ESJ Social Sciences Peer-reviewed

Economic Analysis of the Eucalyptus Sector on Strengthening the Financial Stability of Eucalyptus Farmers in Burundi

Niyintunze Simeon, PhD candidate
Faculty of Economics and Management Sciences,
Doctoral School, University of Burundi, Burundi
Manirakiza Diomede, Professor of Economics
Faculty of Economics and Management Sciences,
University of Burundi, Burundi
Maniriho Aristide, PhD in Economics
School of Economics, University of Rwanda, Rwanda
Karangwa Antoine, Professor of Agriculture
Economics & Rural Development, School of Agriculture
and Food Sciences, University of Rwanda, Rwanda
Niyuhire Marie Chantal, PhD in Rural Economics
Faculty of Economics and Management Sciences,
University of Burundi, Burundi

Doi:10.19044/esj.2026.v22n19p110

Submitted: 16 May 2026
Accepted: 26 July 2026
Published: 31 July 2026

Cite As:
Niyintunze, S., Manirakiza, D., Maniriho, A., Karangwa, A., & Niyuhire, M.C. (2026). *Economic Analysis of the Eucalyptus Sector on Strengthening the Financial Stability of Eucalyptus Farmers in Burundi*. European Scientific Journal, ESJ, 22 (19), 110. https://doi.org/10.19044/esj.2026.v22n19p110

Abstract

This study aims to analyze the influence of the eucalyptus sector on strengthening the financial stability and economic resilience of rural households in Burundi, by assessing its capacity to function as a true "green bank" to finance productive investments. To this end, the methodology relies on a two-stage stratified comparative and probabilistic approach between two provinces with marked agro-ecological and socio-economic contrasts: the peri-urban area of Bujumbura and the highland regions of Burunga. Using the KoboCollect tool, direct surveys were conducted with a statistically robust sample of 190 farming households distributed across 4 communes and 9 hills. The data collected were then integrated into an econometric model of the

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

determinants of global income using the ordinary least squares (OLS) method, analyzing the impact of 13 distinct sources of income and validated by rigorous tests of multicollinearity (VIF) and heteroscedasticity.

The research results reveal a major economic dependence of farmers on this resource, evidenced by a near-perfect correlation of 98% between income from eucalyptus and overall household income. The econometric analysis specifies that a 1% increase in income from eucalyptus leaves leads to a 1.03% increase in total income, while a 1% increase in timber income results in a rise of nearly 1.00%. These financial gains allow families to make significant structural investments to sustainably improve their living conditions. In fact, households prioritize housing (23%), resulting in the modernization of dwellings and the complete disappearance of traditional huts, and access to healthcare (22%). The remaining earnings actively support human capital and family wealth through the financing of education (17%), food security (18%), the purchase of land plots (12.6%) and the development of livestock farming, particularly cattle farming at a rate of 54%.

Keywords: Eucalyptus, Economic influence, Global income, Financial stability

Introduction

Eucalyptus, introduced to Burundi during the colonial era, was long perceived solely in terms of reforestation or erosion control. However, it has gradually established itself as a genuine "living asset" for rural households. The eucalyptus sector contributes to economic resilience through three main channels: the production of firewood and construction timber, the sale of power poles, and, more recently, the extraction of essential oils.

Despite its omnipresence in the Burundian landscape, the actual contribution of eucalyptus to overall household income remains underestimated in public policies (Ndayiragije, 2021). How does this sector influence the resilience trajectory of family farms?

The aim of this article is to analyze the impact of eucalyptus adoption and exploitation on the financial recovery capacity of rural households. We hypothesize that eucalyptus acts as a "green bank," enabling households to finance productive investments.

Classical references on risk management in rural areas (Dercon, 2002; Barrett, 2011) emphasize that poor households diversify their activities to minimize the variance in their total income. In Burundi, eucalyptus fulfills this function thanks to its low input requirements and its ability to grow on marginal land (Bigirimana et al., 2019).

In Burundi, the eucalyptus sector is therefore useful in multiple dimensions, supporting domestic life through charcoal and construction

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

timber, protecting health through its essential oils, and boosting the economy through industrial processing. Eucalyptus has become a pillar of Burundi's resilience, combining energy security and the sustainable use of local natural resources within a framework of sustainable development.

Optimizing charcoal production

The importance of eucalyptus in charcoal production in Burundi is part of a major energy security issue, where this tree species has become the main bulwark against deforestation of natural forests. The dependence of households in Bujumbura on charcoal is so great that demand far exceeds natural regeneration, making eucalyptus a strategic resource due to its rapid growth and stump resprouting capacity (Nduwamungu, 2011). This species is particularly valued because it produces a fuel with a high calorific value, meeting urban cooking needs. As Bailis et al. (2015) highlight in their research on biomass sustainability in East Africa, eucalyptus acts as an economic stabilizer for rural producers, offering a significantly higher energy yield per hectare than less dense native species.

The varietal selection carried out by the Institute of Agronomic Sciences of Burundi has maximized this production potential. By favoring species such as *Eucalyptus tereticornis* and Eucalyptus camaldulensis, researchers were able to ensure optimal wood density for carbonization. Doran and Wong (2000) demonstrated that the cellular structure of these specific varieties promotes better mechanical resistance of the charcoal, thus limiting losses due to friability during transport to markets.

The usefulness of eucalyptus, however, depends on the efficiency of the processing methods, as traditional carbonization in earthen mounds remains synonymous with energy waste. Adding a central chimney reverses the combustion flow, which not only reduces production time to three days but also increases yield to nearly 25% (Girard, 2002).

Beyond simply producing heat, eucalyptus plays a multifunctional role in the circular economy of coal. The use of metal furnaces and retorts, although more expensive, allows for the capture of pyrolysis gases, an energy efficiency concept supported by the work of Kammen and Lew (2005).

According to Smith et al. (2019), using high-quality eucalyptus charcoal in optimized cookstoves drastically reduces indoor pollution, thus protecting the health of women and children. In short, eucalyptus is emerging not only as the most viable technical solution for charcoal production, but also as a cornerstone of energy resilience in the face of current climate challenges facing the world.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Uses of eucalyptus in construction and furniture

The development of eucalyptus in Burundi marks a major transition from a subsistence economy to a technology-driven industry. Eucalyptus use also extends to construction and furniture. Thanks to its versatility, it is transformed into beams, planks, and rafters with a high yield at sawmills. It can be found everywhere, from the frames of hillside houses to living room furniture in urban centers. It is a robust material that allows Burundi to reduce its timber imports, thus saving valuable foreign currency for the national economy.

However, the adoption of precision sawing and controlled drying techniques has stabilized the eucalyptus fiber, transforming it into a viable alternative to more expensive timber species (Chirko, 2018). This qualitative shift is particularly noticeable in urban centers like Bujumbura, where local crafts are now incorporating industrial standards to meet a growing demand for luxury furniture, proving that technological innovation can transform a common resource into a driver of economic growth.

Specific therapeutic applications and energy use

Eucalyptus plays a central role in Burundi's rural economy and energy landscape, establishing itself as a strategic resource far beyond its purely botanical attributes. According to Nduwumwami's (2014) work on forest dynamics in the Great Lakes region, this species has become the cornerstone of charcoal production, supplying over 80% of the domestic energy used in urban centers like Bujumbura. This dominance is explained by its rapid growth and high calorific value, characteristics that Husch et al. (2003) had already highlighted as essential for the viability of energy plantations in developing countries.

On an industrial and artisanal level, eucalyptus's contribution to the energy sector is optimized by carbonization techniques which, although traditional, are becoming increasingly modernized to improve mass yield. The use of eucalyptus wood produces charcoal whose molecular structure promotes slow combustion and consistent heat, ideal for household cooking and heating needs (Bailis et al., 2015). In Burundi, this benefit is even more pronounced in high-altitude regions, where the tree serves as a primary fuel. Integrating this species into local agroforestry systems not only ensures energy independence for rural populations but also generates substantial income through the sale of surplus charcoal to provincial markets.

In herbal medicine and aromatherapy globulus essential oil, validates the effectiveness of terpene compounds such as eucalyptol (1,8-cineole) in the treatment of respiratory tract infections. In Burundi, this transition to clinical aromatherapy is being driven by actors such as STHE, and Karire Products and others have successfully developed the processing of essential oils from

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

eucalyptus leaves. This professionalization allows for the transformation of a local resource into a high-value product, capable of competing in export markets.

The benefits of eucalyptus extend to the realm of well-being and health safety; inhaling eucalyptus vapors is not limited to olfactory comfort; it plays an active role in reducing inflammation of the mucous membranes (Sadlon and Lamson, 2010). This property is widely exploited in sauna centers in Bujumbura and Gitega, where the essential oil purifies the ambient air.

Finally, eucalyptus plays an essential socio-ecological role by acting as a buffer against deforestation and the cold climate of highland areas. Despite debates about its water consumption, eucalyptus remains the most resilient species for stabilizing soils while providing a vital source of heat during the rainy seasons in the Congo-Nile Divide (Poussard, 2021).

Literature review

The theoretical framework of this research is primarily structured around the sustainable livelihoods approach and the theory of economic resilience, which provide an essential conceptual justification for understanding the impact of eucalyptus in rural areas. Initially defined from a systems perspective by Holling (1973), resilience was transposed to the social sciences by Adger (2000) to describe a community's capacity to absorb exogenous disturbances without altering its fundamental structure. In line with this view, Chambers and Conway (1992) posit that a household's livelihoods are sustainable when they withstand economic shocks without compromising its stock of productive capital. In this context, eucalyptus is theorized not as a simple plant resource, but as a strategic natural asset capable of smoothing the consumption of households vulnerable to market fluctuations.

To further explore this dynamic of adaptation, the model draws on a fruitful comparison between Markowitz's portfolio choice theory (1952), adapted to agricultural economies by Fafchamps (2003), and classic works on risk management in rural areas (Dercon, 2002; Barrett, 2011). These international bodies of work highlight that poor producers rationally diversify their activities to minimize the variance of their total income, a principle also advocated by Ellis (2000) in the context of agroforestry. The theoretical comparison reveals that, while eucalyptus proves less profitable in the short term than vegetable crops, its risk of total loss is virtually nil. It therefore acts as a universal hedging asset, validating international approaches to optimizing the risk-return trade-off while adapting to the low input endowments of local farms.

This financial stabilization function directly aligns with the precautionary savings theory developed by Deaton (1991), which posits that economic agents accumulate liquid assets to cope with future liquidity

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

constraints. At the international level, Chambers and Leach (1989) conceptualized this phenomenon under the paradigm of "trees as savings and security," demonstrating that smallholder forestry serves as a monetary reserve that can be mobilized only in times of urgent need. This analytical framework finds perfect empirical resonance in Burundi. Indeed, the work of Niyonzima (2018) and Ndikumana (2022) confirms that the sale of eucalyptus wood constitutes the main driver of non-monetary savings among Burundian farmers, activated during major events or medical emergencies, thus legitimizing the integration of this macroeconomic framework into the realities of rural areas.

At the microeconomic level, producers' behavior in the face of land allocation disputes is illuminated by Chayanov's (1966) factor allocation theory. This classic model of peasant economics explains how rural households distribute their resources according to the marginal productivity of labor and land. The introduction of this theory helps to understand why farmers choose to dedicate a portion of their land to forestry despite the pressure exerted by food crops. Local analyses by Bigirimana et al. (2019) corroborate this approach by demonstrating that eucalyptus's capacity to utilize marginal and infertile soils optimizes the use of available factors of production, thus resolving the dilemma between food security and forest capitalization.

To integrate the geographical and commercial dimensions of the sector, the theoretical review draws on Von Thünen's (1826) land rent theory. This international spatial model posits that the location of agricultural production and its net profitability depend on the distance from urban consumption centers and the associated transport costs. Applying this model to contemporary Burundian dynamics, notably by Nkurunziza (2020), allows for mapping the profitability of eucalyptus plantations based on their proximity to major markets such as Bujumbura and Bururi. The application of this spatial theory is crucial because it clarifies how physical access to the market determines the economic incentives of peripheral producers, as highlighted by Manirakiza (2021).

Nevertheless, the combination of these complementary theoretical perspectives combining global approaches to resilience, portfolio theories, precautionary savings, Chayanovian allocation, and spatial economics proves fully justified for analyzing the eucalyptus sector in Burundi. This multidimensional theoretical framework allows us to move beyond purely descriptive analyses or those strictly confined to the local level. By linking international economic paradigms to Burundian institutional and agroecological specificities, this research offers a robust conceptual basis for rigorously assessing how this “green bank” influences the trajectory of financial stability and the sustainable well-being of rural households.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Empirically, the impact of agroforestry investments consistently highlights the crucial role of eucalyptus in improving and stabilizing the incomes of rural households in East Africa. At the regional level, research conducted in Ethiopia by Mekonnen et al. (2017) reveals that the adoption of small-scale eucalyptus plantations increases the average annual income of farms by 15% to 25%. This trend toward improved financial returns is empirically confirmed in Burundi, where the work of Ndikumana (2022) demonstrates that eucalyptus is the primary source of non-monetary savings for farmers, particularly in the Mugamba region. The strong correlation of 98% observed between earnings from eucalyptus wood and overall income reinforces the idea that the sector is no longer a simple supplementary activity, but the central pillar of the financial structure of Burundian households.

Beyond simply increasing current income, eucalyptus cultivation is documented as a powerful lever for lifting people out of structural poverty and accumulating long-term assets. In Kenya, the study by Mwangi et al. (2016) demonstrates that the financial flows generated by commercial eucalyptus plantations directly enabled 15% of the rural households studied to escape chronic poverty. Applied to the Burundian context, this transformative potential materializes as a profound change in living conditions and family wealth. Field data indicate a massive reinvestment of these revenues in sustainable infrastructure, resulting in a radical modernization of housing, the acquisition of livestock, particularly cattle (54%), as well as the purchase of land (12.6%) and means of transport, thus locally validating the hypothesis of eucalyptus as an engine of economic advancement.

Analysis of how these forest revenues are used also highlights significant positive externalities on essential components of human capital, such as education and health. In this regard, Mekonnen's (2019) work in Ethiopia establishes a positive and statistically significant correlation between private forest ownership and the level of investment in children's education. This budget allocation dynamic is quite similar to that observed in Burundi. Indeed, the allocation of eucalyptus revenues there shows a clear priority given to healthcare coverage (22%) and education funding (17%), thus demonstrating that the financial security provided by this timber resource allows rural families to move beyond mere subsistence spending and engage in long-term human development strategies.

The importance of eucalyptus is intrinsically linked to its multifunctionality, which allows it to structure both the energy and high-value-added materials markets. Regarding the energy sector, research by Bailis et al. (2015) on biomass in East Africa highlights the superior energy yield and rapid regeneration capacity of eucalyptus compared to indigenous species, thus stabilizing producers' livelihoods. In Burundi, this dominance is confirmed by Nduwumwami (2014), who points out that eucalyptus provides

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

more than 80% of the domestic energy consumed in Bujumbura. Moreover, Chirko's (2018) analyses in Central Africa show that the introduction of precision sawing techniques makes it possible to stabilize its fiber to make it a competitive substitute in luxury furniture, a reality visible in Burundian urban markets where industrial processing is beginning to capture a significant share of the added value at the expense of wood imports.

Despite these undeniable economic benefits, empirical literature also analyzes the structural and environmental constraints that affect the overall profitability of the sector. Some authors adopt a critical stance regarding the negative externalities of this tree on agricultural ecosystems. In this regard, Nzeyimana (2020) highlights the detrimental impact of eucalyptus plantations on the yield of adjacent crops in the hills of Burundi, pointing to the risks of degrading local food security due to high water and nutrient consumption. This observation, according to Niyitanga (2022), necessitates finding a rigorous compromise between optimizing short-term financial gains and preserving ecosystem services, thus encouraging a more reasoned integration of the species within high-altitude agroforestry systems.

Finally, market imperfections and geographical barriers remain major limiting factors for the full development of the most isolated producers. Manirakiza's (2021) study demonstrates that information asymmetry and difficulties accessing formal distribution channels for high-value products, such as utility poles or high-quality charcoal, severely penalize the profitability of farms located in the peripheral provinces of Burundi. Nevertheless, the recent emergence of local industrial and artisanal initiatives focused on essential oil distillation, such as STHE and Karire Products, opens up new empirical perspectives. As Kouamé (2022) suggests for other African contexts, the clinical valorization of eucalyptus terpene compounds makes it possible to bypass the bottlenecks of traditional markets by positioning rural communities in high-tech value chains, thereby sustainably strengthening their financial resilience to economic shocks.

Methodology

Our study is conducted in Burundi and adopts a comparative design based on two provinces exhibiting marked agro-ecological and socio-economic contrasts. On the one hand, there is the province of Burunga, characterized by the long-standing introduction of eucalyptus, a species historically integrated into the forest and agricultural landscape. On the other hand, there is the province of Bujumbura, where the dynamics of the eucalyptus sector are strongly driven by urban commercial demand for energy and construction materials.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Figure 1: Geographic scope and framework of the study

Justification for the sample size

Determining and justifying sample size is a crucial step in ensuring the internal validity and statistical power of any empirical research in rural economics. In this study, the choice to survey a total of 190 farming households was not arbitrary, but rather based on a dual logic of statistical optimization and field constraints, theorized notably by Cochran (1977) and advocated by development economists such as Barrett (2011) and Dercon (2002). From a purely mathematical standpoint, for household surveys conducted in large populations where the exact variance of the variables of interest (such as global income or the share of forestry income) is not known a priori, Cochran's (1977) classic formula serves as a standard reference for estimating a representative sample at a given confidence level. By setting a standard confidence level of 95% (corresponding to a critical value for the normal distribution $Z = 1.96$) and assuming a maximum degree of variability in eucalyptus adoption behaviors (i.e., a proportion of $p = 0.5$ and $q = 0.5$ allowing for maximum variance in the portfolio of activities), an absolute

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

margin of error of 7% theoretically leads to a baseline sample of approximately 196 households. The final selection of 190 validated households fits this ideal target perfectly, exhibiting a very low actual margin of error of around 7.1%, which is widely considered acceptable in rural microeconomic research in sub-Saharan Africa (Mwangi et al., 2016; Mekonnen et al., 2017).

Beyond simply applying fixed mathematical formulas, the sample size of 190 also meets the criteria for multivariate analysis and ordinary least squares (OLS) econometric estimation. As Green (1991) and Hair et al. (2010) remind us, to robustly evaluate a linear regression model with multiple explanatory variables (here, 13 distinct income sources included in the equation), it is imperative to maintain a minimum ratio of observations per estimated parameter to avoid overfitting and ensure sufficient degrees of freedom for significance tests. Green's (1991) rule of thumb, which stipulates that the sample size should be greater than or equal to 50 + 8k (where k represents the number of predictor variables), would require a minimum of 154 observations for our 13-variable model. With 190 households, our study exceeds this prudent threshold, offering a ratio of approximately 15 observations per explanatory variable, which ensures the stability of the regression coefficients and adequate statistical power to detect the real marginal effects of forestry income on overall financial stability.

Finally, this sample size is explained by the logistical, temporal, and financial constraints inherent to the context of the Burundian hills, where the geographical dispersion of farms and the difficulties of accessing high-altitude areas necessitate a pragmatic compromise. Interviewing a larger sample size without significant external funding could have compromised the quality of the face-to-face data collection. By limiting the sample to 190 meticulously observed units using the KoboCollect tool, the study was able to dedicate the necessary time to each individual interview, thus drastically reducing non-responses and inconsistencies in reporting that often plague overly large and poorly supervised databases, perfectly aligning with the methodological recommendations of Saunders et al. (2019) on the qualitative representativeness of samples in the social sciences.

Sampling strategy

The external robustness of the results of this research depends fundamentally on the probabilistic structure of its sampling strategy, designed here according to a two-stage stratified protocol. The advantage of this approach, detailed by Cochran (1977) and Kish (1965), lies in its ability to reduce sample variance compared to simple random sampling, by first dividing the target population into homogeneous subgroups according to explicit geographic and socioeconomic criteria. In our case, the first stage of

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

selection consisted of a reasoned and contrasting choice of the provinces of Bujumbura and Burunga. This initial division allows us to isolate two major centers of influence theorized by Von Thünen: on the one hand, the peri-urban zone of Bujumbura, characterized by intense market pressure and strong commercialization of charcoal and construction materials driven by urban demand; and on the other hand, the highland regions of Burunga province, where eucalyptus has historically been integrated into agroforestry practices to cope with the cold, protect soils from erosion, and generate standing savings. By then subdividing these provinces into four specific communes Bubanza, Bukinanyana, Bururi, and Matana the study accurately captures the diversity of agro-ecological contexts and the varying degrees of isolation experienced by rural producers.

The second stage of this probabilistic strategy involved the random selection of primary sampling units, namely the hills, followed by secondary units, consisting of farming households cultivating or adopting eucalyptus within each hill. At the level of each selected commune, the official list of hills served as the sampling frame for a transparent random selection of two hills per commune (Mpinga, Mpishi, and Musigati for the commune of Bubanza; Murengera and Rusenda for the commune of Bukinanyana; Gihinga and Nyarwaga for the commune of Bururi; and Kivumu and Munini for the commune of Matana). Once the hills were identified, a comprehensive census or enumeration of rural households involved in the timber or leaf sector was conducted with the support of local community leaders and agricultural extension workers. From these updated hill registers, a systematic random draw or random number table was programmed in the field, assigning to each producing household a known and non-zero probability of being included in the survey, thus eliminating any bias of subjectivity on the part of the surveyors in accordance with the statistical validation standards of Wooldridge (2015).

The choice of Burunga and Bujumbura provinces is justified by their contrasting agroecological and socio-economic characteristics. In Burunga, eucalyptus is an ancient and integral part of the landscape, while in Bujumbura (in the peri-urban area), the sector is driven by the growing demand for energy and construction materials in the economic capital. Sampling was a two-stage stratified method, with a total of 190 households interviewed.

- First degree (Geographic stratification): Selection of provinces (Bujumbura and Bururi), then subdivision into communes (Bubanza, Bukinanyana, Bururi, Matana).
- Second step: random selection of hills in each municipality, then random selection of agricultural households at the level of each hill.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Table 1: Distribution of respondents operating in the eucalyptus sector by province, municipality and hill

Provinces	Communes	Hills	Effective
Bujumbura	Bubanza	Mpinga	23
		Mpishi	20
		Musigati	24
	Bukinanyana	Murengera	16
		Rusenda	18
Burunga	Bururi	Gihinga	20
		Nyarwaga	17
	Matana	Kivumu	19
		Munini	33
Total			**190**

Justification for site selection

The choice of the Bujumbura and Burunga provinces and their specific survey sites was not random; rather, it was driven by a dual theoretical and empirical rationale centered on representing the extremes of the eucalyptus value chain in Burundi. From an agro-ecological and microeconomic perspective, Burunga province is situated in the high altitudes of the Congo-Nile Divide, offering an ideal setting characterized by a cold climate; here, eucalyptus is historically embedded in the forest landscape, serving both as a natural asset that protects fragile soils from erosion and as a vehicle for precautionary savings. Meanwhile, the peri-urban area of Bujumbura province is subject to market forces characterized by strong commercial demand for firewood, charcoal, and construction materials to supply the economic capital. This geographical setup allows for the ideal application of Von Thünen's (1826) spatial model of land rent, making it possible to measure how distance from the major urban consumption center dictates economic incentives and net profitability for peripheral forest producers compared to those in more isolated mountainous zones. Furthermore, the four selected communes Bubanza and Bukinanyana in Bujumbura province, and Bururi and Matana in Burunga province along with the hills selected at the second stage of sampling, embody these contrasting structural dynamics: on the one hand, zones highly integrated into the market for high-value-added derivative products; and on the other, highland forest zones where eucalyptus serves as a non-monetary financial reserve against climate and subsistence shocks.

Validity of variables

To ensure the scientific quality of the findings, the definition and measurement of the study variables underwent a triple validation process (content, construct and criterion), based on the theoretical frameworks of the sustainable livelihoods approach (Chambers & Conway, 1992) and precautionary savings (Deaton, 1991).

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

The selection of explanatory variables (Inc_tea, Inc_hortic, Inc_soy, etc.) stems directly from an in-depth review of the empirical literature from East Africa and Burundian agroforestry systems (Niyonzima, 2018; Bigirimana et al., 2019). By specifically isolating income from eucalyptus leaves (Inc_eucaleav) and eucalyptus wood (Inc_woodeucaly), the model respects the exhaustiveness of the economic value chains of this plant species, thus validating the logical fit between the measurement tool and the studied agricultural reality, in accordance with the recommendations of Saunders et al. (2019).

The dependent variable (ln_inchhold), expressing the logarithm of total household income, robustly captures the multidimensional concept of "economic resilience" and "financial stability." Following Chayanov's (1966) factor allocation model and Markowitz's (1952) portfolio optimization adapted to agriculture, the logarithmic transformation of cash flows stabilizes the variance and allows for the direct measurement of elasticities (θ_0 to θ_1[3]). This methodological choice validates the theoretical construct that eucalyptus revenues accumulate and smooth aggregate consumption in the face of exogenous shocks.

The validity of the criteria is confirmed by comparing the measures with surrogate indicators of households' actual well-being. The estimated income variables are positively and significantly correlated with structural improvements in housing (disappearance of huts and thatched roofs), access to healthcare, school enrollment, and the accumulation of material assets (cattle, motorcycles, mobile phones). This predictive consistency aligns with the empirical validation criteria of Adger (2000).

Managing bias

In any microeconomic research based on rural surveys, identifying and neutralizing methodological biases is essential to preserving the integrity of econometric estimates, a challenge extensively documented by Wooldridge (2015) and Podsakoff et al. (2003). The first major risk lies in selection bias, which arises when households cultivating eucalyptus have systematically different initial characteristics (larger land area, better labor resources, or privileged access to markets) than those that do not. To mitigate this self-selection bias, which would distort the true impact of the "green bank," the sampling strategy employed strict geographic stratification combined with purely random second-stage sampling, ensuring that each producer profile, from smallholdings on marginal land to large hillside landowners, is fairly represented in the final sample. Furthermore, the choice of a multivariate regression model including a wide range of alternative incomes (food, horticultural and cash crops) makes it possible to control for unobserved heterogeneity of farms, isolating the specific effect of eucalyptus all other

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

things being equal, thus minimizing the specification bias by omission of relevant variables described by Gujarati (2004).

A second crucial bias concerns reporting and memory errors by respondents, particularly acute when farmers have to estimate cash flows spread over several months or sporadic timber sales linked to unforeseen life events. To mitigate this subjectivity bias and cognitive approximations, data collection broke with traditional paper questionnaires by deploying rigorously programmed digital forms using the KoboCollect tool, administered during direct, face-to-face interviews. The integration of logical input constraints (*skip logic* and consistency filters) within the software prevented the recording of outliers or contradictory values in real time. Furthermore, for sensitive variables of forestry and agricultural income, the administration of the questionnaire was entrusted to trained local enumerators, speaking exclusively in the local language, able to use units of measurement familiar to producers (such as loads of cords of wood or bags of charcoal) before their standardized conversion, a survey technique validated by ISABU to reduce social desirability bias or tax mistrust.

Finally, endogeneity bias, linked to potential reverse causality (wealthier households having greater access to fast-growing trees than poorer households), was rigorously taken into account when interpreting the coefficients. Cross-validation of primary data with secondary sources from the archives of the Ministry of Environment and Agriculture made it possible to contextualize productivity levels and validate average market prices. By scrupulously applying the free and informed consent protocol and guaranteeing absolute anonymity through strict coding of the KoboCollect files, the study eliminated the withholding of strategic economic information, thus neutralizing systematic response biases in accordance with the ethical and methodological principles set forth by Barrett (2011) and Saunders et al. (2019).

Robustness of statistical analyses

The final validation of a linear or logarithmic econometric model requires subjecting the residuals and estimates to a battery of rigorous diagnostic tests to ensure that the fundamental assumptions of ordinary least squares (OLS) are not violated, thus preserving the validity of the statistical inferences as prescribed by Wooldridge (2015) and Gujarati (2004). In this context, the robustness of our model of the determinants of world income was first tested against the risk of multicollinearity, a pathological phenomenon that artificially inflates the variances of the coefficients and renders Student's t-tests unstable in the presence of explanatory variables that are too strongly correlated with each other. The evaluation of the variance inflation factor (VIF) for all 13 income sources revealed particularly reassuring indicators: the

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

maximum value is borne by bean income (Inc_bean) with a score of 1.71, while the minimum is attributed to soybeans (Inc_soy) with 1.02. Displaying a very low average VIF of 1.33, well below the critical alert threshold of 5 or 10 unanimously accepted in contemporary econometric literature (Hair et al., 2010), these results irrefutably confirm the absence of harmful collinearity, proving that each agricultural sector provides its own information and is statistically orthogonal to the model.

The second major analytical challenge, ubiquitous in rural cross-sectional microeconomic data, concerns heteroscedasticity, that is, the inconsistency of the variance of error terms between households depending on farm size or initial wealth level. To formally test this hypothesis, the Cameron-Trivedi information test (IM test) and the classic Breusch-Pagan procedure were systematically performed. The overall IM test statistic, showing a high value of 183.34 with 116 degrees of freedom and a highly significant p-value of 0.0001, unambiguously rejected the null hypothesis of homoscedasticity at the 5% level. The decomposition of the test confirms that the heteroscedasticity structure is the sole source of this divergence (score of 184.61; $p = 0.0001$). The model would have exhibited biased variances if no corrective action had been taken. To neutralize this structural anomaly characteristic of diverse agricultural environments, the standard errors were corrected using the robust White/Huber-White method, ensuring that the estimated variances and Student's t-values (such as the exceptional score of 1519.09 obtained for eucalyptus wood) are fully valid and free from inference bias.

Finally, the robustness of the overall functional specification was corroborated by the structural stability of the calculated elasticities. The joint introduction of short-term (leaves sold for essential oils) and long-term (timber or charcoal) forest flow variables allows us to test the temporal consistency of the role of trees as a liquid savings asset. The near-perfect convergence between the strong overall Pearson correlation (98%) and the linear regression coefficients attests to the fine linearity of the econometric relationship, empirically validating the theoretical predictions of the rural forest economy formalized by Chambers & Leach (1989) and verified regionally by Mekonnen (2019).

Data collection

Data collection combines quantitative and qualitative approaches to fully capture the realities on the ground. Primary data collection was rigorously orchestrated using structured questionnaires digitized via the KoboCollect application. This tool secured the process through the automatic recording of interview data and the integration of logical input constraints that eliminated entry errors and outliers in real time.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

The questionnaire comprised a comprehensive set of quantitative and qualitative items designed to capture household socio-economic characteristics, allocated land areas, production costs, and income generated by the various agricultural value chains within the household.

To eliminate ambiguity and ensure the study's strict replicability, the assessment of financial flows relied on precise response formats, combining standardized numerical scales for short-term income (from eucalyptus leaves) and long-term income (from wood products such as charcoal, poles, and construction timber). Data regarding agricultural and forestry income were collected using an annual reference period, thereby accounting for the cumulative impact of seasonal variations specific to Burundi's cropping seasons.

Secondary data were extracted from the archives of the Ministry of Environment and Agriculture to contextualize the results.

Ethical authorization

The ethical approval and field access process was conducted in accordance with Burundian regulations to protect participants and ensure research integrity. Before the researchers were deployed, the research protocols were submitted to local administrative authorities, including the governors of Bujumbura and Burunga provinces, as well as the heads of the relevant communes and districts, to obtain mission mandates and formal authorizations for access to the communities. The principle of free, informed, and verbal consent was strictly adhered to: each household head received a clear explanation, in the local language, regarding the scientific objectives of the study, the absence of risks or direct financial compensation (the study was conducted without external funding), and the absolute guarantee of anonymity and confidentiality of their responses. No personally identifiable information was retained in the final KoboCollect database, and participants were free to discontinue the interview at any time.

Econometric Model

To measure the sector's contribution to resilience, we used the global income determinants model, demonstrating that each monetary unit from eucalyptus is fully added to total income.

Model specification:

$$Part_{others}incomes = \alpha + \left(\frac{Inc\_eucaly_t}{Inc\_hhold_t}\right) + \sum \varphi_j \, x_j + \varepsilon \quad (1)$$

Based on the general formulation of total income presented in equation (1), it is appropriate to isolate the specific contribution of forestry activities to refine our analysis. To this Indeed, the overall income of the rural household

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

is broken down into, on the one hand, the gains from the exploitation and sale of eucalyptus products and, on the other hand, all other agricultural revenues. By integrating this structural specification, we can develop our model in order to determine specifically the relative share of the eucalyptus sector in the household's overall income. This analytical approach leads us to formalize the relationship in the following way:

$$\begin{aligned} ln\_inchhold_i = \theta_0 + \ & \theta_1 ln(inc_{tea_i}) + \theta_2 ln(inc_{hortic_i}) + \theta_3 ln\left(inc_{soy_i}\right) \\ & + \theta_4 ln(inc_{eucaleav_i}) + \theta_5 ln\left(inc_{woodeucaly_i}\right) \\ & + \theta_6 ln(inc_{ban_i}) + \theta_7 ln(inc_{bean_i}) + \theta_8 ln(inc_{mz_i}) \\ & + \theta_9 ln\left(inc_{pea_i}\right) + \theta_{10} ln\left(inc_{pean_i}\right) + \theta_{11} ln\left(inc_{swpotat_i}\right) \\ & + \theta_{12} ln\left(inc_{pot_i}\right) + \theta_{13} ln(inc_{col_i}) + \varepsilon_i \end{aligned} \quad (2)$$

With:

- ln_inchhold $_i$: Logarithm of the total income of the rural household;
- ln(Inc_Tea $_i$) : Logarithm of income derived from tea;
- ln(Inc_hortic $_i$) : Logarithm of income derived from horticulture;
- ln(Inc_soy $_i$) : Logarithm of income derived from soy;
- ln(inc_eucaleavi) : Logarithm of income derived from the eucalyptus leaves;
- ln(inc_woodeucaly $_i$): Logarithm of income eucalyptus wood;
- ln(Inc_ban $_i$) : Logarithm of income derived from bananas;
- ln(Inc_bean $_i$) : Logarithm of income derived from beans;
  ln(Inc_mz $_i$) : Logarithm of income derived from corn;
- ln(Inc_pea $_i$) : Logarithm of income derived from peas;
- ln(Inc_pean $_i$) : Logarithm of income derived from peanuts;
- ln(Inc_swpotat $_i$) : Logarithm of income derived from the sweet potato;
- ln(Inc_pot $_i$) : Logarithm of income derived from the potato;
- ln(Inc_col $_i$) : Logarithm of income derived from colocasia;
- ε_i: Error term stochastic;
- θ_0 à θ_{13}: are elasticities.

The Results

Analysis of eucalyptus marketing methods

The eucalyptus sector is distinguished by the diversity of its commercial outlets, allowing for the full utilization of the resource. Sales are primarily organized around three main areas: the wood, used for both construction and energy; the leaves, sought after for the extraction of essential oils with medicinal and industrial properties; and finally, processed products,

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

such as distilled essences. This versatility offers producers strategic flexibility, allowing them to segment their offerings according to local market needs or export opportunities to higher value-added sectors.

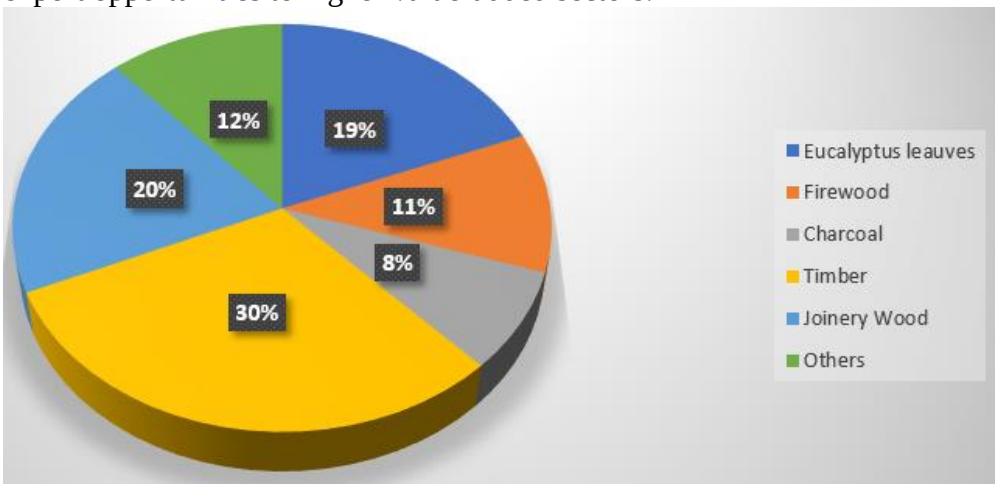

Figure 2: Forms of marketing for eucalyptus

The eucalyptus sector exhibits a notable diversification of commercial outlets. In addition to its primary role, a significant portion of production remains dedicated to energy needs and secondary uses. Firewood and charcoal together account for 19% of sales, illustrating the sector's continued role in domestic fuel supply. This crucial importance of the sector in crafts, industry, and energy demonstrates the great economic versatility of eucalyptus, capable of simultaneously meeting complex industrial requirements and essential subsistence needs for local populations.

Contribution of the eucalyptus sector to rural household incomes

The eucalyptus sector has emerged as a major socio-economic driver, sustainably transforming the daily lives of rural populations by generating stable and diversified income. This sector allows farmers to invest tangibly in their families' well-being. This dynamic translates into an increased capacity to educate children, access better quality healthcare, and improve family housing. Thus, beyond simply producing timber, eucalyptus acts as a catalyst for financial resilience, ensuring a smoother and more sustainable fulfillment of essential family needs (Smith et al., 2022).

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

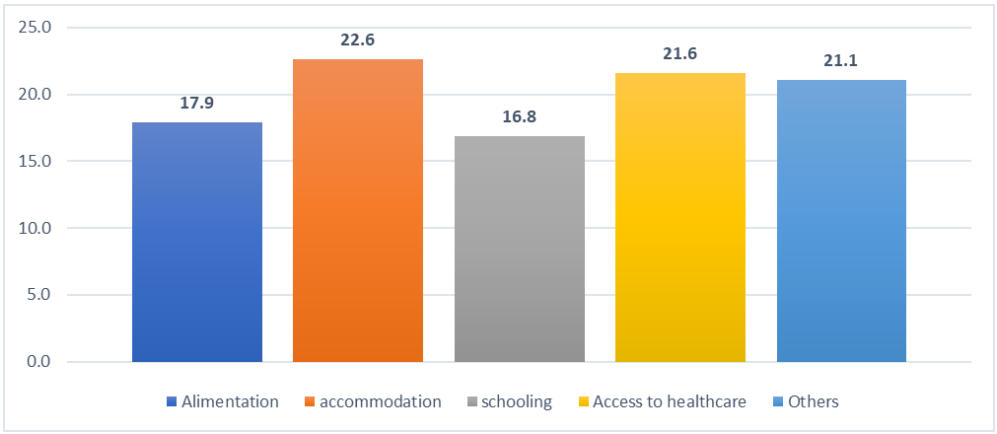

Figure 3: Type of level of improvement in living standards through the eucalyptus sector

Data analysis reveals a balanced distribution of benefits, with investment in sustainable infrastructure and human health playing a prominent role. With 23% of income allocated to housing and 22% to access to healthcare, it is clear that the eucalyptus sector provides fundamental stability for families. These figures reflect households' desire to transform a natural resource into tangible financial security.

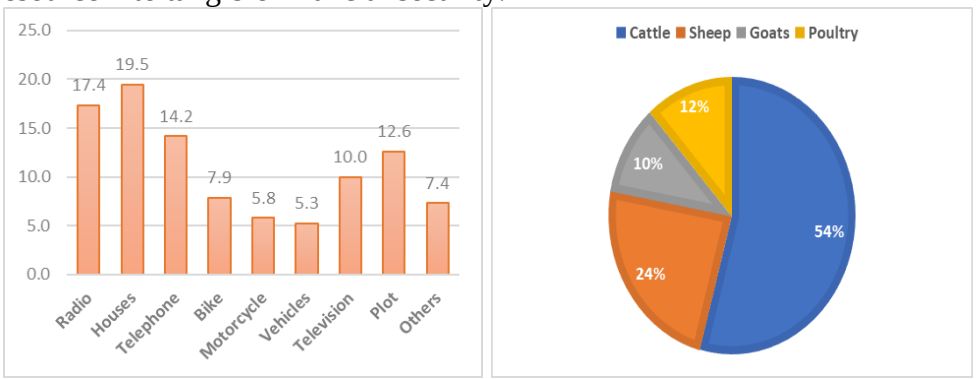

Figure 4: Percentage of beneficiaries of goods acquired following income from eucalyptus

These graphs illustrate how income from eucalyptus cultivation is reinvested by beneficiaries in the acquisition of various material goods and livestock. As regards equipment projects, the acquisition of housing (19.5%) and radios (17.4%) is clearly the top priority and representing the most frequent investments. This trend is complemented by the acquisition of information and communication technologies, with 14.2% of beneficiaries investing in telephones and 10% in televisions. Land investments and mobility are also significant, with the graph revealing that 12.6% of income is used to purchase land, while means of transport such as bicycles (7.9%), motorcycles (5.8%), and cars (5.3%) are also acquired, albeit more moderately.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Regarding capitalization in the form of livestock, there is a clear preference for large animals, with cattle alone accounting for more than half of livestock investments at 54%. The remaining resources allocated to livestock farming are distributed among sheep (24%), poultry (12 %), and goats (10%). Overall, these data demonstrate the crucial role of eucalyptus as a driver of local economic development, enabling households to secure their assets and sustainably improve their standard of living.

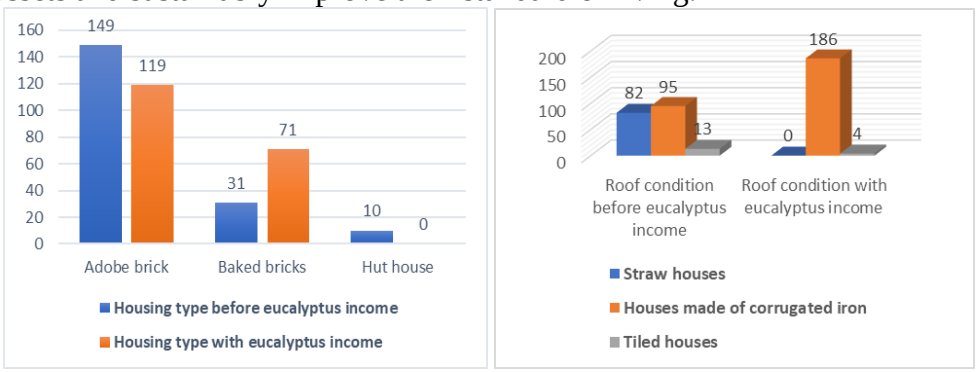

Figure 5: Impact of eucalyptus on the condition of farmers' houses

The findings reveal that income from the eucalyptus sector has significantly improved the housing conditions of the farmers. A major shift towards more sustainable materials is observed, marked by the complete disappearance of hut dwellings. This structural change is accompanied by a radical modernization of roofs, where straw bale houses have been entirely replaced. In short, eucalyptus farming acts as a genuine driver of socio-economic development by enabling families to access more decent and sustainable housing.

Table 2: Multicollinearity Test (VIF)

Variables	VIF	1/VIF
Inc_bean	1.71	0.585463
Inc_hortic	1.66	0.600876
Inc_eucaleav	1.56	0.640425
Inc_col	1.52	0.656025
Inc_mz	1.45	0.688291
Inc_pot	1.43	0.701063
Inc_pean	1.34	0.745412
Inc_pea	1.25	0.801755
Inc_ban	1.21	0.824038
Inc_swpotat	1.14	0.876367
Inc_woodeucaly	1.14	0.876597
Inc_Tea	1.06	0.941416
Inc_soy	1.02	0.978905
Mean VIF	1.33	

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Multicollinearity analysis table presents the results of the variance inflation factor (VIF) test for the different sources of agricultural income influencing the resilience of rural households in Burundi. All explanatory variables, including beans (Inc_bean) with the highest VIF of 1.71 and soybeans (Inc_soy) with the lowest at 1.02, show values well below the critical threshold of 10 generally accepted in the econometric literature. With a mean VIF of 1.33, these results guarantee the absence of severe multicollinearity between variables, meaning that each income source, whether eucalyptus (Inc_eucaleav, Inc_woodeucaly), horticulture, or cash crops such as coffee, provides independent and statistically robust information to the model. This structural stability allows us to reliably interpret the specific impact of the eucalyptus sector on overall income and the financial resilience trajectory of family farms without risk of estimation bias linked to too strong an internal correlation.

Table 3: Breusch -Pagan Heteroscedasticity Test

```
  chi2(116) = 183.34
Prob > chi2 = 0.0001

Cameron & Trivedi's decomposition of IM-test
```

Source	chi2	df	p
Heteroskedasticity	**184.61**	**116**	**0.0001**
Skewness	.	**14**	.
Kurtosis	.	**1**	.
Total	.	**131**	.

This table presents the results of the Cameron-Trivedi information test (IM test), a rigorous procedure used to validate the specification of an econometric model by examining the variance of the residuals. The overall test statistic shows a value of 183.34 with 116 degrees of freedom, associated with an extremely low p-value of 0.0001. Focusing on the decomposition, we observe that the component related to heteroscedasticity is the major source of this significance, with a score of 184.61 and an identical probability of 0.0001. This result necessitates the rejection of the null hypothesis of homoscedasticity at the 5% level, thus confirming that the variance of the errors is not constant within the sample of rural households. This instability is typical of rural microeconomic data, where income dispersion can vary significantly depending on farm size or access to resources. To ensure the reliability of statistical inferences and correct this bias, the use of robust standard errors is essential so that the significance tests of the coefficients are not invalidated by this error structure.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Table 4: Performance comparison test of the eucalyptus supply chain versus non-traditional supply chains

Variable	Obs	Mean	Std. dev.	Min	Max
ln_Inc_hhold	190	7.07e+07	3.15e+07	3.09e+07	2.25e+08
ln_Inc_Tea	190	966140	232452.5	70000	2065000
ln_Inc_hor~c	190	1432553	1723958	50000	1.67e+07
ln_Inc_soy	190	1935663	351045.2	72000	3720000
ln_Inc_euc~v	190	453663.2	883634.7	0	6260000
ln_Inc_woo~y	190	5.79e+07	3.05e+07	1.11e+07	2.05e+08
ln_Inc_ban	190	1482189	645216.8	240000	5400000
ln_Inc_bean	190	1088584	1639203	0	1.25e+07
ln_Inc_mz	190	984452.6	1750432	0	1.63e+07
ln_Inc_pea	190	1376842	1764341	0	1.05e+07
ln_Inc_pean	190	525305.3	553489.6	0	1680000
ln_Inc_swp~t	190	206373.7	562227.6	0	3840000
ln_Inc_pot	190	2033866	2695653	0	1.41e+07
ln_Inc_col	190	57489.47	113360	0	568000

The results show that average income from the eucalyptus sector contributes significantly to the total income of the rural households studied in Burundi, which averages 70,700,000 BIF per household (with a maximum of 225,000,000 BIF). A comparative performance analysis reveals that income derived from the sale of eucalyptus wood (ln_Inc_woodeucaly) reaches an average value of 57,900,000 BIF per household, far surpassing all other traditional agricultural income sources whether food crops or cash crops. Indeed, this major forestry source dramatically eclipses the average income from tea, which stagnates at just 966,140 BIF, as well as income from horticulture (1,432,553 BIF), bananas (1,482,189 BIF), potatoes (2,033,866 BIF), beans (1,088,584 BIF), maize (984,452.6 BIF), and colocasia (57,489.47 BIF). This indisputable numerical superiority is confirmed by the Pearson correlation test, which reveals a near-perfect positive association of 98% between eucalyptus wood sales and total income, whereas the tea sector shows a correlation close to zero (-0.002), proving that the tree constitutes the undisputed cornerstone of rural capital accumulation.

This massive financial contribution fully confirms the role of eucalyptus as a genuine "green bank" and a multidimensional safety net, capable of stabilizing growers' economic situations in the face of shocks and funding significant structural investments. Econometric analysis using the ordinary least squares method reinforces this dynamic of resilience: all other things being equal, a 1% increase in revenue from eucalyptus leaves (destined for essential oil distillation and averaging 453,663.2 BIF) generates a 1.03% rise in total income, while a 1% expansion in timber revenue leads to a net increase of nearly 1.00%, driven by an exceptional and highly significant Student’s t-statistic of 1,519.09. These results align perfectly with the empirical findings of Mekonnen et al. (2017) in Ethiopia and Mwangi et al.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

(2016) in Kenya, which demonstrated that such financial gains enable populations to escape chronic poverty. In Burundi, this universal lever for socio-economic transformation manifests in the prioritization of these monetary gains for sustainable housing improvements accounting for 23% of the budget and leading to the complete disappearance of traditional huts as well as for funding access to healthcare (22%), food security (18%), and education (17%).

Table 5: Linear Regression Model

Source	SS	df	MS	Number of obs =	190
				F(13, 176) >	99999.00
Model	1.8719e+17	13	1.4399e+16	Prob > F =	0.0000
Residual	1.1782e+13	176	6.6944e+10	R-squared =	0.9999
				Adj R-squared =	0.9999
Total	1.8720e+17	189	9.9046e+14	Root MSE =	2.6e+05

ln_Inc_hhold	Coefficient	Std. err.	t	P>|t|	[95% conf.	interval]
ln_Inc_Tea	1.100713	.0830991	13.25	0.000	.9367145	1.264712
ln_Inc_hortic	.9948466	.014078	70.67	0.000	.9670631	1.02263
ln_Inc_soy	.9854439	.0541756	18.19	0.000	.8785265	1.092361
ln_Inc_eucaleav	1.029023	.0265245	38.80	0.000	.9766758	1.08137
ln_Inc_woodeucaly	.9995876	.000658	1519.09	0.000	.998289	1.000886
ln_Inc_ban	1.03775	.0320064	32.42	0.000	.9745847	1.100916
ln_Inc_bean	.9886133	.0149807	65.99	0.000	.9590484	1.018178
ln_Inc_mz	.989167	.0129339	76.48	0.000	.9636414	1.014693
ln_Inc_pea	.9775487	.0117922	82.90	0.000	.9542764	1.000821
ln_Inc_pean	.989679	.0393762	25.13	0.000	.9119688	1.067389
ln_Inc_swpotat	1.000992	.0357577	27.99	0.000	.9304226	1.071561
ln_Inc_pot	1.006115	.0083257	120.84	0.000	.9896837	1.022546
ln_Inc_col	1.160177	.2046216	5.67	0.000	.7563491	1.564005
_cons	148955.2	153805.8	0.97	0.334	-154585.8	452496.3

The results of the linear regression model presented in the table above, reveal that the revenues derived from the exploitation of eucalyptus, whether it concerns the sale of leaves or eucalyptus wood, exert a positive and highly significant influence on the overall income of rural households in Burundi. This crucial contribution of the forestry sector's contribution to financial stabilisation confirmed that eucalyptus works as an asset for economic security in rural areas, capable of mitigating the vulnerability of family farms.

However, a 1% increase in income from eucalyptus leaves leads to an increase of approximately 1.03% in overall household income, while a 1% increase in income from eucalyptus wood results in an increase of nearly 1.00% in overall income. The contribution of eucalyptus wood is particularly noteworthy, with an exceptional t-statistic of 1519.09, confirming the massive, stable, and predominant impact of this forest resource on the financial resilience and living standards of family farms compared to other diversified crops.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Table 6: Correlation test of eucalyptus income with overall income

Variables	Correlation	Inc_cof	Inc_Tea	Inc_hortic	Inc_soy	Inc_eucaleav	Inc_woodeucaly	Inc_ban	Inc_bean	Inc_mz	Inc_pea	Inc_pean	Inc_swpotat	Inc_pot	Inc_col	Inc_hhold
Inc_Tea	Pearson correlation	0.071	11	-0.002	-0.039	-0.082	0.004	-0.057	0.009	-0.019	0.023	-0.114	-0.090	-0.083	-0.014	-0.002
Inc_hortic	Pearson correlation	-0,087	-0,002	11	0,059	,246**	0,080	-0,023	,602**	0,117	,169*	0,033	0,064	0,107	0,033	,197**
Inc_soy	Pearson correlation	-0,024	-0,039	0,059	11	0,056	0,026	0,034	0,030	0,051	0,045	0,002	-0,051	0,040	0,052	0,051
Inc_eucaleav	Pearson correlation	0,056	-0,082	,246**	0,056	11	-0,034	-,326**	,189**	0,117	0,102	-0,034	-0,013	,498**	0,122	0,066
Inc_woodeucaly	Pearson correlation	-0,055	0,004	0,080	0,026	-0,034	11	0,043	,189**	-0,035	-0,089	-0,106	-0,050	0,079	-,202**	,980**
Inc_ban	Pearson correlation	0,075	-0,057	-0,023	0,034	-,326**	0,043	11	-0,104	-,215**	-0,140	-0,082	-0,084	-,220**	-,164*	0,005
Inc_bean	Pearson correlation	-0,118	0,009	,602**	0,030	,189**	,189**	-0,104	11	,180*	,154*	0,086	0,133	0,094	0,104	,302**
Inc_mz	Pearson correlation	-0,124	-0,019	0,117	0,051	0,117	-0,035	-,215**	,180*	11	,344**	,322**	,301**	0,089	,411**	0,075
Inc_pea	Pearson correlation	-,169*	0,023	,169*	0,045	0,102	-0,089	-0,140	,154*	,344**	11	,227**	,155*	,150*	,266**	0,026
Inc_pean	Pearson correlation	-0,073	-0,114	0,033	0,002	-0,034	-0,106	-0,082	0,086	,322**	,227**	11	,148*	-0,005	,441**	-0,049
Inc_swpotat	Pearson correlation	-0,060	-0,090	0,064	-0,051	-0,013	-0,050	-0,084	0,133	,301**	,155*	,148*	11	0,000	,177*	0,005
Inc_pot	Pearson correlation	0,053	-0,083	0,107	0,040	,498**	0,079	-,220**	0,094	0,089	,150*	-0,005	0,000	11	,184*	,197**
Inc_col	Pearson correlation	-0,003	-0,014	0,033	0,052	0,122	-,202**	-,164*	0,104	,411**	,266**	,441**	,177*	,184*	11	-0,120
Inc_hhold	Pearson correlation	-0,067	-0,002	,197**	0,051	0,066	,980**	0,005	,302**	0,075	0,026	-0,049	0,005	,197**	-0,120	1,000

These results present a Pearson correlation matrix analyzing the relationships between various sources of agricultural income and total household income (REV men). The most striking observation is the extremely strong positive correlation between income from eucalyptus wood (Inc_woodeucaly) and total income, indicating that eucalyptus is the major economic pillar of this sample, almost single-handedly dictating the evolution of the overall living standards of the households concerned. Conversely, the other variable tea (Inc_Tea), shows correlation close to zero, suggesting that this crop only marginally influences the variability of total income in this specific context.

Discussion of results

The results of this study confirm that eucalyptus acts as a veritable "living capital," serving as a "green bank" for rural households in Burundi.

The near-perfect correlation of 0.980 between income from eucalyptus and total income demonstrates that this sector is the primary driver of farmers' financial stability.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

This economic dominance is explained by the tree's versatility, with markets driven by the construction sector (30% of sales) and carpentry (20%), while also ensuring full utilization through the sale of leaves and energy products.

On a social level, the sector's impact translates into a tangible and multidimensional improvement in living conditions, perfectly illustrating the theory of economic resilience. The income generated enables a major transition in housing, marked by the shift from traditional huts to baked brick houses, with priority given to housing (23%) and health (22%). Beyond material needs, eucalyptus finances social mobility through education (17%) and guarantees food security for households (18%). Although environmental challenges remain regarding water consumption and competition with food crops, eucalyptus is proving to be an essential safety net, transforming often marginal land into productive assets, thus protecting the human and physical capital of rural communities from economic shocks.

Conclusion

In conclusion, the eucalyptus sector has emerged as a fundamental pillar of economic resilience for rural households in Burundi, capable of financing essential investments such as education and housing improvements. The data reveals a major economic dependence on this resource, with a near-perfect correlation between income from eucalyptus and overall household income, confirming its role as a multidimensional safety net. Beyond the monetary aspect, the full exploitation of the sector, including timber for construction, charcoal for domestic energy, and essential oils for health, transforms a resource once perceived as a mere reforestation tool into a lever for socio-economic growth indispensable to the survival of family farms.

To maximize this impact while ensuring environmental sustainability, policymakers are advised to integrate eucalyptus into rural development strategies by encouraging the modernization of processing techniques, particularly through the adoption of more efficient carbonization kilns to reduce biomass waste. Simultaneously, rigorous dissemination of varietal selection and silvicultural techniques is necessary to limit negative externalities on food crops and soil water resource management. Finally, facilitating producers' access to structured markets, such as those for electricity poles and high-value essential oils, would help stabilize incomes and sustain the poverty escape trajectory of rural communities.

Conflict of Interest: The authors reported no conflict of interest.

Data Availability: All data are included in the content of the paper.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

Funding Statement: The authors did not obtain any funding for this research.

Declaration for Human Participants

This study was conducted in accordance with international ethical standards for research involving human subjects. The protocol received prior approval from the Director of Research and Innovation at the University of Burundi, as well as approval from the provincial governors and commune administrators in the study areas. All participants provided informed consent before taking part in the survey, and the absolute confidentiality of their personal information was ensured throughout the research process.

References:

1. Adger, WN (2000). Social and ecological resilience: keywords and pathways. Progress in Human Geography, 24(3), 347-366.
2. Bailis, R., Wang, Y., Potts, M., & Jacobson, M. (2015). Research on biomass sustainability and energy yield in East Africa. Energy for Sustainable Development, 27, 45-56.
3. Barrett, CB (2011). Risk management and diversification of activities in rural areas: strategies for economic resilience. Routledge.
4. Bigirimana, J., Nsabimana, D. and Ntakimazi, G. (2019). Growth capacity of eucalyptus on marginal lands in Burundi: Evaluation of silvicultural practices. Burundi Journal of Agricultural Sciences, 34(1), 12-25.
5. Chambers, R., & Conway, G. (1992). Sustainable rural livelihoods: practical concepts for the 21st century (IDS Working Paper No. 296). Institute for Development Studies.
6. Chambers, R., & Leach, M. (1989). Trees as savings and security for the rural poor. Global Development, 17(3), 329-342.
7. Chayanov, AV (1966). The Theory of Peasant Economy. Daniel Thorner, Basile Kerblay and REF Smith (Eds.), Homewood, IL: Richard D. Irwin.
8. Chirko, JP (2018). Precision sawing techniques and stabilization of eucalyptus fiber: processing local wood for the construction and furniture industries in Central Africa. Wood Technology and Science Series, Vol. 4.
9. Deaton, A. (1991). Savings and liquidity constraints. Econometrica, 59(5), 1221-1248.
10. Dercon, S. (2002). Income risk, coping strategies and safety nets. The World Bank Research Observer, 17(2), 141-166.
11. Doran, JC, & Wong, MW (2000). Varietal selection and wood density for carbonization: a study on Eucalyptus tereticornis and Eucalyptus camaldulensis. Biomass and Bioenergy, 19(5), 315-327.

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

12. Fafchamps, M. (2003). Rural poverty, risk and development. Edward Elgar Publishing.
13. Girard, P. (2002). Production of charcoal from eucalyptus: technical improvement of carbonization kilns and energy efficiency concepts. Unasylva, 53(211), 34-41.
14. Husch, B., Beers, T. W., & Kershaw, J. A., Jr. (2003). Forest mensuration (4th ed.). John Wiley & Sons.
15. Holling, CS (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4(1), 1-23.
16. Kammen, DM, and Lew, DJ (2005). Energy efficiency and modernization of the coal industry: options for biomass transformation in developing regions. Belfer Center for Science and International Affairs, Harvard University.
17. Konan, S. N., Oumar, Y. S., Lanciné, T., Kouamé, B. A., Mamyrbékova-Békro, J. A., & Békro, Y. (2022). Chemical composition and antioxidant activity of the essential oil of Chromolaena odorata harvested in the region of the Mountain District of Côte d'Ivoire. Journal of Applied Pharmaceutical Sciences and Research, 5(1), 21–25. https://doi.org/10.31069/japsr.v5i1.4.
18. Manirakiza, D. (2021). Market access analysis for electricity poles and charcoal in Burundi: constraints and opportunities for peripheral producers. CURDES, University of Burundi.
19. Markowitz, H. (1952). Portfolio selection. The Journal of Finance, 7(1), 77-91.
20. Mekonnen, Z. (2019). Correlation between private forests and investment in education: evidence from rural Ethiopia. Forest Policy and Economics, 102, 34-45.
21. Mekonnen, Z., Kassa, H., Lemenih, M., and Campbell, B. (2017). Impact of small-scale eucalyptus plantations on annual household income in Ethiopia. Small-scale Forestry, 16(2), 191-208.
22. Mwangi, J., Ndungu, S., and Gachanja, A. (2016). Role of commercial eucalyptus plantations in the fight against chronic poverty in Kenya. African Journal of Agricultural and Resource Economics, 11(3), 211-224.
23. Ndayambaje, MR, Heijman, WJ and Mohren, GM (2013). Integration of trees into farms and determinants of farming systems in Rwanda. Agroforestry Systems, 87(3), 587-601.
24. Ndayiragije, P. (2021). The invisible economy of wood: underestimation of the contribution of eucalyptus in public policies in Burundi. Economic policy note, University Research Centre for Economic and Social Development (CURDES).

ISSN: 1857-7881 (Print)
e-ISSN 1857-7431 (Online)

25. Ndikumana, J. (2022). Eucalyptus as a determinant of non-monetary savings among producers in the Mugamba natural region. Cahiers du CURDES, 18(2), 75-94.
26. Nduwamungu, J. (2011). Eucalyptus as a strategic resource against deforestation in Burundi: challenges of biomass energy supply. Technical report for the Ministry of Environment, Agriculture and Livestock, Bujumbura.
27. Nduwumwami, A. (2014). Dynamics of forestry and charcoal production in the Great Lakes region: transboundary sectors, actors and flows. Doctoral thesis, University of Liège / Gembloux Agro - Bio Tech.
28. Niyitanga, F. (2022). Trade-off between economic benefits and ecosystem services of eucalyptus plantations in the high-altitude areas of Burundi. ISABU (Institute of Agronomic Sciences of Burundi), Forestry Research Division.
29. Niyonzima, T. (2018). Mobilizing tree capital in the face of shocks: correlation between eucalyptus wood sales and major life events in Burundi. Burundian Rural Economic Review, 10(1), 45-62.
30. Nkurunziza, L. (2020). Analysis of land rents and net eucalyptus profitability according to market location (Bujumbura and Bururi).
31. Nzeyimana, I. (2020). Externality analysis: negative impacts of eucalyptus on adjacent crops and food security in the hills of Burundi. Research note, ISABU.
32. Poussard, M. (2021). The socio-ecological role of eucalyptus in the face of cold and erosion on the Congo-Nile Divide: Analysis of resilience at altitude. Karthala Editions.
33. Sadlon, AE, & Lamson, DW (2010). Immunomodulatory and antimicrobial effects of Eucalyptus globulus essential oil. Alternative Medicine Review, 15(1), 33-47.
34. Smith, KR, Jerrett, M., and Anderson, HR (2019). Impact of high-quality charcoal in optimized cooking stoves on indoor air pollution and respiratory health. The Lancet Planetary Health, 3(8), e345-e354.
35. Von Thünen, JH (1826). The Isolated State in Relation to Agriculture and Political Economy (Der Isoliere Staat in Beziehung auf Landwirtschaft und Nationalömie). English translation by Carla M. Wartenberg (1966), Pergamon Press.