmental impacts feature prominently in qualitative discussions. Many KIIs, particularly with environmental authorities and NGOs, view the EUDR as a catalyst for strengthening forest protection, improving land-use documentation, and increasing accountability for deforestation risks. However, FGDs and document review highlight significant concerns about unintended environmental consequences. Studies indicate that 8–12% of traditional coffee areas in parts of Southwest Ethiopia have already been converted to more immediately lucrative crops such as khat or eucalyptus plantations, contributing directly to deforestation. Stakeholders warn that, without supportive incentives and alternative livelihood options, stricter compliance requirements could intensify these trends, undermining both biodiversity conservation and the long-term resilience of coffee-based livelihoods.

Overall, the qualitative evidence points to a widening gap between policy ambition and implementation capacity. While Ethiopia has initiated a range of strategic, institutional, and pilot-level responses to the EUDR, these efforts remain insufficiently coordinated, under-resourced, and inadequately anchored at the farmer and primary cooperative levels. KIIs and FGDs consistently emphasize that without accelerated, targeted support—particularly in farmer-level capacity building, affordable traceability solutions, financial assistance, and strong inter-sectoral coordination—the EUDR risks producing uneven socioeconomic outcomes and falling short of its

intended environmental objectives. These qualitative findings complement and deepen the quantitative results by illuminating the structural, institutional, and equity dimensions that shape both readiness for, and the potential impacts of, the EUDR in Ethiopia's smallholder coffee systems.

5. Discussion

This study provides one of the first micro-level empirical assessments of smallholder readiness for the European Union Deforestation Regulation (EUDR). By synthesizing and triangulating household-level descriptive and econometric evidence with qualitative stakeholder insights, it contributes to the growing literature on the "regulatory turn" in global value chain governance (Grabs et al., 2024). The findings highlight a critical tension between the EUDR's stringent due-diligence requirements and the structural realities of smallholder-based production systems.

5.1. The Awareness-Capacity Paradox: Structural Constraints to Regulatory Agency

A primary finding of this study is the significant decoupling between regulatory awareness and functional compliance capacity. While awareness levels are non-trivial, compliance capacity—particularly regarding plot-level geolocation, traceability documentation, and legal verification—remains limited. This asymmetry reflects a widening preparedness gap observed across producer countries, where awareness of the EUDR spreads relatively quickly, yet the material, technical, and institutional resources necessary to translate that awareness into effective compliance lag substantially behind (IIED et al., 2025; Tropenbos International, 2025).

Importantly, the determinants analysis indicates that readiness is shaped less by individual characteristics than by structural positioning. Sustainability standard certification, production system, cooperatives, land endowments, and market integration significantly condition both awareness and compliance capacity. This supports perspectives on governance in the value chain, emphasizing that compliance with transnational regulation is mediated by access to organizational infrastructure, assets, and institutional support rather than by knowledge alone (Ponte et al., 2023). From an EUDR perspective, this challenges implicit assumptions that transparency requirements can be met through information provision and private initiative alone. Instead, the findings point to a structural compliance gap, in which farmers may understand regulatory expectations but remain constrained in their ability to operationalize them depending on their other conditions.

5.2. Voluntary Sustainability Standards as Partial Readiness Mechanisms

The analysis further demonstrates that VSS certification has a strong and robust effect on regulatory awareness but a weaker and method-sensitive effect on compliance capacity. This pattern is consistent with the evolving understanding of VSS as hybrid governance instruments that prioritize procedural upgrading—such as training, internal control systems, and documentation—over legally enforceable land-use verification (Van der Ven et al., 2021; Ponte, 2022). A recent study also shows that certification improves knowledge, monitoring practices, and administrative routines even when impacts on assets or land tenure remain limited (Doswald et al., 2025).

The limited effects on compliance capacity reflect a structural misalignment between VSS design and EUDR requirements. EUDR mandates plot-level geolocation, historical deforestation cut-off verification (post-2020), and legal proof of land-use rights—elements that are not systematically embedded in most certification schemes. Under the EUDR, VSS are recognized as "complementary

tools" for risk assessment but cannot replace the operator's responsibility for due diligence (EU Reg 2023/1115, Recital 52). A recent policy analyses emphasize, certification systems were not designed to serve as legal due-diligence instruments and therefore cannot substitute for public land administration, cadastral systems, or national traceability infrastructure (Cosimo et al., 2024). Our findings also suggest that relying on VSS as a "de facto" compliance infrastructure is risky. As benchmark analyses demonstrate, the "zero-deforestation" criteria of VSS often differ from the EUDR's specific 2020 cut-off dates and legality requirements, creating a "false sense of security" for certified farmers who may still lack the precise point or polygon data required for EU market entry (Schilling-Vacaflor & Lenschow, 2023).

5.3. The Ecological Paradox: Risk of Uneven Exclusion

The findings also illuminate the distributive implications of EUDR implementation. Farmers operating in integrated, forest and semi-forest coffee systems—despite their comparatively low deforestation footprints—exhibit systematically weaker compliance capacity. This reflects the inherent tension between the ecological complexity of agroforestry systems and the technical logic of spatially explicit regulation, representing a "governance paradox": the very farmers maintaining the most carbon-sequestering and biodiverse coffee systems face the highest risk of regulatory de-linking (Karsenty & Salau, 2023).

The EUDR's requirement for geolocation points (for plots under 4 ha) or polygons (for plots above 4 ha) implicitly assumes a legible, cadastral landscape. In forest-based production systems, however, overlapping canopy cover, agroforestry management, and customary tenure arrangements make "clean" spatial mapping both technically challenging and costly. This finding resonates with broader critiques of environmental governance instruments that rely on spatial verification technologies, which may systematically disadvantage ecologically embedded smallholders while favoring simplified production systems characterized by fixed boundaries, formal land titles, and standardized documentation (McCarthy et al., 2018).

In the Ethiopian context, where coffee production is historically intertwined with forest landscapes, the EUDR may therefore generate exclusion risks not because of deforestation behavior, but because of verification constraints. This highlights a critical governance challenge: without differentiated pathways, the EUDR may inadvertently incentivize "sourcing simplification," where European buyers shift procurement away from complex forest landscapes toward large-scale, easily mapped plantations, leading to "regulatory-induced leakage" (Lambin & Furumo, 2023).

5.4. Selection Endogeneity and the "Matthew Effect" in Compliance

The divergence between our PSM and ESR estimates illuminates the "Matthew Effect" (cumulative advantage) in sustainability governance. The positive selection bias in compliance capacity suggests that certification tends to "cream-skim" farmers who already possess higher latent managerial ability and institutional connectivity. This endogeneity implies that the farmers most in need of support to avoid EUDR exclusion are the least likely to be reached by current market-based certification schemes. As Grabs (2020) argues, when private standards become the gatekeepers for public regulations, they risk reinforcing pre-existing inequalities. Our results suggest that if the EUDR substantially relies on existing market channels for implementation, it will disproportionately benefit "compliance-ready" elites while marginalizing the most vulnerable smallholders.

5.5. Toward an Enabling and Differentiated Governance Architecture

Our synthesis indicates that private sustainability certifications make a meaningful contribution to EUDR preparedness, particularly by enhancing awareness and procedural familiarity, but they are insufficient as standalone mechanisms for achieving effective compliance. Bridging the gap between regulatory knowledge and verifiable compliance requires an enabling governance framework that combines private initiatives with targeted public and collective action. Such a framework is essential not only to translate awareness into operational capacity but also to mitigate the risk of exclusionary outcomes. Five complementary pillars emerge from the analysis.

First, farmer capacity-building efforts must shift from a primary focus on awareness-raising toward targeted, compliance-oriented support. Training programs should extend beyond general sustainability knowledge to include hands-on assistance with GPS-based farm mapping, digital record-keeping, and documentation management. Without these practical competencies, basic regulatory awareness and certification-related knowledge cannot be translated into legally defensible compliance under the EUDR.

Second, sustained public investment in land administration and digital infrastructure is indispensable for effective EUDR implementation. Core compliance requirements—traceability, tenure verification, and geospatial accuracy—constitute public goods that cannot be delivered through private certification alone. Accelerating second-level (georeferenced) land certification, expanding interoperable national geodatabases, and integrating participatory forest management (PFM) records into national due-diligence systems are therefore critical priorities (FAO, 2024). Explicit recognition of PFM agreements and customary land certificates as admissible compliance evidence would further reduce exclusion risks in regions where formal titling remains incomplete, while preserving the regulation's environmental integrity.

Third, compliance pathways must be differentiated according to production system characteristics and farmers' social positions. Group-based or landscape-level compliance mechanisms are likely to be more suitable for forest and semi-forest coffee systems, where fragmented plots, collective land-use arrangements, and gradual canopy change complicate farm-level verification. At the same time, targeted support measures are essential to prevent the systematic exclusion of structurally disadvantaged groups—particularly women-headed households and very small producers—who face higher compliance costs and more limited access to technical and institutional resources.

Fourth, coordinated multi-stakeholder governance is essential. Effective EUDR implementation cannot be delivered through fragmented institutional action. A national coordination platform—bringing together agricultural authorities, environmental agencies, land administration bodies, cooperative unions, exporters, and civil society organizations—would help clarify roles and responsibilities, align public and private investments, and reduce duplication across mapping, traceability, and verification initiatives. Such coordination is critical for translating EU-level regulatory requirements into coherent, nationally embedded implementation pathways.

Fifth, equitable cost-sharing and due-diligence responsibility must be institutionalized. The current upstream transfer of compliance costs to smallholders and local cooperatives is neither equitable nor sustainable. Policy frameworks should therefore promote long-term partnership arrangements in which EU-based roasters and traders co-invest in supplier-side mapping, documentation, and monitoring systems, rather than treating EUDR compliance as a binary "pass/fail" procurement condition. Consistent with the logic of Article 10 of Regulation (EU) 2023/1115, shared

responsibility for compliance costs is not only an ethical consideration but a functional requirement for maintaining stable, inclusive, and deforestation-free supply chains (Grabs et al., 2024).

5.6. Limitations and Future Research

This study is limited by its cross-sectional nature and reliance on self-reported capacity indicators. Although the Endogenous Switching Regression (ESR) model explicitly addresses unobserved selection bias, it cannot account for the temporal dynamics of learning, behavioral adjustment, and institutional adaptation that are likely to unfold as EUDR implementation progresses. Longitudinal data would therefore be required to strengthen causal inference and to track how awareness, compliance capacity, and institutional support evolve over time—an approach that was not feasible at this early stage of EUDR implementation.

Future research should integrate objective geospatial verification data, compliance audits, and panel surveys to track adjustment trajectories over time. Comparative studies across commodities and institutional settings are also needed to assess how different governance architectures mediate EUDR outcomes. Finally, greater attention should be paid to the distribution of compliance costs and market access effects to evaluate whether the EUDR can achieve its environmental objectives without deepening inequalities in global commodity chains.

6. Conclusion

This study shows that the challenge of implementing the EU Deforestation Regulation (EUDR) in smallholder coffee systems is not primarily one of unwillingness, but of uneven preparedness. Ethiopian smallholders are not detached from global environmental governance; many are already aware of the regulation and its objectives. The core problem lies in the translation of regulatory knowledge into operational capability. Compliance with the EUDR requires not only understanding new rules, but also navigating digital technologies, formal documentation systems, and spatial verification tools that remain weakly embedded in smallholder production landscapes.

Voluntary sustainability standards emerge in this context as imperfect but strategically important intermediaries. Rather than functioning as full compliance mechanisms, certification systems operate as early connectors between smallholders and evolving global regulatory expectations. They help farmers interpret distant regulatory signals and embed them within local institutional routines. Yet the study demonstrates that information alone does not build compliance. The distance between knowing and doing remains wide where infrastructure, land governance, and cooperative capacity are underdeveloped.

The findings also reveal a deeper tension at the heart of contemporary environmental regulation. The EUDR seeks to protect forests through technical traceability, but forest-embedded farming systems are precisely those for which such verification is most difficult. This creates a risk that the regulation unintentionally penalizes ecological complexity. If left unaddressed, this contradiction could weaken both conservation and development objectives by shifting market access away from smallholders operating in historically sustainable landscapes.

Ultimately, the study suggests that the success of the EUDR in countries like Ethiopia will depend less on the precision of its rules than on the inclusiveness of its implementation pathways. Regulations that travel faster than institutional capacity risk hardening existing inequalities within

global value chains. Aligning environmental ambition with development reality therefore requires treating smallholder compliance not as a private obligation, but as a shared governance project between states, markets, and producers.

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