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Welfare Effects and Gender Dimensions of the Licit and Illicit Biodiversity Economy

The Case of the Great Limpopo Transfrontier Conservation Area

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Abstract

The establishment of Transfrontier Conservation Areas reflects efforts by governments to promote biodiversity-based economic opportunities while curbing illicit environmental resource extraction. Our understanding of the ways in which the biodiversity economy contributes to the livelihoods of communities living near protected areas is, however, constrained by the limited availability of data on illicit environmental activities. Based on a mixed method approach combining descriptive statistics and regression analysis, this study presents a novel approach to bridging this gap, using the Great Limpopo Transfrontier Conservation Area as a case study. In this paper, our aim is to answer the following research questions: i) How does participation in the biodiversity economy (especially resource extraction) impact household welfare? ii) Does the impact differ across income distributions and according to gender? iii) Are there differences between the treatment effects of licit and illicit resource extraction?

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WELFARE EFFECTS AND GENDER DIMENSIONS OF THE LICIT AND ILLICIT BIODIVERSITY ECONOMY: THE CASE OF THE GREAT LIMPOPO TRANSFRONTIER CONSERVATION AREA

By

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ABSTRACT

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1. INTRODUCTION

The economy of Transfrontier Conservation Areas (TFCAs) in Southern Africa is rooted in income-generating activities connected to the sustainable use of natural resources, which collectively form the 'biodiversity economy'. Conceptually, the biodiversity economy encompasses a broad range of livelihood activities available to households, including both extractive uses of biological resources, such as harvesting for subsistence or commercial purposes, and non-extractive uses, such as participation in ecotourism and related value chain opportunities. For instance, South Africa's bioeconomy policy outlines the economic utilization of its biodiversity as a national development strategy – the Biodiversity Economy (Förster et al., 2021). More broadly, bioprospecting involves the systematic search, collection, or gathering of indigenous biological resources for research and development aimed at commercial or industrial exploitation (Crouch et al., 2008). This includes activities such as extracting compounds from these resources to develop products like pharmaceuticals, cosmetics, and other commercially valuable goods. Additionally, bioprospecting encompasses the utilization of traditional knowledge associated with these biological resources, recognizing the significant role that indigenous communities play in identifying and utilizing such resources.

Previous theoretical and empirical studies suggest that integrating local communities into the mainstream biodiversity economy can lift poor households out of poverty, reduce rural inequality, and strengthen resilience to shocks, provided that supportive policies are effectively implemented and translated into tangible actions on the ground. (Wu, 2009). However, the potential of the biodiversity economy to improve the welfare of rural and peri-urban communities living within TFCAs, particularly through its capacity to enhance household incomes, remains largely untapped (Ntuli and Muchapondwa, 2017). Our understanding of the ways in which the biodiversity economy contributes to the livelihoods of communities living near protected areas is hampered by the limited data available on illicit environmental activities. Many environmental income-generating activities around TFCAs are considered illegal under the current laws and policies, making it challenging to gather accurate information through standard household surveys (Munanura et al., 2018). Moreover, while the literature indicates that men and women both perceive and are involved in illicit environmental activities to different degrees, the gender dimensions of the biodiversity economy are often overlooked (but see Ntuli and Muchapondwa, 2018; Sundström et al., 2019). As a result, regional policies that are meant to protect biodiversity tend to be based on weak empirical evidence, and fervently endorsed without taking the needs and actual situation of local communities into consideration (Dawson et al., 2021).

Our study bridges these gaps by providing scientific evidence of the welfare impacts and gender dimensions of both the licit and illicit biodiversity economy through rigorous econometric techniques based on recent primary data. The data originates from the three countries whose borders the Great Limpopo Transfrontier Park and Conservation Area (GLTFCA) straddles - Mozambique, South Africa, and Zimbabwe (e.g., Siltanu et al., 2024; Ntuli & Muchapondwa, 2018; Fonta & Ayuk, 2013; Cavendish, 1999).

In addition to the long-standing inquiry into the factors driving environmental resource extraction and dependence in park-adjacent communities, a topic that has received considerable attention across developing regions, we address three key policy questions to assess the welfare impacts of participation in the biodiversity economy using the GLTFCA as a case study: i) How does participation in the biodiversity economy (especially resource extraction) impact household welfare? ii) Does the impact differ across income distributions and by gender? iii) Are the treatment effects of licit and illicit resource extraction different?

Our results reveal several structural factors driving illicit environmental resource extraction and dependence within the GLTFCA. Low education levels restrict employment opportunities, fostering reliance on natural resources, while weak institutional capacity, limited perceived benefits, and distrust in local leadership discourage participation in community-based management, leading to unsustainable practices. Human–wildlife conflict, especially with elephants and carnivores, imposes heavy economic burdens on households, with gender- and country-level disparities showing high poverty and inequality among female-headed households, particularly in South Africa. Although illicit activities sometimes provide higher returns for these households, they are more prevalent in Mozambique, while male-headed households report higher rates of illegal park entry and arrests. Regression results indicate that higher levels of education lower illicit extraction, non-farm income reduces dependence on environmental income but may increase illicit participation, and larger households rely more heavily on natural resources. These findings highlight the need for policy interventions that strengthen rural education, diversify income sources, and expand non-farm employment opportunities. Enhancing community-based institutions, improving conflict management, and promoting targeted social protection and asset-building programmes are essential to reduce poverty, inequality, and environmental crimes rooted in household vulnerability.

This study adds to the existing literature by focusing on the broader welfare impacts of the biodiversity economy. We address the existing knowledge gaps by designing a robust methodology for collecting primary data on the illicit biodiversity economy. The study provides policymakers and development practitioners with empirical evidence on the role of the biodiversity economy in the livelihoods of communities adjacent to protected areas in GLTFCA constituencies. In so doing, the study informs ongoing political and policy debates in sub-Saharan Africa focused on improving access to natural resources and the benefits of conservation, and exploring alternative livelihoods beyond tourism initiatives. The findings of this study will help policymakers interrogate their policies and strategies to ensure that local needs are met by creating an enabling environment, identifying synergies to promote biodiversity conservation, and detecting both weak signals of potential economic drivers[1] and emerging economic opportunities that can be supported through policy interventions to improve welfare, empower women, and reduce illegal resource extraction.

2. LITERATURE REVIEW

2.1 The role of TFCAs in the Biodiversity Economy

Current literature and existing national and regional strategies, such as the Southern African Development Community (SADC) Programme for TFCAs, recognize the growing importance of the biodiversity economy as a mechanism to enhance the livelihoods of poor rural communities. Sustainably managed natural ecosystems have the potential to generate both financial and social benefits, including income from tourism, employment in conservation-related sectors, and access to natural resources for subsistence and small-scale enterprise (Spenceley, 2005). The biodiversity economy framework extends traditional conservation models by integrating economic development with environmental stewardship, particularly in regions where rural populations are heavily dependent on nature-based livelihoods.

The SADC Programme for TFCAs specifically promotes the collaborative management of shared natural and cultural resources across international boundaries, aiming to balance conservation goals with socio-economic development (SADC, 1999). These cross-border landscapes are designed to facilitate ecological connectivity, ensure coordinated resource governance, and promote peace and cooperation between neighbouring countries. By linking protected areas and community lands, TFCAs

[1] An economic driver is defined as an income-generating activity pursued by a household, regardless of whether the activity is environment-based or not.

also seek to increase the participation of local communities in conservation efforts and broaden their access to the benefits generated by biodiversity. In this regard, TFCAs are positioned not only as conservation tools, but also as vehicles and platforms for regional economic integration, inclusive growth, and poverty reduction—objectives that are central to the SADC regional agenda.

However, not all reported benefits from natural resource-based initiatives, such as community-based natural resource management (CBNRM) or ecotourism, are accessible to local communities equitably. This is largely due to a combination of inadequate technical and managerial skills, limited access to natural resources, and exclusion from lucrative segments of the value chain. Structural barriers, including restrictive laws and institutional frameworks governing land and natural resource use, often limit local communities' ability to fully participate in and benefit from these initiatives (Ntuli et al., 2019; Ntuli et al., 2021). For instance, communities may be legally prohibited from directly exploiting wildlife or forests, or may lack secure land tenure, making it difficult for them to attract investment or manage resources sustainably (Roe et al., 2010). These constraints disproportionately affect marginalized groups, including women and youth, who already face systemic disadvantages in accessing economic opportunities and decision-making structures (Nelson & Agrawal, 2008). This limitation highlights the pressing need for inclusive and transformative policies that not only devolve rights over natural resources to local levels, but also build the capacity of communities to engage effectively in natural resource governance and associated value chains. Capacity-building initiatives, such as technical training, access to credit, and institutional support, are essential to bridge the gap between potential and realized benefits from conservation and development initiatives (Blaikie, 2006; Fabricius et al., 2004).

As a result of these inequities, there is growing pressure on regional and national governments to ensure that communities benefit tangibly from natural resources and are supported in developing alternative and diversified livelihoods. Such alternative livelihoods are particularly important given the inherent volatility of tourism markets, which are vulnerable to global shocks such as pandemics, political instability, or the impacts of climate change (Spenceley and Meyer, 2012). Livelihood diversification beyond tourism, including sustainable agriculture, non-timber forest product harvesting, or renewable energy initiatives, can boost household income, enhance food security, and bolster community resilience (Ashley & Carney, 1999; Wolmer, 2003). In sum, to achieve equitable and sustainable outcomes in natural resource management, addressing structural inequalities and supporting community capacity and rights are critical factors.

2.2 Licit and Illicit Resource Extraction and the Gender Dimension

The existing literature examining the contribution of environmental resources towards the welfare of both urban and rural households is vast (Ntuli and Muchapondwa 2017; Thondhlana and Muchapondwa 2014; Thondhlana et al. 2012; Fonta and Ayuki 2013; Fonta et al., 2011; Kamanga et al. 2009; Shacketon and Shackleton 2006; Fisher 2004; Cavendish 1999; 2000; Okumu et al. 2020). Several studies across different regions have affirmed the significant role that forest and environmental income perform in rural livelihoods, particularly with respect to poverty reduction and income diversification. Drawing on data from the Poverty and Environment Network (PEN), Angelsen et al. (2014) conducted one of the most extensive cross-country analyses in the literature, involving over 8,000 households in 24 countries. They found that forest products contribute, on average, about 22% of total household income in forest-dependent communities, the second-highest contributor after agriculture. The study also noted that poorer households tend to rely more heavily on forest resources, highlighting the safety net function that these resources provide. Similarly, Cavendish (2000), in a study of rural Zimbabwean households, demonstrated that income derived from environmental resources on communal lands constituted a significant portion of total household income among the poorest. He emphasized that this income reduces income inequality by acting as a “hidden subsidy” for low-income households.

Vedeld et al. (2007) conducted a meta-study covering 54 case studies and found that forest environmental income contributed roughly 22% of household income on average, with even higher shares among poorer households. The study highlights how forest dependence is shaped by factors such as household size, education, asset ownership, and proximity to forests. In Ethiopia, Mamo et al. (2007) observed that forest products played a critical role in supplementing household income and smoothing consumption during periods of economic stress. They also found that access to markets, education, and forest institutions influenced the level of income derived from forest-based activities. William (2013) found that forest-based income significantly contributes to poverty reduction and reduced income inequality in Cross River State, Nigeria. The study identified key factors influencing household participation and income from forest activities, including demographics, household characteristics, and proximity to forests. These findings are reinforced by Siltanu et al. (2024), whose meta-analysis confirms the broader relevance of similar determinants across different contexts. Based on these studies, Ntuli and Muchapondwa (2017) established that environmental income contributes between 15% and 50% of total household income. Although richer households consumed more environmental resources in total, the contribution of environmental income was found to be much greater for poor households than relatively wealthier families (Thondhlana and Muchapondwa 2014. Thondhlana et al. 2012; Fonta and Ayuki 2011). Furthermore, they found environmental income to be equalized with income inequality (Kamanga et al. 2009; Shacketon and Shackleton 2006; Fisher 2004; Cavendish 1999).

In many TFCAs across Africa, environmental resource extraction encompasses a range of licit and illicit activities, shaped by varying national laws, governance structures, and local socio-economic conditions (Cumming and Dzingirai, 2017; Munanura et al., 2018). Legal extraction activities, such as regulated logging, fishing, or tourism-related resource use like trophy hunting, are often tightly controlled and typically benefit individuals or entities with access to permits, capital, and networks (Fabricius et al., 2004; Coad et al., 2015). In contrast, illicit practices, including poaching, unregulated timber and firewood harvesting, and illegal mining, persist due to weak enforcement, limited livelihood alternatives, and porous borders within TFCAs (Ntuli et al., 2022). These illegal activities not only threaten biodiversity and ecosystem integrity, but also undermine conservation goals and the welfare of local communities, and contribute to conflict over resources. The coexistence of formal and informal economies in these areas reflects broader challenges of governance, economic inequality, and marginalization of local communities (Dahlberg and Söderberg, 2024).

The gender dimension of resource extraction in TFCAs is a critical yet often overlooked aspect. Women, who frequently rely on natural resources such as firewood, water, or non-timber forest products for household sustenance and income, face significant barriers in accessing legal extraction opportunities due to patriarchal land tenure systems, exclusion from decision-making bodies, and lack of capital or formal education (Ntuli and Muchapondwa, 2018). Consequently, women may become disproportionately involved in or affected by illicit resource use, either as participants in informal economies or as victims of enforcement crackdowns that ignore their social realities (Sundström et al., 2019). Gender-blind conservation policies risk reinforcing these inequities, thus it is essential that policymakers integrate gender-sensitive approaches into resource governance and benefit-sharing frameworks within TFCAs. In addition to legal reforms, addressing these issues also requires targeted support that enhances women's agency and participation in sustainable natural resource management.

3. RESEARCH METHODS

This section provides a brief overview of the sample size, data collection procedures, and the approach used for impact evaluation. For a more comprehensive account of the study's methodology, including detailed descriptions of the study site characteristics, sampling strategies employed, and the underlying mathematical foundations of the econometric techniques, readers are referred to the Annexes.

3.1 Sampling and data collection

This study collected primary data using household surveys in the GLTFCA. Secondary data was not available since most standard household surveys do not collect data on the use of environmental resources and illicit activities. Estimating the number of households in the GLTFCA is difficult due to its large size and the diversity of communities spread across three countries it encompasses. The Peace Parks Foundation reports that about 104,880 individuals benefit from programs in the area. Based on an average household size of 4 to 5 people, this figure suggests an estimated 26,561 households, although this only reflects program beneficiaries and not the entire population of the GLTFCA. The statistics provided in the report show that the target population in each country is 36.7% for Mozambique, 34.8% for South Africa, and 28.5% for Zimbabwe, which translate into 9,753, 9,237 and 7,571 respectively. The actual sample size from each country depends on the proportion of households in each constituency or part of the TFCA within each country. The initial total sample size targeted was 1,000 households, divided proportionally according to the number of beneficiary households in each constituency as shown in Table 1. However, some questionnaires were rejected due to incompleteness and inconsistences, which affected the sample balance across the three countries. To correct this problem, additional surveys were conducted in Mozambique and South Africa, resulting in additional questionnaire and an actual sample size 10.8% larger than expected. As a result, a total of 1,108 households were sampled in Mozambique (412), South Africa (374) and Zimbabwe (322), based on a combination of stratified sampling and simple random sampling techniques.

Table 1: Sample size and distribution by country

Country	Population		Targeted sample		Actual sample	
	Frequency	**Percent**	**Frequency**	*Percent*	*Frequency*	*Percent*
Mozambique	9753	36.7	375	37.5	412	37.18
South Africa	9237	34.8	335	33.5	374	33.75
Zimbabwe	7571	28.5	290	29.0	322	29.06
Total	**26,000**	**100.0**	**1000**	**100.00**	**1108**	**100.00**

Source: Household survey (2022/23)

The study complemented the household survey data with qualitative methods, including focus group discussions (FGDs) and key informant interviews (KIIs). Twenty trained enumerators were employed to conduct the survey, receiving payment per completed questionnaire at a rate equivalent to the shadow wage of US$5 per day. Rigorous control over data quality was maintained by checking questionnaires daily for consistency and completeness. The survey instrument collected information on demographics, socio-economic characteristics, agricultural activities, income sources (e.g., employment, remittances, and grants), environmental resource use, wildlife benefits, and tourism. Importantly, questions about economic activities did not distinguish between legal and illegal practices, allowing respondents to disclose illicit livelihood activities without fear of repercussions. This approach was particularly useful for capturing widespread subsistence hunting of species like kudu and impala, which are treated leniently by authorities and openly discussed by households (Ntuli et al., 2021).

To evaluate the impact of the biodiversity economy on household welfare, the study calculated standard income (excluding environmental sources), environmental income (from both direct use and cash values), and total income. Environmental income was valued using reported and market prices, and its contribution was measured as a share of total income, reflecting levels of environmental dependence. This approach follows Cavendish (1999) and allows for the estimation of the biodiversity economy's total value by extrapolating average environmental income onto the broader GLTFCA population. Income distributions were compared across groups (e.g., by gender or income quintiles), and poverty was assessed using the Foster-Greer-Thorbecke (FGT) indices, including the headcount ratio, poverty gap, and Gini coefficient (Ntuli & Muchapondwa, 2017). The study also employed average and quantile treatment effects (Okumu & Muchapondwa, 2020) and quantile regression to assess household mobility across income strata.

To explore the drivers of participation in the biodiversity economy and environmental dependence, the study used multivariate regression models, incorporating gender as both a variable and a lens of analysis. Qualitative methods, such as FGDs and expert interviews, were used to further examine gender dynamics, especially cultural influences. Recognizing potential endogeneity issues like reverse causality and omitted variable bias, the study applied instrumental variable (IV) estimation using instruments such as distance to law enforcement offices or the socio-economic characteristics of neighbours (Okumu & Muchapondwa, 2020; Ntuli & Muchapondwa, 2018). When valid instruments are unavailable, heteroskedasticity-based IV methods (Lewbel, 2012) were employed to improve estimation efficiency and address bias, an approach increasingly adopted in models with unobserved common factors (Banerjee et al., 2017; Mishra & Smyth, 2015).

A comprehensive livelihood and welfare analysis of park-adjacent communities must account for human-wildlife conflict and the resulting damage, as these occurrences represent significant external costs of living near protected areas. To balance the trade-off between wildlife conservation and livelihoods, communities in the region resort to poaching, either as retaliation for the costs incurred or in protest against historical injustices (Ntuli et al., 2021; Hubschle, 2017). Such conflicts can undermine livelihoods and contribute, both directly and indirectly, to negative conservation outcomes like poaching and illegal wildlife trafficking (Baru et al., 2013).

3.2 Variables

The analysis uses a wide range of demographic, socioeconomic, institutional, and human–wildlife conflict variables to understand household livelihoods and their interaction with the biodiversity economy. The survey collected data on household characteristics, income sources, expenditures, and institutional participation, as well as environmental income from both licit and illicit activities. It also included information on wildlife governance, livelihood shocks, and human–wildlife conflict to assess how these factors influence household welfare and resilience. Table 2 provides a description of the variables used in the econometric analysis and the expected sign.

Variable	Description	Sign
Illicit participation	Participation in illicit activities (dependent variables)	
Environmental income	Environmental dependence (dependent variables)	
Country	1 = Mozambique, 2 = South Africa, 3 = Zimbabwe	±
Gender	Gender of the household head (Female = 0, Male = 1)	±
Age	Age of the household head (continuous)	+
Schooling	No. of years in school of the household head (continuous)	-
Employment	Employment status of the household head (n=0, 1=y)	-
Household size	Household size (continuous)	+
No. of rooms	Number of rooms (continuous)	+
Local CPR institutions	Participation in local CPR institutions (n=0, 1=y)	-
State-based institutions	Interaction with state-based institutions (n=0, 1=y)	-
Non-farm income	Non-farm income (continuous)	-
Wildlife crop damage	Wildlife crop damage (n=0, 1=y)	+
Hhld ran out of food	Household ran out of food in the past 12 months (n=0, 1=y)	+

3.3 Impact analysis

The study framework is based on the occupational choice model defined by Roy (1951), where households choose whether to engage in the biodiversity economy legally or illegally based on the option that maximizes their utility. Illegal activities in the GLTFCA context include unauthorized harvesting from protected areas, illegal tree cutting, and poaching. Data collected from households include records of arrests or involvement in illegal activities. Households are categorized based on their participation (or non-participation) in the legal and illegal biodiversity economy. This categorization serves as the treatment variable, by which the impacts on household welfare measured by income, poverty and inequality are assessed. The analysis assumes that households will participate in the biodiversity economy if they expect benefits, making treatment assignment non-random. Utility (V_{ij}) is defined for each household $i = 1 \ldots N$ based on whether they participate or not, with the treatment outcome ($D_i = 1$) determined by whether the utility from participation (V_{i1}) exceeds the utility from non-participation (V_{i0}). The potential outcome variable (Y_{ij}) is per capita income, with differences between Y_{i1} and Y_{i0} used to measure the impact on household welfare. This differential impact is measured primarily in terms of per capita income, analyzed at the household level.

According to Rubin (1973), program impact is defined as the difference between observed and counterfactual outcomes, which cannot be directly observed for the same individual. Since participation in the biodiversity economy is non-random, the study adopts a quasi-experimental approach to identify its true impact. Differences in income or expenditure between participants and non-participants may result from unobserved factors, thus it is essential to control for these factors to avoid biased conclusions. The biodiversity economy involves two selection levels: eligibility through natural resource management committees and voluntary participation. Whereas poorer households may be eligible to participate but lack the resources, wealthier or more educated households may opt out due to higher opportunity costs. Unobservable factors like household income or access to information also influence participation decisions, making it critical to account for selection bias when evaluating outcomes.

To assess the welfare effects of participation, the study employs several econometric techniques. Propensity Score Matching (PSM) and Ordinary Least Squares (OLS) are used to estimate average treatment effects on per capita monthly income or expenditure. However, these methods may produce biased results if unobserved factors affect participation, necessitating the use of control function approaches or Instrumental Variable (IV) methods (Wooldridge, 2010). Since both PSM and OLS estimate mean effects only, the study also applies the Quantile Treatment Effect (QTE) model to analyse how participation impacts different segments of the income distribution, helping to address endogeneity concerns and evaluate the broader sustainability of the biodiversity economy initiative. The mathematics behind the models and analysis is provided in appendix B. For a detailed explanation of the methods used in this paper, we refer the reader to the following articles: Okumu and Muchapondwa (2020), Banerjee et al., (2017), Mishra and Smyth (2015) and Ntuli and Muchapondwa (2018).

Key diagnostic tests and robustness checks were also conducted. The significant mean differences for some covariates suggest that the observed outcomes for non-participants may not provide a good counterfactual for participants. This implies that estimations assuming random treatment assignment would produce biased results that call for an alternative impact evaluation approach. Our results could be sensitive to the inclusion of additional covariates. Moreover, despite sensitivity to the choice of counterfactual, the direction and size of the program impacts may not be particularly sensitive to the inclusion of a broader set of covariates.

5. DATA DESCRIPTION

The data description section is organized into three subsections. It begins with descriptive statistics that profile the household economy in the GLTFCA across several dimensions to provide insight into household dynamics. Next, we examine participation in licit activities in the formal GLTFCA biodiversity economy and the benefits derived therefrom. Finally, a comprehensive assessment of the level of participation in local common pool resource institutions and illicit environmental extraction is provided.

5.1 Descriptive statistics of the household economy in the GLTFCA

The statistics in Table 3 show the demographic characteristics of the sampled households in the GLTFCA. The average age of household heads is 48.8 years with a standard deviation of 14.6 years. Most household heads in the GLTFCA have either primary (40%) or no education (31%) while fewer heads have secondary (21%), advanced level (18%) or tertiary (3%) education. The mean number of years in school is 5.3 with a standard deviation of 4.8 years, which is still at the primary level of education, highlighting very low levels of human capital development in the GLTFCA. The results demonstrate very high levels of unemployment (66%) in the GLTCA among household heads, with only 20% being self-employed and 15% formally employed.

Table 3: Household demographics

Variable		Obs.	Mean	Std. Dev	Min	Max
Age		1,108	48.79	14.64	17	94
Gender		1,108	0.61	0.49	0	1
Education	None	1,108	0.31	0.46	0	1
	Primary	1,108	0.40	0.49	0	1
	Secondary	1,108	0.21	0.41	0	1
	Matric	1,108	0.05	0.21	0	1
	Tertiary	1,108	0.03	0.18	0	1
No. of years in school		1,108	5.30	4.78	0	19
Employment	Unemployed	1,108	0.66	0.48	0	1
	Self-employed	1,108	0.20	0.40	0	1
	Employed	1,108	0.15	0.35	0	1
Household size		1,108	6.10	2.80	1	22

Source: Household survey (2022/23)

Table 4 shows the mean asset values per category and their contribution to total household asset value. The mean total asset value (in South African Rand) is R35,536.29, with a standard deviation of R57,095.00 ranging from R0.00 to R568,480.00. Farm infrastructure contributes 38% of the total asset value with a mean of R13,541.34 and a standard deviation of R27,768.94. The next-largest contributor to total asset value is farm transportation, which contributes 26% with a mean of R9,194.32 and a standard deviation of R32,418.95. The high standard deviation in mean asset values indicates significant inequality in asset ownership, with variation also evident across asset categories. Ownership of modern technology contributes 17%, while conventional household assets contribute 16%. Farm implements contribute only 3% to total asset value, which is concerning given that most rural economies depend on agro-based activities.

Table 4: Value of household assets, technology, machinery and infrastructure

Variable	Obs.	Mean	Std. dev.	Min	Max	% Contribution
Household assets	1,108	5670.21	10254.66	0	136180	15.96
Modern technology	1,108	6090.72	10258.84	0	117900	17.14
Farm implements	1,108	1039.69	1922.89	0	28100	2.93
Farm transportation	1,108	9194.32	32418.95	0	290600	25.87
Farm infrastructure	1,108	13541.34	27768.94	0	241500	38.11
Total asset value	1,108	35536.29	57095.41	0	568480	100.0

Source: Household survey (2022/23)

Table A1 in the annex shows asset ownership across a list of 45 assets that are commonly reported in household surveys, along with the asset values. These assets are categorised into five groups, namely conventional household assets, modern technology, farm machinery, farm transport, and farm infrastructure. The most common household assets are chairs (88%), beds (72%), tables (57%), and wood stoves (48%). Ownership of modern technology is dominated by cell phones (85%), refrigerators

(32%), television sets (29%), solar panels (29%), satellite dishes (17%), and solar batteries (16%). The most common farm implements or machinery owned are hand hoes (78%), shovels (44%), axes (44%), machetes (39%), ploughs (26%) and picks (24%). The most common items under farm transport are wheelbarrows (34%), bicycles (17%), and cars (7%). When it comes to farm infrastructure, most households indicated that they own a house (62%), followed by a goat house (27%), cattle kraal (24%), fowl run (16%), and granary (10%).

Table 5 summarises household expenditure based on the standard household budget divided into five categories according to 28 expenditure items and including environmental resource expenditure. The last two columns show the contribution of each expenditure item without and with environmental resource expenditure. The results show that the total household expenditure is R1,483.37 per month, which translates to R17,800.44 per annum, thus almost exhausting the total household income of R20,943.14. The largest expenditure items are grocery items, which account for 83.1% of the total expenditure budget, with basic food, main food, and non-food grocery items contributing 30.64%, 36.18% and 16.28%, respectively. When environmental resource expenditure is included, it constitutes a significant portion, accounting for 27.0% of total household expenditure. These spending patterns suggest a high level of environmental dependence among households in the GLTFCA, both through direct resource extraction and indirect purchases of environmental goods.

Table 5: Household expenditure in the past 12 months

Variable	**Obs.**	**Mean**	**Std. dev.**	**Min**	**Max**	**% Contribution**	
						Without	**With**
Standard expenditure items							
Basic food grocery items	1,108	454.55	439.92	0	3250	30.64	22.36
Main food grocery items	1,108	536.65	744.41	0	16200	36.18	26.40
Non-food grocery items	1,108	241.49	546.82	0	10120	16.28	11.89
Household assets	1,108	107.59	2046.81	0	50000	7.25	5.29
Services and bills	1,108	128.31	511.97	0	8800	8.65	6.31
Subtotal expenditure	**1,108**	**1483.37**	**2623.29**	**0**	**55939**	**100.00**	
Environmental resource expenditure							
Environment resource items	1,108	549.63	971.80	0	5960		27.04
Grand total expenditure	**1,108**	**2032.99**	**2893.99**	**0**	**58539**		**100.00**

Source: Household survey (2022/23)

Table 6 provides a summary of household income per annum by income sources, categorised into non-farm, crop, livestock and environmental income. Non-farm income is the most dominant income source, accounting for 56.35% of the total household income, followed by environmental income, which accounts for 25.67%. As expected, the contribution made by environmental income is quite substantial, demonstrating very high levels of environmental dependence. That makes this income source very interesting from an academic, development, and policy perspective, given the nature of the resource system and the fact that activities can be either legal or illegal. The smallest contribution comes from crop income, which accounts for 5.40% of the total household income, while livestock contributes 12.58% in total. The contribution of processed environmental resources (10.78%) and wildlife-based enterprises (5.57%) are higher than income from processed crops (2.89%) and livestock products income (2.44%).

Table 6: Household income per annum by source

Income source	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**	**% Contr.**
Non-farm income	1,108	17040.94	28439.57	1500	680040	56.35
Crop income	251	1633.64	1544.79	50	9250	5.40
Processed crop income	115	874.17	694.25	80	3500	2.89

Livestock income	428	3803.18	5315.60	50	30857	12.58
Processed livestock products	188	736.69	817.20	30	3000	2.44
Environmental income	503	7761.19	6376.99	40	38271	25.67
Processed resources	382	3259.45	3290.89	20	23845	10.78
Wildlife-based enterprises	87	1683.45	4029.10	50	36250	5.57
Total household income	1,108	22312.74	29445.89	1500	691270	100.00

Source: Household survey (2022/23)

Tables A2–A7 show the disaggregated statistics and ranking for these income sources. Households in South Africa earn more income in total, followed by households in the Zimbabwean constituency of the GLTFCA. As expected, the contribution of non-farm income is significantly higher for households in South Africa, followed by households in Zimbabwe, whereas the contribution of crop income, livestock income, and environmental income is higher for households in Mozambique, who generate more income from livestock and environmental resources. In the poultry and livestock category, the most popular enterprises are chicken (44.1%), goats (42.8%) and cattle (38.3%). Of the 12 livestock enterprises identified in the GLTFCA, the most lucrative categories are draught power (R8,798.23), cattle (R7,238.82), sheep (R3,158.33), pig (R2,325.00) and goat (R1,526.03) production.

Although maize is the dominant crop, cultivated by 60.8% of households, those who grow cash crops earn more income from beans (R1,570.34), groundnuts (R1,454.61), sunflower (R1,411.00), and roundnuts (R1,400.00) compared to maize (R1,087.24). The contribution of crop income is approximately the same for households in South Africa and Zimbabwe, while the contribution from livestock and environmental income categories is slightly higher in Zimbabwe than in South Africa. In general, male-headed households earn more income in total than female-headed households across all income categories. Generally, male-headed households earn more environmental income in total than female-headed households.

Generally, local communities in the GLTFCA obtain higher prices for processed products sold to distant markets, particularly during the off-season. Among these products, processed environmental resources generate the highest average income (R3,259.45), followed by processed crops (R874.17) and processed livestock products (R736.69). The income from processed livestock products is relatively low compared to the sale of live animals, while the income from processed crops and environmental resources is about half that of unprocessed commodities. Data presented in Tables A8–A10 (for processed crop and livestock products) and Table A12 (for processed environmental resources) indicate that households engage in processing a wide range of resources.

Table 7 shows the statistics of human-wildlife conflict in the GLTFCA. The survey data show that 41% of households experienced crop damage in the past 12 months, 20% reported livestock predation, and 12% reported human injuries, with elephants (71%) being cited as the primary threat to crop-based agriculture. Perceptions of conflict trends over the past year indicate that 47% believe incidents have increased, 25% see no change, and 28% report a decrease. Wildlife-related damage is substantial in the GLTFCA. On average, households report 1.5 hectares of crop damage (SD = 1.3, range: 0.1–6 ha), which aligns with the ownership of large plots typical in arid rural areas. With respect to livestock, households lost an average of 2.4 animals (SD = 1.6, range: 1–8) to predators such as lions, hyenas, leopards, and crocodiles. Among those respondents who did not report damages in the previous season, the average time since their last incident was 6.3 years for crops and 7.3 years for livestock.

The average value of crop losses was R2,453.75 (SD = R2,165.23, range: R180–R10,000), while livestock losses averaged R5,220.54 (SD = R5,739.65, range: R300–R27,000). Damage severity is influenced by proximity to park boundaries and farm size and varied widely, ranging from minor losses to the destruction of entire harvests or herds. Only 2% of households received any form of compensation, averaging R3,859.39 per incident. These households were primarily in South Africa, and the compensation excluded crop damages. Of those compensated, 38% expressed satisfaction with the amount received.

Table 7: Human-wildlife conflict

Variables	Obs.	Mean	Std. Dev.	Min	Max
Human wildlife conflict					
Household suffered crop damages	1,108	0.41	0.49	0	1
Household suffered livestock predation	1,108	0.20	0.40	0	1
Household suffered human injuries	1,108	0.12	0.13	0	1
Dynamics of human-wildlife conflict					
Decreased	1,108	0.28	0.45	0	1
Remained the same	1,108	0.25	0.43	0	1
Increased	1,108	0.47	0.50	0	1
Extent of wildlife damages					
Hectares of crops damaged	449	1.51	1.31	0.1	6
No. of livestock killed	223	2.42	1.56	1	8
No. of years since last crop damages	213	6.31	6.81	0	33
No. of years since last livestock predation	220	7.34	6.98	0	48
Value of damages					
Value of crop damages	446	2452.75	2165.23	180	10000
Value of livestock killed	206	5220.54	5739.65	300	27000
Total value of damages	520	4171.84	4930.06	100	35000
Compensation for wildlife damages					
% Household received compensation	1,108	0.02	0.15	0	1
% Household expressing satisfaction	24	0.38	0.49	0	1
Value of compensation	16	3859.38	2848.93	500	10000

Source: Household survey (2022/23)

Table 8 presents the various typologies of wild animals responsible for causing damage within the GLTFCA according to the survey results. During the survey, 17 species in total were identified in the GLTGCA as damage-causing animals, including some unspecified species. A diversity of species feature in the top 10 list of damage-causing animals, i.e., herbivores (3%), carnivores (4%), primates (2%) and birds (2%). Among all the damage-causing animals in the GLTFCA, the African elephant is the most frequently identified species, accounting for 71% of reported incidents. Following the African elephant, the hyena (29%), baboon (26%), buffalo (24%), lion (22%), leopard (15%), and crocodile (12%) are the next most frequently reported damage-causing species in the GLTFCA. While buffaloes are often regarded as dangerous due to their involvement in human fatalities in the region, the existing literature identifies the hippopotamus as the species responsible for the highest number of human deaths. Among the animals in the common carnivore category, the hyena is the most notorious species, followed by the lion, leopard and crocodile. Among the less frequently reported damage-causing species in the GLTFCA, birds (6%), eagles (4%), monkeys (4%), snakes (3%), and wild pigs (3%) were identified by few households as having a negative impact on livelihoods and potentially on human life. Additionally, a group of emerging species, including some unspecified wildlife species (2%), wild dogs (2%), jackals (1%), and zebra (0.004%) are beginning to draw attention.

Table 8: Damage-causing animals

Damage-causing animals	Obs.	Mean	Std.	Min	Max	Rank
Common herbivores/omnivores						
Elephant	1,108	0.71	0.45	0	1	1
Buffalo	1,108	0.24	0.43	0	1	4
Hippo	1,108	0.08	0.29	0	1	8
Baboon	1,108	0.26	0.44	0	1	3
Common carnivore species						
Lion	1,108	0.22	0.42	0	1	5
Hyena	1,108	0.29	0.45	0	1	2
Leopard	1,108	0.15	0.36	0	1	6
Crocodile	1,108	0.12	0.32	0	1	7
Less common species						
Bird	1,108	0.06	0.25	0	1	9
Eagle	1,108	0.04	0.20	0	1	10
Monkey	1,108	0.04	0.20	0	1	10
Snake	1,108	0.03	0.17	0	1	12
Wild pig	1,108	0.03	0.16	0	1	12
Emerging species						
Wild dog	1,108	0.02	0.14	0	1	14
Jackal	1,108	0.01	0.07	0	1	16
Zebra	1,108	0.004	0.06	0	1	17
Unspecified	1,108	0.02	0.02	0	1	14

Source: Household survey (2022/23)

5.2 Licit Extraction Behaviours in the GLTFCA Wildlife Economy

Table 9 summarises the nature of wildlife benefits in the GLTFCA. Despite relatively strong stakeholder engagement at a higher level in wildlife-related matters, our findings suggest that the overall outcomes of community and household participation in the wildlife economy remain suboptimal in the GLTFCA. Only 5% of households report having at least one member formally employed in the wildlife sector, and just 11% of households participate in wildlife-based enterprises. These figures highlight a significant underutilization of opportunities by local communities within the legal wildlife economy. Wildlife-based enterprises encompass both consumptive and non-consumptive uses of wildlife, including trophy hunting, sales of game meat rations, employment as tour guides, and involvement in activities such as wildlife photography, filming, and tourist accommodation services. However, participation in these enterprises remains limited. Only 1% of households own registered wildlife-related businesses, 3% are employed by others in this sector, and 10% operate informal or unregistered businesses. In terms of direct benefits derived from these activities, the returns are similarly modest. Only 2% of households reported receiving benefits from trophy hunting, 11% from game meat rations, and 3% from other wildlife-related enterprises. These statistics underscore the need for more inclusive and equitable access to opportunities in the wildlife economy, capacity-building initiatives, and supportive policies that enable greater community benefit from conservation-linked economic activities.

When quantified in monetary terms, the average total household benefit derived from wildlife-related activities in the GLTFCA is R3,040.48 per annum, with a standard deviation of R4,683.44. These benefits range widely from as little as R50.00 to as much as R36,250.00 annually, indicating substantial variability in household earnings from legal wildlife sources. A closer breakdown of income sources reveals further disparities. The mean income from formal employment in the wildlife sector is R4,728.98 per annum, with a standard deviation of R3,562.70 and a range of R300.00 to R25,000.00. Income specifically from game meat rations averages R1,449.80 annually with considerable variation (standard deviation of R2,107.75), ranging from R100.00 to R9,000.00. Income generated from participation in wildlife-based enterprises, such as informal tourism, trophy hunting, guiding, photography, or small-scale trade, averages R1,683.43 per household, with a broader standard deviation of R4,029.44 and a maximum reported value of R36,250.00. These figures illustrate a generally low level of economic return from wildlife activities among most households, and highlight the limited extent to which communities are currently able to capitalize on conservation-linked income opportunities. The relatively small average benefits, combined with the high variability and low participation rates, suggest a lack of structured engagement or investment in wildlife conservation as a viable and sustainable source of livelihood. This underscores the need for more targeted interventions, capacity development, and access to markets to unlock the full potential of the wildlife economy for local communities.

Table 9: Legal wildlife benefits to the individual and the community

Income source	Obs.	Mean	Std.	Min	Max
Indication of benefits at the household level					
Formal employment (%)	1,108	0.05	0.22	0	1
Participation in wildlife-based enterprises	73	0.11	0.45	0	1
Ownership of a formal enterprise	8	0.01	0.10	0	1
Work for others	27	0.03	0.18	0	1
Informal individual business	56	0.10	0.42	0	1
Nature of other benefits					
Trophy hunting income	1,108	0.02	0.13	0	1
Game meat rations	1,108	0.11	0.31	0	1
Other[†]	1,108	0.03	0.15	0	1
Employment income	54	4728.98	3562.70	300	25000
Value of other benefits, e.g. game meat	50	1449.80	2107.75	100	9000
Income from wildlife-based enterprises	87	1683.45	4029.10	50	36250
Total wildlife benefits	156	3040.48	4682.44	50	36250
Indication of benefits at the community level					
Benefit from TFCAs (%)	1,108	0.30	0.45	0	1
Benefit from conservation & tourism (%)	1,108	0.47	0.50	0	1
Benefit from TFCA rules (%)	1,108	0.20	0.40	0	1
Benefit from wildlife income (%)	1,108	0.15	0.36	0	1
Total value of community benefits	**119**	**14363.41**	**14870.41**	**1000.00**	**80,000.00**

Source: Household survey (2022/23)

[†] Loan, research, education, medical aid, tips, donations, seed, e.tc.

At the community level, our findings reveal that participation in GLTFCA activities stands at just 30%, a statistic that is considerably lower than expected, especially given the extensive advocacy and promotional efforts by non-governmental organizations (NGOs) and regional bodies championing TFCAs across Africa. Despite the widespread discourse around community involvement and benefit-sharing, actual engagement remains limited. In terms of perceived benefits, 47% of households reported gaining some form of advantage from wildlife conservation and tourism initiatives. However, only 20% indicated that they benefit specifically from TFCA governance structures or rules. This percentage drops further when examining direct economic returns, with just 15% of households reporting any income derived from wildlife-related activities. The estimated mean total benefit received by communities from GLTFCA-linked activities is R14,363.41 per annum, with a high standard deviation of R14,870.41. Reported values range widely, from as low as R1,000.00 to as high as R80,000.00 per year. When considering average community sizes, this aggregated figure suggests that per capita benefits are likely to be significantly lower than individual household-level gains.

5.3 Illicit extraction behaviour and the GLTFCA household economy

Table 10 shows the index of household participation in community-based institutions (CBOs), involvement in TFCA activities, and participation in illicit activities in the GLTFCA. The index of

CBOs is 0.36 out of a total score of 1, providing evidence of very low participation by GLTFCA households in community-based organizations. This result is worrying for two main reasons. First, because of the important role community institutions must play in terms of driving development and conservation goals. Second, the result does not warrant the substantial work and effort that have been expended by regional governments and NGOs over the past four decades to promote community development and conservation initiatives. The results in Table A11 in the annex show that out of more than twenty community-based organizations identified in GLTFCA communities, household membership participation in church (45%) is the dominant activity, followed by rotating savings clubs (28%), burial societies (19%), and farmer organizations (13%), while membership is less than 10% for the rest, including NRM institutions.

Table 10: Participation in community-based institutions and illicit resource extraction

Institutions	Obs.	Mean	Std. Dev.	Min	Max
CBO Index	1,108	0.36	0.57	0	100
Is household involved in park activities?	1,108	0.15	0.38	0	1
Is community involved in park activities?	1,108	0.64	0.48	0	1
Household involvement in TFCA	1,108	0.25	0.43	0	1
Community involvement in TFCA	1,108	0.45	0.50	0	1
Participation in illicit activities	1,108	0.97	0.16	0	1
No. of resources extracted in total	1.108	3.24	2.04	1	13
Participate1_PA	1,108	0.41	0.49	0	1
Participate2_PA_Bushmeat	1,108	0.44	0.50	0	1
Participate3_PA_Bushmeat_arrested	1,108	0.51	0.50	0	1

Source: Household survey (2022/23)

At the park level, our findings indicate that household involvement in park-related activities is relatively limited, with only 15% of households reporting direct participation. Involvement in broader TFCA activities is slightly higher at 25%, however this is still a modest value considering the potential for community integration into conservation and tourism initiatives. In contrast, when assessed at the community level, participation rates are notably higher. Approximately 64% of communities report involvement in park-related activities, suggesting that engagement tends to be collective or institutional rather than individual. Similarly, community-level involvement in TFCA activities is reported at 45%, demonstrating a stronger community-level presence in transboundary conservation efforts compared to household-level participation. When asked about their participation in resource extraction, 97% of households reported engaging in harvesting activities, collecting an average of 3.24 different resources with a standard deviation of 2.04 resources. The number of species extracted per household ranged from one to thirteen, encompassing both flora and fauna. Thus, only 3% of households were classified as non-participants, as they reported no harvesting of environmental resources from either the buffer zone or protected areas.

Participation in illicit resource extraction was also assessed across three levels. The first level (Participate1_PA) captures instances where resources were harvested specifically from protected areas. The second level (Participate2_PA_Bushmeat) includes both harvesting from protected areas and the extraction of wildlife or bushmeat. The third level (Participate3_PA_Bushmeat_arrested) builds on the previous level by considering whether any household member had been arrested for violating park regulations within the past 12 months. The results indicate that 41% of respondents harvested resources from within protected areas. This figure increases to 44% when including those who specifically extracted bushmeat. Furthermore, 51% reported harvesting resources, including bushmeat, from protected areas, and that at least one household member had been arrested for violating park regulations. The low level of household participation in local CPR institutions suggests that NRM institutions may be ineffective at regulating environmental behaviour, resulting in increased participation in illicit activities. Excluding the 3% of non-participants, 46% of households harvested resources specifically from the buffer zone, without engaging in wildlife extraction or violating park regulations.

Table 11 presents the distribution of household involvement in the illicit biodiversity economy by income quintiles. In general, the results show that households from the low-income quintiles participate less in the illicit biodiversity economy, while those in higher income quintiles participate more. Households in the 3rd and 4th income quintiles participate more in illicit activities.

Table 11: Participation in the illicit biodiversity economy by income quintiles

Income distribution	N	Participate1_PA Harvested from park	Participate2_PA Including bushmeat	Participate3_PA Bushmeat & arrested
First quintile	222	0.27	0.30	0.39
Second quintile	222	0.44	0.46	0.51
Third quintile	221	0.44	0.48	0.54
Fourth quintile	222	0.49	0.51	0.58
Fifth quintile	221	0.43	0.48	0.55
Total	1108	0.41	0.44	0.51

Source: Household survey (2022/23)

6. RESULTS AND DISCUSSION

The results section is organized into three subsections according to the three research questions. The analysis in the first section answers research questions one and two and examines how participation in the biodiversity economy influences household poverty and inequality, and whether these effects vary by income group and gender. Next, research question three is answered by means of an evaluation of the treatment effects of participating in illicit activities, using Propensity Score Matching (PSM) and Inverse Probability Weighting (IPW) techniques. The section concludes by examining the drivers of illicit environmental extraction and household dependence. The main results are presented in the tables within the text, while additional results are provided in Appendix A. Where there is need for in-depth analysis, we refer to the results in the supplementary tables.

6.1 Analysis of participation in the biodiversity economy and household welfare in the GLTFCA

This section examines how participation in the biodiversity economy (especially resource extraction) impacts household welfare. We adopted a poverty line of R12,588.93 per annum as the threshold to distinguish between households considered to be living in poverty or not. Following van de Ven et al. (2021) and Moatsos (2025), the poverty line was derived using recent survey data, which included variables such as household income, expenditure patterns, and cost of living indicators. The chosen poverty line reflects the minimum income necessary to meet basic needs, including food, shelter, clothing, healthcare, and other essential services within the context of the local economy. By basing the poverty line on empirical survey data, we ensure that it is grounded in the actual socio-economic conditions experienced by the population (Moatsos, 2025). The methodology aligns with standard practices in poverty analysis, where income thresholds are calculated relative to the prevailing cost of a basic basket of goods and services required for a minimally acceptable standard of living (Cutillo et al., 2022). The R12,588.93 figure therefore serves as a realistic and context-specific benchmark for assessing poverty levels within the studied population.

The results presented in Table 12 provide a comparative poverty analysis, disaggregated by country and gender within the GALTFCA. The findings indicate that poverty levels are highest in Mozambique, followed by Zimbabwe and South Africa, respectively. This outcome is particularly noteworthy given the widely-documented economic challenges facing Zimbabwe in recent decades, including hyperinflation, political instability, and declining formal employment (Mlambo, 2017). These conditions would intuitively be expected to result in higher poverty rates. However, our results suggest that despite Zimbabwe's economic struggles, local communities in Mozambique continue to face deeper and more widespread poverty, which can be attributed to historically weak institutions, poor infrastructure, lower levels of human development, and a high dependency on subsistence agriculture. (Silva et al., 2018; Massé, F., 2019; Ntuli et al., 2022).

Table 12: Poverty analysis of headcount by country and gender

Proportion of poor households		Mean	Std. err.	95% conf. interval	
Mozambique	Female	0.46	0.04	0.38	0.55
	Male	0.37	0.03	0.31	0.42
	Total	0.40	0.02	0.35	0.45
South Africa	Female	0.29	0.03	0.23	0.35
	Male	0.30	0.03	0.24	0.37
	Total	0.30	0.02	0.25	0.34
Zimbabwe	Female	0.41	0.05	0.31	0.51
	Male	0.30	0.03	0.24	0.36
	Total	0.34	0.03	0.28	0.39
Full sample	**Female**	**0.37**	**0.02**	**0.32**	**0.42**
	Male	**0.33**	**0.02**	**0.29**	**0.37**
	Total	**0.35**	**0.01**	**0.32**	**0.37**

Source: Household survey (2022/23)

Moreover, the analysis reveals a consistent trend in poverty by gender across all three countries. Poverty rates are significantly higher among female-headed households compared to male-headed households. This is in line with findings from previous studies, which show that female-headed households in many African contexts are disproportionately affected by poverty due to structural inequalities, including limited access to education, employment, productive assets, and financial capital (Quisumbing et al., 2001; Chant, 2008). Especially in rural areas, women often bear a dual burden of unpaid domestic labour and agricultural work, compounded by limited institutional support or ownership rights (Sundström et al., 2019). This entrenched gender disparity contributes to the feminization of poverty, a concept widely discussed in development literature. Our findings thus reinforce the need for gender-sensitive poverty alleviation strategies, and highlight the persistent regional disparities in poverty within the GALTFCA. Policies that promote gender equity in education, land ownership, and access to credit could play a critical role in reducing poverty among female-headed households in these countries.

The results presented in Table 13 reveal notable income inequality across the three countries within the GLTFCA, disaggregated by income source. The findings indicate a complex and uneven distribution of income, with patterns of inequality varying significantly depending on both the country and the income category. Using the Gini coefficient, a widely accepted measure of income inequality, our analysis shows that South Africa exhibits the highest levels of inequality across most income sources, except for livestock income, where Zimbabwe reports greater inequality. These findings are consistent with a well-established body of literature identifying South Africa as one of the most unequal societies globally (Bhorat and Kanbur, 2006; Leibbrandt et al., 2010). These studies argue that the country's inequality is deeply rooted in its apartheid history, which institutionalized economic exclusion and created persistent disparities in income distribution, asset ownership, and access to quality education and employment opportunities. According to Sulla and Zikhali (2018), South Africa consistently ranks among the highest globally in terms of the Gini coefficient, reflecting extreme income polarization.

Interestingly, while inequality in Mozambique is relatively lower with respect to environmental and livestock income sources, livestock income in Zimbabwe stands out with a higher Gini coefficient than all other income categories. This may reflect the fact that livestock ownership in Zimbabwe tends to be concentrated among wealthier households and small-scale commercial farms, especially in newly resettled areas where there is greater access to grazing land and veterinary services for smallholders (Scoones et al., 2012). Notably, our findings show that crop income inequality is most pronounced in South Africa, whereas Zimbabwe exhibits the lowest level of inequality. This likely reflects structural differences in land tenure, agricultural productivity, and market access.

Table 13: Income inequality by country

Proportion of poor households		Sk	Gk	Rk	Share	% Change
Environmental	MZ	0.4044	0.3310	0.6333	0.3187	-0.0858
	SA	0.1568	0.4386	0.5909	0.1513	-0.0056
	ZW	0.3488	0.4170	0.6668	0.3501	0.0012
Livestock	MZ	0.2130	0.5368	0.5845	0.2513	0.0383
	SA	0.1157	0.6175	0.3966	0.1054	-0.0102
	ZW	0.1180	0.6215	0.5809	0.1537	0.0357
Crop	MZ	0.0516	0.4288	0.3242	0.0270	-0.0247
	SA	0.0629	0.4989	0.1898	0.0222	-0.0408
	ZW	0.0549	0.3947	0.4214	0.0330	-0.0219
Total income	**MZ**		**0.2660**			
	SA		**0.2687**			
	ZW		**0.2771**			

Source: Household survey (2022/23)

Many rural Mozambicans rely on subsistence farming with limited surplus production available for sale, while a small proportion of better-resourced farmers participate in higher-value agricultural markets (Walker et al., 2015). These disparities contribute to significant income inequality within the agricultural sector, despite relatively widespread engagement in crop production. Overall, the mixed results across income categories underscore the importance for policy-makers of considering the multifaceted nature of inequality in transboundary regions like the GLTFCA. Addressing such inequality requires targeted interventions that account for both country-specific dynamics and the heterogeneity of rural livelihoods.

Table 14 presents the results of income inequality in the GLTFCA, disaggregated by both income source and the gender of the household head. The data reveal distinct patterns of inequality that differ by gender and livelihood type. In general, male-headed households display greater overall income inequality than female-headed households. This suggests a broader range of income levels among male-headed households, potentially reflecting greater and more diverse access to economic opportunities and assets, such as formal employment, access to markets, and land (Leibbrandt et al., 2010).

Table 14: Income inequality by income source and gender

Proportion of poor households		Sk	Gk	Rk	Share	% Change
Environmental	Female	0.3132	0.5055	0.5617	0.3707	0.0575
	Male	0.3411	0.3860	0.6030	0.2804	-0.0608
	Total	0.3360	0.4140	0.5899	0.2962	-0.0397
Livestock	Female	0.0882	0.6617	0.5148	0.1252	0.0370
	Male	0.1712	0.5724	0.5704	0.1974	0.0262
	Total	0.1558	0.6088	0.5475	0.1876	0.0317
Crop	Female	0.0548	0.4394	0.2281	0.0229	-0.0319
	Male	0.0551	0.4355	0.3563	0.0302	-0.0249
	Total	0.0551	0.4376	0.3415	0.0297	-0.0253
Total income	**Female**		**0.2399**			
	Male		**0.2832**			
	Total		**0.2769**			

Source: Household survey (2022/23)

However, a notable exception is observed in the livestock income category, where female-headed households exhibit higher income inequality. This pattern may be attributed to the uneven ownership and control of livestock among women. In many rural African contexts, although women participate actively in livestock rearing, ownership and decision-making power over livestock assets are often concentrated among a few women with better socioeconomic standing, while the majority of female-headed households only engage in livestock rearing at subsistence levels (Njuki and Sanginga, 2013; Salomon, 2015). This disparity leads to skewed income distribution within this category.

Conversely, crop income appears to be more evenly distributed among female and male-headed households, suggesting relatively lower inequality. This could be due to the widespread involvement of both men and women in subsistence crop farming where income levels tend to be uniformly low, resulting in a more equal distribution, albeit at the lower end of the income spectrum (Quisumbing et al., 2014). Additionally, women's access to land for crop farming, although often limited in size and quality, is generally more common than their access to other productive assets, leading to a more balanced distribution of earnings within this income source. These findings highlight the gendered nature of inequality in rural livelihoods and suggest that income-generating opportunities and resource ownership are unevenly distributed both across and within gender groups. Addressing these disparities requires policies that promote equitable access to productive resources for women, particularly in high-value sectors such as livestock and commercial agriculture.

6.2 Analysis of the treatment effects on licit and illicit activities

Table 15 presents the estimated average treatment effects (ATE) of households participating in illicit environmental activities, as compared to non-participating households. Non-participating households are defined as those that either harvest environmental resources through legal channels or do not engage in resource extraction at all. However, it is important to note that most households either harvest directly or access environmental resources indirectly by purchasing them from other households. In practice, nearly all households in the study area consume environmental products, particularly firewood, which is a key energy source. In this analysis, total household income serves as the outcome variable, while participation in illicit activities constitutes the treatment variable. This treatment captures multiple dimensions of illicit behaviour as previously defined in the study (e.g., illegal harvesting within protected areas, wildlife poaching, and arrests for park rule violations). To estimate the treatment effects, both Propensity Score Matching (PSM) and Inverse Probability Weighting (IPW) methods were applied. While PSM provides a robust baseline by balancing covariates between treated and control groups, IPW was selected for final interpretation due to its methodological advantages, particularly its superior ability to mitigate self-selection bias and retain more observations in the estimation process (Austin & Stuart, 2015). The results demonstrate that IPW consistently produces statistically significant treatment effects, whereas several ATEs estimated using PSM are not significant. Therefore, the discussion of treatment effects focuses on the more reliable IPW estimates.

The findings reveal that, on average, a marginal increase in household participation in illicit environmental activities is associated with a rise in total annual household income of approximately R7,248.74 across the full sample encompassing all three countries. Disaggregating this effect by gender, the income gains are more pronounced among female-headed households, who experience an estimated increase of R9,127.39 per annum compared to R5,542.48 for male-headed households. This suggests that illicit environmental activities may represent a more significant livelihood strategy for women relative to men, likely due to their limited access to formal employment and productive assets, as has been documented in other studies in sub-Saharan Africa (Quisumbing et al., 2014; Wunder et al., 2014). When examining country-specific impacts, the economic returns from participation in illicit activities are substantially higher in South Africa compared to Mozambique and Zimbabwe. Specifically, households in South Africa gain approximately R21,784.93 annually from engaging in such activities, while the corresponding figures for Mozambique and Zimbabwe are significantly lower at R4,084.57 and R3,582.97, respectively. These disparities may reflect differences in enforcement intensity, access to markets, or the relative availability and value of natural resources across the three countries (Ferraro et al., 2011; Ntuli et al., 2022).

Table 15: PSM and IPW results

ATE of participation in illicit activities (Yes vs No)			Coef.	Std. err.	Z	P>|z|	95% Conf. Interval	
Mozambique	Female	PSM	1862.17	2471.05	0.75	0.451	-2980.99	6705.34
		IPW	3894.36**	1953.45	1.99	0.046	65.66	7723.05
	Male	PSM	2678.57	2671.20	1.00	0.316	-2556.89	7914.02
		IPW	4408.58**	1807.51	2.44	0.015	865.91	7951.24
	Total	PSM	3970.65**	1626.07	2.44	0.015	783.61	7157.69
		IPW	4084.57***	1396.62	2.92	0.003	1347.24	6821.89
South Africa	Female	PSM	19058.03***	6681.77	2.85	0.004	5962.01	32154.06
		IPW	20541.18***	7445.06	2.76	0.006	5949.13	35133.22
	Male	PSM	8046.73	12395.36	0.65	0.516	-16247.73	32341.19
		IPW	22777.25	15195.99	1.50	0.134	-7006.34	52560.83
	Total	PSM	18495.55***	7098.72	2.61	0.009	4599.96	32391.14
		IPW	21784.93***	7653.35	2.85	0.004	6784.65	36785.21
Zimbabwe	Female	PSM	5268.06**	2711.92	1.94	0.052	-47.20	10583.33
		IPW	3334.06	2474.55	1.35	0.178	-1515.96	8184.07
	Male	PSM	1711.60	1962.44	0.87	0.383	-2134.71	5557.91
		IPW	3956.89**	1913.84	2.07	0.039	205.83	7707.96
	Total	PSM	2143.18	1693.06	1.27	0.206	-1175.15	5461.52
		IPW	3582.97**	1515.12	2.36	0.018	613.40	6552.55
Total income (full sample)	**Female**	**PSM**	**10641.58*** **	**3977.57**	**2.68**	**0.007**	**2845.69**	**18437.47**
		IPW	**9127.39*** **	**3551.04**	**2.57**	**0.010**	**2167.48**	**16097.30**
	Male	**PSM**	**5480.56**	**5111.24**	**1.07**	**0.284**	**-4537.30**	**15498.41**
		IPW	**5542.48***	**3280.53**	**1.69**	**0.091**	**-887.25**	**11972.21**
	Total	**PSM**	**5397.84****	**2217.05**	**2.43**	**0.015**	**1052.51**	**9743.17**
		IPW	**7248.74*** **	**2520.85**	**2.88**	**0.004**	**2307.95**	**12189.52**

Source: Household survey (2022/23)

Gendered patterns within each country further reveal that in South Africa, female-headed households derive significant benefit from participation in illicit activities in the magnitude of R8,046.73, while the results for male-headed households are statistically insignificant. This pattern aligns with existing literature that shows female-headed households often face greater economic vulnerability and limited livelihood options, and thus may resort to environmentally exploitative activities as a coping mechanism (Mwangi et al., 2016). However, results from the Propensity Score Matching (PSM) analysis show the opposite trend in South Africa, suggesting that male-headed households derive more economic benefit from illegal resource use. This discrepancy is noteworthy and may point to gendered differences in the scale, type, or risks associated with illicit activities—an area warranting further investigation.

In Mozambique, the income gains from illicit activities are much higher for male-headed households (R4,408.58) than for female-headed households (R3,894.36), whereas in Zimbabwe, the estimated increase is higher for male-headed households only (R3,956.89), while female-headed households show no significant income gain. These cross-country and gender-based differences underscore the complex socio-economic and institutional contexts that mediate the economic outcomes of illicit environmental resource use. Similar patterns have been reported in prior studies that highlight how household structure, access to markets, and state enforcement capacity can shape the costs and benefits of engaging in illegal natural resource extraction (e.g., Cavendish, 2000; Mamo et al., 2007; Babulo et al., 2008; Kamanga et al., 2009; Fonta and Ayuk, 2013; Angelsen et al., 2014; Wunder et al., 2014; Ntuli and Muchapondwa, 2017).

6.3 Regression analysis of participation and environmental dependences

In this section we examine the drivers of environmental resource extraction. Table 16 presents the results of four econometric models examining household participation in illicit environmental activities within the GLTFCA. The first three models utilize a binary logit regression to explore varying definitions of illicit behaviour, while the final model is based on IV estimation with heteroscedasticity-based instruments. Specifically, Model 1 identifies households that illegally harvest environmental resources from within protected areas. Model 2 expands on this by including households that also harvest wildlife resources both within and outside protected zones alongside other protected resources. Model 3 further includes households where at least one member has been arrested within the past five years for violating park regulations, in addition to engaging in the previously mentioned illicit activities. Model 4 adopts a different approach by using relative environmental income, defined as the ratio of environmental income to total household income, as a proxy for environmental dependence. All four models are statistically significant at the 1% level, indicating a strong fit. Notably, the intercept in Model 4 is also highly significant, suggesting the possible influence of omitted variables or unobservable contextual factors not captured in the model. This issue of unobserved heterogeneity is well-documented in environmental and development economics (Ntuli et al., 2021) and ideally, model specification should account for all relevant variables to reduce the influence of the constant term.

Our results do not show statistically significant evidence that some socioeconomic factors, such as age, employment status, household wealth (proxied by the number of rooms), and institutions (measured by the existence of community- or state-based institutions) play a role in driving illicit behaviours and environmental dependence in the study area. The lack of significance of these variables, especially institutions, is also an important result often overlooked by researchers, which calls for policy interventions to enhance the influence of such factors in social-ecological systems. This situation may be attributed to the complexities in balancing wildlife conservation goals with community needs and the context-specific nature of rural livelihoods in the GLTFCA. As a result, the effects of age, employment, and wealth on illicit behaviour and environmental dependence are not straightforward. While the age of the household head may or may not translate into desired ecological outcomes, the literature also shows mixed results in the relationship between household wealth and resource extraction. There is also evidence demonstrating that employment in the informal rural economies of Africa often does not necessarily equate into economic security.

Table 16: Results of the logit models and IV regression with heteroskedasticity based instruments

Variable		**Participation**			**Relative environmental income (dependence)**
		Model 1	*Model 2*	*Model 3*	*Model 4*
Country	South Africa	-0.3900***	-0.3604***	-0.2892***	-0.0568
		(0.046)	(0.0470)	(0.0482)	(0.0315)
	Zimbabwe	-0.0203***	-0.1843***	-0.1766***	-0.0114
		(0.040)	(0.0411)	(0.0421)	(0.0285)
Gender (F = 0, M=1)		0.0508*	0.0450	0.0666**	0.0134
		(0.030)	(0.0302)	(0.0309)	(0.0208)
Age		0.0005	0.0008	0.0002	-0.0006
		(0.0011)	(0.0011)	(0.0012)	(0.0008)
No. of years in school		-0.0064*	-0.0076**	-0.0071*	-0.0013
		(0.0037)	(0.0038)	(0.0039)	(0.0026)
Employment status		-0.0062	-0.0093	-0.0296	-0.0262
		(0.0200)	(0.0204)	(0.0209)	(0.0143)
Household size		0.0122**	0.0124**	0.0091	0.0103***
		(0.0055)	(0.0056)	(0.0058)	(0.0035)
No. of rooms		0.0081	0.0041	0.0051	-0.0158
		(0.0090)	(0.0092)	(0.0094)	(0.0064)
Local CPR institutions		0.0009	0.0002	0.0003	0.0007
		(0.0014)	(0.0015)	(0.0015)	(0.0010)
State-based institutions		0.0003	0.0007	0.0010	0.0012
		(0.0011)	(0.0011)	(0.0011)	(0.0007)
Interaction term		-0.00001	$-7.53e^{-06}$	-0.0001	-0.0002
		(0.00002)	(0.00002)	(0.0002)	(0.00001)
Non-farm income		$7.32e^{-07}$*	$8.77e^{-07}$**	$1.00\ e^{-06}$**	$-4.38e^{-06}$***
		($4.16\ e^{-07}$)	($4.25e^{-07}$)	($4.35e^{-07}$)	($3.95e^{-07}$)
Wildlife crop damage		0.0682**	0.0639*	0.0531	-0.0042
		(0.0320)	(0.0327)	(0.0335)	(0.0218)
Hhld ran out of food		-0.0558*	-0.0620**	-0.0093	0.0181
		(0.0297)	(0.0304)	(0.0311)	(0.0207)
Constant		0.4483	0.4766	0.5390	0.3490***
		(0.0769)	(0.0785)	(0.0804)	(0.0555)
Obs.		1,108	1,108	1,108	1,108
F(14, 1093)		15.04	12.93	9.75	F(14, 488) =12.28
Prob > F		0.0000	0.0000	0.0000	0.0000

Source: Household survey (2022/23)

Significance level * 10%, ** 5%, *** 1%

According to previous empirical accounts, institutional participation is hindered by social and structural barriers such as elite capture, exclusion of marginalized groups, and limited incentives, which reduce the relevance and accessibility of these institutions for many households (Cleaver, 2017). Therefore, the lack of significance of institutional variables in our models also suggests deeper structural challenges. Local institutions may lack the trust, transparency, resources, or enforcement capacity needed to influence environmental behaviour meaningfully. This is consistent with literature indicating that institutional effectiveness in conservation depends heavily on perceived legitimacy and tangible household benefits (Krause and Nielsen, 2014; Bixler et al., 2015; Cetas and Yasué, 2017) in addition to NGO activities in the area (Ntuli et al., 2022). These findings underscore the need for more inclusive and better-resourced governance structures to effectively influence environmental behaviour in the GLTFCA. Despite some discrepancies among the models, particularly with respect to gender, household size, wildlife crop damage, and recent food insecurity, the first three models generally yield consistent findings. The results highlight that household involvement in illicit activities is influenced by a combination of socio-economic and contextual factors. These include the respondent's country of residence, gender, level of education, household size, non-farm income, experiences of crop damage due to wildlife, and whether the household experienced food shortages in the past year.

Model 3, which incorporates the most comprehensive definition of illicit activity, is used for detailed interpretation. Using Mozambique as the reference category, the analysis shows that households in South Africa and Zimbabwe are significantly less likely to participate in illicit environmental activities. This finding may be explained by the socio-political and economic conditions specific to Mozambique, where some communities still reside illegally within protected areas and have resisted government-led relocation efforts (Massé, 2020). This aligns with previous research indicating that local compliance with conservation rules is often linked to historical grievances and perceived legitimacy of relocation programs (Brockington & Wilkie, 2015; Massé, 2016). Furthermore, environmental dependence, reflected in reliance on natural resources for income, has been shown in various studies to be a key driver of non-compliant behaviour in conservation areas, particularly where livelihood alternatives are limited (Babulo et al., 2008; Kamanga et al., 2009; Coad et al., 2015). Food insecurity and crop raiding by elephants and other wildlife have also been identified as significant predictors of illegal resource use in similar contexts (Tolbert et al., 2023).

The analysis reveals that male-headed households are significantly more likely to engage in illicit environmental extraction inside protected areas and to be arrested for violating park rules compared to their female-headed counterparts, while no significant gender difference is found in terms of harvesting wildlife both inside and outside protected areas. The former results are consistent with prior empirical research conducted in the GLTFCA, as well as broader studies across sub-Saharan Africa that highlight gendered patterns in natural resource exploitation and risk-taking behaviour (Mamo et al., 2007; Babulo et al., 2008; Sundström et al., 2019; Ntuli et al., 2022). Male household heads are often more mobile, physically capable of harvesting resources, and more likely to engage in activities perceived as high-risk but also potentially high reward, such as illegal wildlife harvesting or timber extraction. Level of education also plays a critical role in shaping household behaviour. The results show that a marginal increase in the education level of the household head reduces the likelihood of participation in illicit environmental activities. This is likely due to the greater employment opportunities and income diversification options available to more educated individuals, which reduce their dependence on environmental resources for survival (Hicks and Cinner, 2014). Education has also been linked to greater awareness of conservation laws and the long-term value of ecosystem preservation (Børresen et al., 2023).

Interestingly, the results also indicate a positive association between non-farm income and participation in illicit activities, i.e., households with greater non-farm income are more likely to engage in illegal resource use. This result aligns with previous studies that suggest relatively wealthier households may exploit environmental resources more intensively, as they can afford technologies such as vehicles, carts, chainsaws, guns, and traps that increase extraction efficiency and allow them to transport resources over longer distances (Babulo et al., 2008). Previous empirical accounts also demonstrate that wealthier households with extended families working in peri-urban and urban areas are also more likely to have access to market opportunities by turning environmental products into commercial ventures. This complexity is further reflected in findings from Ntuli and Muchapondwa (2017), who studied the Zimbabwean section of the GLTFCA. They found that while poorer households rely more heavily on environmental resources as a proportion of their total income, wealthier households consume greater absolute quantities due to their ability to scale up harvesting activities. This duality underscores the importance of considering both relative and absolute environmental dependence when analysing the drivers of illicit natural resource use. Consistent with our expectations, households experiencing crop damage from wildlife intrusion are more likely to engage in illegal resource extraction or harvesting wildlife resources within the park. Finally, our results show that households that experienced food shortages in the past 12 months were less likely to engage in illegal resource extraction or the harvesting of wildlife resources within the park – a finding that may seem counterintuitive.

Using the instrumental variables estimation with heteroskedasticity-based instruments, the results presented in Model 4, which employs relative environmental income as a proxy for environmental dependence, reveal important dynamics in household behaviour. Specifically, the findings indicate that a marginal increase in household size is associated with a significant rise in environmental dependence. This is consistent with prior studies suggesting that larger households tend to rely more heavily on natural resources, such as fuelwood, water, and wild foods, to meet basic subsistence needs (Babulo et al., 2008; Mamo et al., 2007). Larger households often experience higher consumption demands, and may experience labour surpluses which increase their capacity to extract resources from the surrounding environment (Angelsen et al., 2014; Wunder et al., 2014).

Finally, our results demonstrate that a marginal increase in non-farm income is associated with a significant, albeit small, reduction in environmental dependence. This finding appears to contradict the results of the logit model, where the same variable was identified as one of the key drivers of participation in resource extraction. Thus, participation in and dependence on resource extraction are not synonymous concepts as applied in the literature. This suggests the need for differentiated policy approaches that separately address the factors influencing resource extraction behaviour and broader environmental dependence. However, the inverse relationship aligns with the existing literature, which shows that access to alternative income sources such as remittances, salaried employment, or small-scale enterprises can reduce reliance on environmental goods by enabling households to purchase substitutes (such as gas or electricity for cooking) or invest in livelihood diversification (Vedeld et al., 2007). Non-farm income also tends to reduce vulnerability to environmental shocks, thereby decreasing the need for resource-based coping strategies (Angelsen et al., 2014; Ntuli and Muchapondwa, 2017). Our findings highlight the importance of household composition and economic diversification in shaping environmental reliance and support broader policy strategies that promote alternative livelihoods to reduce pressure on natural ecosystems in conservation areas.

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

Environmental resource extraction continues to play a vital role in the livelihoods of poor households living near protected areas. This study aimed to examine the contribution of both licit and illicit environmental resource use to household welfare across the GLTFCA constituencies.

A significant share of household heads possesses only primary-level education (equivalent to Grade 5), which limits their employment prospects and contributes to their reliance on illegal resource extraction for income generation. This situation is further exacerbated by human-wildlife conflict, which impacts a significant number of households in the GLTFCA by raising the external costs associated with coexisting with wildlife. While crop raids by the African elephant species account for the largest share of overall damage, the most severe damage is typically inflicted by large carnivores such as hyenas, lions, and leopards via livestock predation.

Gender- and country-disaggregated statistics reveal elevated levels of poverty among female-headed households, particularly in Mozambique and Zimbabwe. Our analysis using the Gini coefficient indicates high income inequality with respect to livestock, with the most pronounced disparities observed in Zimbabwe and South Africa. In terms of environmental income, inequality is highest in South Africa, followed by Zimbabwe, whereas crop income inequality is greatest in South Africa, followed by Mozambique. When disaggregated by gender, the data show that female-headed households in the GLTFCA experience greater inequality in both environmental and livestock income, highlighting the need for more inclusive and gender-responsive policy interventions.

The economic benefits of illicit activities are most pronounced in South Africa, where households earn substantially more than their counterparts in Mozambique and Zimbabwe, with female-headed households experiencing greater income gains than male-headed ones. This suggests that illicit environmental extraction may serve as a critical livelihood strategy, particularly for more vulnerable groups with limited access to alternative income sources. Interestingly, while South African female-headed households benefit most according to the inverse probability weighting (IPW) approach, the Propensity Score Matching (PSM) analysis presents contrasting evidence, highlighting the importance of methodological considerations in policy interpretation.

Based on the main results of this study, we suggest several policy recommendations. First, government and NGO policy interventions must prioritize investment in rural education and skills development in the GLTCA and other regions. Expanding access to quality education beyond the primary level is critical. Higher levels of education reduce the likelihood of participation in illicit activities by equipping individuals with the skills required for formal employment and entrepreneurship. Government and development partners should prioritize adult literacy programs, vocational training, and youth empowerment initiatives in conservation areas.

Second, targeted policy interventions aimed at promoting economic diversification and non-farm employment in local communities living adjacent to protected areas are needed to address both participation in illicit resource extraction and environmental dependence. Stimulating rural economic growth through farm and non-farm employment opportunities in the form of non-consumptive wildlife use is essential to reduce environmental dependence. This calls for investments in infrastructure, agricultural value chains, ecotourism, and small-scale enterprise development to provide viable alternatives to illegal resource use.

Third, policy interventions are needed to strengthen community-based organizations (CBOs), especially local CPR institutions. To enhance CBO participation, targeted capacity-building programs should be introduced for both leaders and members. These programs must include governance training, participatory decision-making, and monitoring mechanisms to ensure accountability. In addition, financial support and technical assistance are needed to improve institutional functionality and demonstrate tangible household-level benefits. More resources in terms of expertise and sustainable funding sources that go beyond NGO activities are also required.

Fourth, capacity to deal with human-wildlife conflict and local enforcement to build the legitimacy of local CPR institutions discharging enforcement duties must be increased. Effective enforcement of environmental laws must be balanced with efforts to build trust and legitimacy among local communities. Participatory enforcement strategies involving CBOs and traditional authorities may improve compliance while simultaneously reducing conflict.

Finally, to reduce environmental crimes induced by household vulnerability to external shocks, regional governments should implement targeted social protection and asset-accumulation initiatives that bridge poverty gaps and income inequality both within and between gender and countries. Female-headed and vulnerable households who show higher income gains from illicit activities require targeted social protection measures such as conditional cash transfers, food aid, or access to microfinance. Additionally, incentive-based conservation programs, such as Payments for Ecosystem Services (PES), can align household needs with conservation goals.

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APPENDIX A: ADDITIONAL TABLES

Table A1: Asset ownership and asset value

Asset	Yes		Value	
	Freq.	%	Mean	Std. Dev.
Household assets				
Wood stove	536	48.38	128.24	196.70
Primus stove	4	0.36	270	220.45
Sofa	189	17.06	8159.96	11758.31
Chairs	978	88.27	580.88	1073.69
Tables	627	56.59	831.79	3874.09
Bed	797	71.93	4535.80	5527.16
Modern technology				
Refrigerator	351	31.68	4350.72	4436.67
Electric stove	162	14.62	2523.04	3507.61
TV	320	28.88	2691.67	3359.31
DVD player	98	8.84	664.10	641.80
Satellite dish	191	17.24	663.25	421.34
Radio	362	32.67	987.69	2060.09
Cell phone	947	85.47	2740.14	4542.54
Solar panels	318	28.70	1599.08	2333.33
Solar batteries	179	16.16	1345.90	3246.11
Generator	26	2.35	5217.14	5428.00
Bow & arrow	1	0.09	400.00	-
Gun	7	0.63	1739.29	2598.07
Farm implements/machinery				
Hoe	864	77.98	235.90	251.48
Plough	293	26.44	1912.94	2040.25
Cultivator	10	0.90	1716.50	1125.92
Planter	6	0.54	1278.50	2353.38
Harrow	66	5.96	232.64	796.80
Sprayer	42	3.79	785.31	1417.84
Shovel	488	44.04	234.52	240.37
Axe	482	43.50	204.26	270.46
Pick	261	23.56	225.78	283.58
Machete	428	38.63	143.57	731.15
Farm transportation				
Cart	208	18.77	2497.01	2610.53
Wheelbarrow	379	34.21	726.85	756.80
Bicycle	186	16.79	1558.20	1136.37
Motorbike	41	3.70	15985.90	20456.70
Tractor	12	1.08	72833.33	63482.04
Car	80	7.22	96024.11	97949.33
Truck	11	0.99	169714.30	117648.70
Farm infrastructure				
Cattle kraal	271	24.46	2429.87	2725.70
Goat house	261	26.91	1016.10	939.59
Pigsty	24	2.17	2263.04	3106.45
Fowl run	182	16.43	570.90	721.47
Granary	109	9.84	1970.76	2555.40
Storeroom/shade	33	2.98	2768.50	3775.81
Grinding mill	19	1.71	15183.33	8941.26
Dwelling	691	62.36	19968.33	32304.89

Bee hive	4	0.36	15225.00	17061.14

Source: Household survey (2022/23)

Table A2: Analysis of household income sources by country and gender

Income source			Obs.	Mean	Std. Dev	Min	Max
Non-farm income	MZ	F	132	10547.81	8461.50	1500	42600
		M	280	11338.77	9625.56	1500	70000
			412	11085.36	9265.62	1500	70000
	SA	F	200	19872.33	22733.84	1500	138000
		M	174	29684.07	61005.06	1500	186360
			374	24437.15	45009.57	1500	186360
	ZW	F	95	15030.63	13063.48	1500	64800
		M	227	16505.70	15293.20	1500	102000
			322	16070.51	14666.02	1500	102000
	All	F	427	14875.95	17597.93	1500	138000
		M	681	16170.07	21156.14	1500	186360
Crop income	MZ	F	24	1500.63	1169.48	500	4950
		M	89	2003.58	1860.50	100	9250
			113	1896.76	1744.50	100	9250
	SA	F	31	1225.48	1196.87	65	4870
		M	17	1859.06	2119.86	80	7950
			48	1449.88	1593.09	65	7950
	ZW	F	17	1188.82	1131.57	75	3700
		M	73	1450.75	1182.82	50	5000
			90	1401.28	1171.60	50	5000
	All	F	72	1308.54	1164.39	65	4950
		M	179	1764.40	1658.59	50	9250
Livestock income	MZ	F	35	4375.23	6393.07	90	30108
		M	114	5226.69	6506.09	50	30857
			149	5026.69	6468.34	50	30857
	SA	F	45	2455.38	3952.70	50	22103
		M	38	3315.08	4285.85	50	14775
			83	2848.98	4105.78	50	22103
	ZW	F	54	2452.11	4038.91	90	18090
		M	142	3590.88	4780.60	50	26000
			196	3277.14	4606.43	50	26000
	All	F	134	2955.52	4778.66	50	30108
		M	294	4189.53	5507.63	50	30857
Environmental income	MZ	F	59	7780.73	7213.24	340	33136
		M	136	8937.77	7228.21	195	38271
			195	8587.69	7224.75	195	38271
	SA	F	80	5907.15	4233.77	100	17800
		M	71	6795.95	4789.76	40	25881.2
			151	6325.06	4510.51	40	25881.2
	ZW	F	42	7883.10	6224.22	535	26620
		M	115	8200.92	6741.15	248.5	36216
			157	8115.90	6588.65	248.5	36216
	All	F	181	6976.38	5862.493	100	33136
		M	322	8202.35	6616.74	40	38271
Total household income	MZ	F	132	15385.24	11019.27	1500	52108
		M	280	18323.75	13757.47	1500	85648
			412	17376.28	13008.62	1500	85648
	SA	F	200	22922.29	23263.53	1500	138054
		M	174	33316.08	61749.38	1500	188460
			374	27757.90	45652.72	1500	188460
	ZW	F	95	20019.62	14859.45	1780	68187.5

		M	227	23249.76	17648.74	1950	105170
			322	22296.77	16915.43	1780	105170
	All	F	427	18909.88	18481.04	1500	138054
		M	681	22218.04	22643.77	1500	188460

Table A3: Percentage of households with income source and mean income ranking

Income source	Obs.	Freq.	Percent	Rank	Mean	Rank
Casual labour	1,108	98	8.84	5	12387.69	5
Formal employment	1,108	153	13.81	3	44357.21	1
Self employed	1,108	223	20.13	1	13118.82	4
Pension	1,108	41	3.70	7	14723.92	3
Remittance	1,108	178	16.06	2	8324.889	8
Donations	1,108	13	1.17	9	3254.091	9
NGO cash transfer	1,108	6	0.54	10	11034.29	6
Disability grant	1,108	6	0.54	10	10770	7
Child support grant	1,108	145	13.09	4	7329.073	9
Elderly grant	1,108	80	7.22	6	15607.75	2
Other	1,108	33	2.98	8	2859.659	10

* Beer brewing, sap/wine, traditional healer, etc.
Source: Household survey (2022/23)

Table A4: Frequency of households with crop income and ranking

Income source	Freq.	Percent	Ranking
Maize	674	60.83	1
Sorghum	264	24.04	2
Groundnuts	198	17.87	3
Leafy vegetables	122	11.01	4
Beans	121	10.92	5
Roundnuts	79	7.13	6
Tomatoes	57	5.14	7
Millet	47	4.24	8
Onions	42	3.79	9
Sunflower	15	1.35	10
Cabbage	15	1.35	10
Rapoko	11	0.99	12

Source: Household survey (2022/23)

Table A5: Crop production statistics, income and ranking

Income source	Obs.	Hectares	Harvest	Consumed	Sold	Price	Income	Ranking
Maize	1,108	1.16	484.81	511.53	288.14	5.93	1087.24	6
Sorghum	1,108	1.40	576.02	583.15	669.17	2.93	1281.54	5
Millet	1,108	1.15	426.74	391.39	252	3.88	792.75	8
Groundnuts	1,108	0.40	150.68	115.95	61.57	33.77	1454.61	2
Roundnuts	1,108	0.22	87.79	90.47	57.50	23.75	1400.00	4
Sunflower	1,108	0.52	325.33	219.09	177	8.55	1411.00	3
Beans	1,108	0.22	170.98	127.33	82.89	22.57	1570.34	1
Rapoko	1,108	0.42	308.33	265	276	5.1	1100.00	7
Cabbage	1,108	0.19	235.00	132.67	150.42	4.25	641.67	11
Tomatoes	1,108	0.11	134.25	94.02	112.43	8.61	762.82	9
Onions	1,108	0.10	123.88	71.38	98.58	9.45	706.64	10
Leafy vegetables	1,108	0.09	125.17	101.85	102.33	5.14	459.09	12

Source: Household survey (2022/23)

Table A6: Analysis of livestock income

Livestock category		Produced	Consumed	Bought	Sold	Unit Price	Income
Draught power	Obs.	128	-	21	33	31	31
	Mean	3.46	-	1.90	1.76	4969.10	8798.23
	Std. Dev	4.10	-	1.81	0.94	1818.22	5770.62
Cattle	Obs.	422	64	56	119	117	118
	Mean	7.67	1.86	1.57	1.68	4374.74	7238.82
	Std. Dev	5.74	1.53	0.87	0.94	1638.49	4728.09
Goat	Obs.	480	268	72	148	153	150
	Mean	8.78	2.27	2.25	2.83	569.90	1526.03
	Std. Dev	6.71	1.79	1.41	2.01	238.41	1151.09
Sheep	Obs.	38	15	7	6	6	6
	Mean	5.24	1.87	2.57	1.67	1953.50	3158.33
	Std. Dev	3.15	1.36	2.15	0.52	456.85	1022.95
Pig	Obs.	54	35	9	18	18	18
	Mean	4.81	1.63	1.89	2.72	1052.78	2325.00
	Std. Dev	2.88	1.00	1.54	0.75	689.30	1062.77
Donkey	Obs.	84	-	6	6	11	11
	Mean	2.31	-	1.83	1.33	1036.36	1127.27
	Std. Dev	1.140	-	1.60	0.52	269.34	395.20
Rabbit	Obs.	10	7	4	5	5	5
	Mean	8.70	4.43	2.75	4.00	224	758
	Std. Dev	3.89	1.90	0.96	1.87	88.77	489.71
Chicken	Obs.	480	400	61	133	154	141
	Mean	12.78	6.47	5.28	4.57	64.64	275.58
	Std. Dev	9.98	6.85	5.66	3.41	19.22	224.28
Turkey	Obs.	17	9	2	2	2	2
	Mean	4.82	3.11	2	4.5	350	1500
	Std. Dev	3.97	3.52	1.41	0.71	212.13	707.11
Guinea fowl	Obs.	46	31	3	17	17	17
	Mean	7.89	3.35	2.67	3.65	136.47	436.18
	Std. Dev	5.70	2.29	2.08	2.76	53.96	319.52
Ducks	Obs.	49	25	10	15	15	15
	Mean	5.57	1.68	1.80	3	164	460.67
	Std. Dev	4.09	0.85	0.63	2.27	48.08	293.76
Bees	Obs.	4	-	-	4	4	4
	Mean	2.75	-	-	6.50	52.50	65
	Std. Dev	0.5	-	-	3.32	54.85	40.41

Source: Household survey (2022/23)

Table A7: Ranking of livestock income

Livestock category	Obs	Freq.	Percent	Ranking	Mean	Ranking
Draught power	1,108	129	11.64	4	8798.23	1
Cattle	1,108	424	38.27	3	7238.82	2
Goat	1,108	474	42.78	2	1526.03	5
Sheep	1,108	40	3.61	9	3158.33	3
Pig	1,108	54	4.87	6	2325.00	4
Donkey	1,108	89	8.03	5	1127.27	7
Rabbit	1,108	10	0.90	12	758.00	8
Chicken	1,108	489	44.13	1	275.58	11
Turkey	1,108	18	1.62	10	1500.00	6
Guinea fowls	1,108	47	4.24	8	436.18	10
Ducks	1,108	49	4.42	7	460.67	9
Bee keeping	1,108	11	0.99	11	65.00	12

Source: Household survey (2022/23)

Table A8: Processed foods and alcohol

Processed food item		Freq.	Percent	Cum.
Peanut butter	No	1,038	93.68	93.68
	Yes	70	6.32	100.00
	Total	1,108	100.00	
Dried vegetables	No	1,027	92.69	92.69
	Yes	81	7.31	100.00
	Total	1,108	100.00	
Fruit jam	No	1,103	99.55	99.55
	Yes	5	0.45	100.00
	Total	1,108	100.00	
Cooked food	No	1,083	97.74	97.74
	Yes	25	2.26	100.00
	Total	1,108	100.00	
Traditional beer	No	1,073	96.84	96.84
	Yes	35	3.16	100.00
	Total	1,108	100.00	
Distilled alcohol	No	1,096	98.92	98.92
	Yes	12	1.08	100.00
	Total	1,108	100.00	

Table A9: Quantities and value of processed crops

Income source		Produced	Consumed	Sold	Unit Price	Income
Peanut butter	Obs.	69	69	24	24	24
	Mean	4.23	2.04	6.23	92.71	510.42
	Std. Dev	4.98	1.60	3.96	11.79	247.50
	Min	0.25	0.25	1.5	70	150.00
	Max	20	5	15	120	1050.00
Dried vegetables	Obs.	80	80	38	38	38
	Mean	71.74	42.93	59.87	6.25	400.00
	Std. Dev	65.15	27.93	43.75	0.93	239.47
	Min	5	5	10	5	80
	Max	300	150	200	8	1150
Fruit jam	Obs.	5	5	3	3	3
	Mean	4.50	2.3	4.33	96.67	433.33
	Std. Dev	2.40	0.45	1.15	5.77	76.38
	Min	2	2	3	90	350
	Max	8	3	5	100	500
Cooked food	Obs.	25	-	25	25	25
	Mean	115.40	-	115.40	9.94	1146.80
	Std. Dev	71.30	-	71.30	1.92	746.02
	Min	50	-	50	7.5	450
	Max	350	-	350	15	3500
Traditional beer	Obs.	35	32	27	27	27
	Mean	133.57	51.88	112.04	9.54	1050.19
	Std. Dev	76.22	18.52	50.60	1.25	549.70
	Min	40	0	45	7	100
	Max	300	90	220	12	2200
Distilled alcohol	Obs.	12	11	12	12	12
	Mean	51.25	13.18	39.17	19.50	752.08
	Std. Dev	14.48	5.13	10.84	2.61	194.93
	Min	30	5	20	15	400
	Max	80	20	60	25	1080

Table A10: Quantities and income from processed livestock products

Livestock category		Produced	Consumed	Bought	Sold	Unit Price	Income
Milk	Obs.	130	131	123	127	127	127
	Mean	41.04	23.18	4.86	18.09	16.49	284.21
	Std. Dev	23.31	9.93	3.48	14.56	1.41	212.34
	Min	12	5	1	3	14	54
	Max	130	50	15	80	19	1120
Sour milk	Obs.	74	74	61	49	49	49
	Mean	13.82	8.39	4.26	8.20	16.82	137.69
	Std. Dev	5.19	2.12	2.10	2.41	1.09	40.87
	Min	4	4	1	4	15	64
	Max	25	15	9	14	19	238
Dried meat	Obs.	139	139	87	54	54	54
	Mean	24.47	18.04	3.61	16.74	82.13	1317.69
	Std. Dev	19.84	12.22	2.00	8.81	9.30	613.67
	Min	3	3	1	4	70	160
	Max	100	60	8	40	100	2800
Cooked meat	Obs.	10			10	10	9
	Mean	24.30			24.30	382.50	2163.33
	Std. Dev	6.18			6.18	910.92	444.66
	Min	15			15	90	1500
	Max	35			35	2975	2850
Eggs	Obs.	201	201	94	28	28	28
	Mean	19.85	16.03	9.45	27.39	3.01	179.68
	Std. Dev	18.99	11.10	6.07	12.69	0.48	338.37
	Min	2	2	2	10	2	30
	Max	95	45	50	50	4	1500

Table A11: Household membership in formal and informal organizations

Membership	Obs.	Mean	Std. dev	Min	Max	Rank
Farmer organization	1,108	0.13	0.34	0	1	4
Grocery stokvel/Rotating savings club	1,108	0.28	0.45	0	1	2
Trader/bus/taxi association	1,108	0.01	0.11	0	1	20
Income-generating project	1,108	0.07	0.25	0	1	7
Village development committee	1,108	0.07	0.26	0	1	7
School development committee	1,108	0.05	0.21	0	1	11
Cultural group	1,108	0.02	0.13	0	1	16
Women's club	1,108	0.06	0.24	0	1	9
Drama club	1,108	0.02	0.14	0	1	18
Church	1,108	0.45	0.50	0	1	1
Health club	1,108	0.03	0.16	0	1	15
Political affiliation	1,108	0.04	0.21	0	1	14
Burial society	1,108	0.19	0.39	0	1	3
Youth club	1,108	0.02	0.15	0	1	18
Sports club	1,108	0.03	0.18	0	1	15
Traditional authority/council	1,108	0.09	0.28	0	1	5
Traditional healer association	1,108	0.01	0.10	0	1	20
Natural resource management	1,108	0.01	0.09	0	1	20
Water resource management	1,108	0.03	0.18	0	1	15
Wildlife resource management	1,108	0.09	0.29	0	1	5
Community rangers	1,108	0.05	0.07	0	1	11
Common property association	1,108	0.06	0.23	0	1	9
Forum	1,108	0.05	0.07	0	1	11
Other	1,108	0.01	0.09	0	1	20

Source: Household survey (2022/23)

Table A12: Income inequality by country and gender

Proportion of poor households			Sk	Gk	Rk	Share	% Change
Mozambique	Environmental income	Female	0.5966	0.2814	0.9076	0.6521	0.0556
		Male	0.3815	0.3295	0.6372	0.3019	-0.0796
		Total	0.4044	0.3310	0.6333	0.3187	-0.0858
	Livestock income	Female	0.0513	0.3165	-0.0719	-0.0050	-0.0563
		Male	0.2323	0.5010	0.5962	0.2615	0.0292
		Total	0.2130	0.5368	0.5845	0.2513	0.0383
	Crop income	Female	0.0437	0.3407	-0.0391	-0.0025	-0.0461
		Male	0.0526	0.4311	0.3591	0.0307	-0.0219
		Total	0.0516	0.4288	0.3242	0.0270	-0.0247
	Total income	Female		0.2336			
		Male		0.2653			
		Total		0.2660			
South Africa	Environmental income	Female	0.1286	0.4213	0.4428	0.0906	-0.0379
		Male	0.1864	0.3036	0.1122	0.0375	-0.1489
		Total	0.1568	0.4386	0.5909	0.1513	-0.0056
	Livestock income	Female	0.1408	0.6551	0.7003	0.2440	0.1033
		Male	0.0895	0.4723	-0.2608	-0.0651	-0.1546
		Total	0.1157	0.6175	0.3966	0.1054	-0.0102
	Crop income	Female	0.0646	0.4213	0.3275	0.0337	-0.0309
		Male	0.0612	0.5202	-0.3769	-0.0710	-0.1322
		Total	0.0629	0.4989	0.1898	0.0222	-0.0408
	Total income	Female		0.2646			
		Male		0.1693			
		Total		0.2687			
Zimbabwe	Environmental income	Female	0.4198	0.3393	0.9977	0.9383	0.5185
		Male	0.3394	0.4187	0.6465	0.3171	-0.0223
		Total	0.3488	0.4170	0.6668	0.3501	0.0012
	Livestock income	Female	0.0191	0.4700	0.9362	0.0554	0.0364
		Male	0.1311	0.5979	0.6298	0.1704	0.0393
		Total	0.1180	0.6215	0.5809	0.1537	0.0357
	Crop income	Female	0.0458	0.4583	0.7636	0.1058	0.0600
		Male	0.0561	0.3842	0.4009	0.0298	-0.0263
		Total	0.0549	0.3947	0.4214	0.0330	-0.0219
	Total income	Female		0.1515			
		Male		0.2897			
		Total		0.2771			
Full sample	Environmental	Female	0.3132	0.5055	0.5617	0.3707	0.0575
		Male	0.3411	0.3860	0.6030	0.2804	-0.0608
		Total	0.3360	0.4140	0.5899	0.2962	-0.0397
	Livestock	Female	0.0882	0.6617	0.5148	0.1252	0.0370
		Male	0.1712	0.5724	0.5704	0.1974	0.0262
		Total	0.1558	0.6088	0.5475	0.1876	0.0317
	Crop	Female	0.0548	0.4394	0.2281	0.0229	-0.0319
		Male	0.0551	0.4355	0.3563	0.0302	-0.0249
		Total	0.0551	0.4376	0.3415	0.0297	-0.0253
	Total income	Female		0.2399			
		Male		0.2832			
		Total		0.2769			

Source: Household survey (2022/23)

Table A13: Participation in environmental resource extraction

Resources harvested	Harvested (Y)		Buffer zone (Y)		Protected area		Permission (Y)		Female		Male		Processed (Y)	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%			Freq.	%
1. Firewood	979	88.36	801	83.35	160	16.65	667	69.41	728	75.83	232	24.17	461	48.22
2. Wild vegetables	439	39.62	336	76.54	103	23.46	278	63.47	413	94.51	24	5.49	189	43.35
3. Common pastures	426	38.45	269	63.74	153	36.26	289	68.81	37	8.89	379	91.11	-	-
4. Watering points	426	38.45	314	74.41	108	25.59	322	76.67	25	6.00	392	94.00	-	-
5. Fish	194	17.51	134	68.37	62	31.63	135	68.57	104	53.61	90	46.39	79	40.51
6. Thatch grass	177	15.97	115	65.34	61	34.66	104	58.76	150	84.75	27	15.25	87	49.71
7. Wild fruits	161	14.53	122	75.78	39	24.22	132	81.48	116	72.05	45	27.95	68	42.24
8. Poles/timber	106	9.57	80	76.19	25	23.81	80	74.77	22	21.15	82	78.85	43	41.35
9. Bushmeat	101	9.12	52	51.49	49	48.51	16	15.84	12	11.88	89	88.12	59	58.42
10. Insects	91	8.21	76	83.52	15	16.48	63	69.23	66	73.33	24	26.67	73	81.11
11.Palm/marula wine	89	8.03	57	61.96	35	38.04	66	71.74	19	20.65	73	79.35	71	77.17
12. Hats	51	4.60	26	50.98	25	49.02	4	7.84	25	49.02	26	50.09	45	88.24
13. Mushrooms	37	3.34	34	91.89	3	8.11	27	72.97	31	83.78	6	16.22	15	40.54
14. Brickmaking	34	3.07	32	91.43	3	8.57	12	34.29	25	71.43	10	28.57	35	100.00
15. Farm implements	32	2.89	14	43.75	18	56.25	10	31.25	5	15.63	27	84.38	32	100.00
16. Charcoal	28	2.53	24	85.71	4	14.29	12	42.86	18	64.29	10	35.71	25	89.28
17. Wild honey	24	2.17	16	66.67	8	33.33	19	76.00	5	20.83	19	79.17	14	58.33
18. Wild birds	24	2.17	19	79.17	5	20.83	11	45.83	7	29.17	17	70.83	16	66.67
19. Medicines	23	2.08	15	62.50	9	37.50	20	83.33	13	54.17	11	45.83	7	29.17
20. Household utensils	22	1.99	12	54.55	10	45.45	9	40.91	4	18.18	18	81.82	22	100.00
21. Mats	16	1.44	13	81.25	3	18.75	14	87.50	14	87.50	2	12.50	16	100.00
22. Furniture	14	1.26	7	50.00	7	50.00	3	21.43	-	-	14	100.00	14	100.00
23. Baskets	13	1.17	8	61.54	5	38.46	8	61.54	10	76.92	3	23.08	12	92.31
24. Manure/mulch	11	0.99	11	100.00	-	-	9	81.82	8	72.73	3	72.72	2	18.18
25. Reptiles	10	0.90	3	25.00	9	75.00	1	8.33	2	16.67	10	83.33	3	25.00
26. Natural resins/glue	9	0.81	3	33.33	6	66.67	3	33.33	2	22.22	7	77.78	7	77.78
27. Flavour/spices	9	0.81	9	90.0	1	10.00	3	30.00	10	100.00	-	-	10	100.00
28. Natural pesticides	8	0.72	5	62.50	3	37.50	6	75.00	4	50.00	4	50.00	5	62.50
29. Amphibians	7	0.63	9	64.29	5	35.71	13	92.86	8	57.14	6	42.86	12	85.71
30. Fibres/rope	7	0.63	5	71.43	2	28.57	5	71.43	1	14.29	6	85.71	5	71.43
31. Sculpture/carving	6	0.54	2	33.33	4	66.67	1	16.67	-	-	6	100.00	6	100.00
32. Pottery	4	0.36	1	25.00	3	75.00	4	100.00	3	75.00	1	25.00	4	100.00
33. Livestock fodder	2	0.18	2	100.00	-	-	2	100.00	1	50.00	1	50.00	1	50.00
34. Livestock medicines	2	0.18	2	100.00	-	-	2	100.00	-	-	2	100.00	1	50.00

Source: Household survey (2022/23)

Table A14: Quantities of environmental resources extracted in kgs/litres/number of items

Resources harvested	Obs.	Freq. of Harvest		Time spend		Harvest		Consumed		Sold		Price		Income	
		Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
1. Firewood	**979**	17.58	37.65	5.59	23.62	2180.00	1111.81	2039.11	1028.53	963.50	560.92	3.04	0.29	6122.05	3422.86
2. Wild vegetables	439	10.45	10.10	2.59	1.79	24.53	33.04	13.92	13.40	10.46	24.90	15.93	5.11	498.57	461.11
3. Common pastures	426	253.00	141.12	2.58	1.06	9800	9870	9800	9870	-	-	4.40	0.20	430.12	424.00
4. Watering points	426	313.61	90.15	2.58	1.06	4303	4323	4303	4323	-	-	2.44	0.16	1051.26	1037.85
5. Fish	194	12.14	18.90	4.64	5.58	30.10	41.45	14.46	14.03	31.31	35.38	78.05	8.56	1187.73	1242.21
6. Thatch grass	177	5.67	2.59	3.39	1.31	292.54	114.38	260.63	141.93	200.95	72.21	6.56	1.26	1710.68	1088.85
7. Wild fruits	161	12.51	19.32	3.62	6.81	25.36	49.61	10.46	9.77	31.63	56.70	22.03	8.73	222.61	186.96
8. Poles/timber	106	4.70	2.31	3.49	2.19	3026.67	1642.60	2311.88	1170.75	3020.00	1517.12	18.10	1.49	426.49	214.12
9. Bushmeat	101	5.87	5.06	4.50	2.77	38.89	31.79	17.86	12.15	31.11	22.62	94.41	6.94	1701.78	1194.46
10. Insects	91	6.26	7.86	3.46	6.87	28.26	41.52	11.21	9.95	33.07	41.91	24.79	5.21	278.69	233.65
11.Palm/marula wine	89	11.82	10.06	3.54	2.68	55.11	79.14	15.45	12.70	56.94	76.81	22.13	3.25	337.09	271.53
12. Hats	51	12.27	6.69	3.25	0.98	23.22	17.42	3.55	1.06	28.66	13.42	39.45	4.81	121.45	45.08
13. Mushroom	37	5.27	5.59	3.56	5.75	10.70	7.82	6.41	4.14	9.94	5.88	52.11	6.43	335.25	224.75
14. Brickmaking	34	19.03	9.43	5.66	1.03	3168.57	2495.85	2213.33	1108.50	2202.73	2115.91	0.83	0.25	1393.33	490.20
15. Farm implements	32	14.00	12.50	2.72	1.14	23.00	23.50	3.19	1.18	39.45	15.71	25.28	5.74	80.69	35.66
16. Charcoal	28	9.18	4.68	5.32	1.85	181.79	117.79	80.71	36.81	160.59	86.13	17.21	1.93	1401.07	721.43
17. Wild honey	24	4.21	4.91	2.47	1.47	17.73	23.73	2.83	2.04	19.86	23.51	85.83	11.67	232.71	135.57
18. Wild birds	24	5.42	8.13	4.54	12.03	14.81	18.69	7.10	6.10	14.09	10.14	42.92	5.09	311.98	268.65
19. Medicines	23	4.13	4.84	2.94	5.90	5.88	10.99	2.56	4.21	11.36	10.27	54.38	13.93	120.20	167.30
20. Household utensils	22	13.91	12.61	2.91	1.23	25.86	26.75	3.45	1.37	44.55	18.16	12.05	1.96	40.23	15.23
21. Mats	16	10.50	5.47	3.00	0.89	8.94	6.20	3.78	0.72	9.78	5.09	22.81	4.46	79.38	25.16
22. Furniture	14	13.07	80.52	3.71	0.99	8.93	5.61	3.29	1.33	9.88	3.72	111.07	34.76	360.71	172.65
23. Baskets	13	11.85	6.96	3.04	1.39	17.85	13.81	2.54	0.97	19.90	12.45	41.54	9.22	108.08	50.93
24. Manure/mulch	11	5.64	2.54	2.45	0.82	158.18	98.57	158.18	98.57	-	-	2.36	0.60	325.00	149.67
25. Reptiles	10	12.58	16.91	3.75	1.42	31.25	34.37	11.58	8.92	26.11	27.25	57.50	8.45	1637.50	1386.80
26. Natural resins/glue	9	4.78	1.99	2.78	0.67	0.94	0.60	0.94	0.60	-	-	53.33	8.29	52.00	29.34
27. Flavour/spices	9	2.40	1.26	1.55	0.69	3.65	3.41	2.50	1.49	3.83	2.02	25.00	3.43	66.50	44.80
28. Natural pesticides	8	1.38	0.74	1.31	0.80	0.94	0.32	0.94	0.32	-	-	55.63	11.48	53.75	29.25
29. Amphibians	7	7.36	3.32	3.36	1.01	17.07	11.83	5.71	2.43	14.90	7.32	21.00	3.16	343.00	121.29
30. Fibres/rope	7	6.29	4.00	2.79	0.81	24.53	23.16	24.53	23.16	-	-	12.71	3.68	272.14	228.73
31. Sculpture/carving	6	15.67	9.89	4.33	1.03	17.00	17.13	-	-	16.67	17.50				
32. Pottery	4	20.25	12.84	6.25	3.86	58.25	42.18	4.00	1.15	55.75	39.69	100.00	35.59	355.00	66.58
33. Livestock fodder	2	7.50	6.36	5.00	1.41	5500.00	707.10	5500.00	707.70	-	-	85.00	21.21	325.00	35.36
34. Livestock medicines	2	1.00	-	3.50	3.54	1.00	-	1.00	-	-	-	85.00	21.21	85.00	21.21

Source: Household survey (2022/23)

Table A15: Quantity processed, consumed and sold, including gender and income

Resource processed	Obs.	Qnty. Processed		Qnty consumed		Qnty. Sold		Place (1=F)	Days taken	No. of ppl	Gender (1=M)	Price		Income	
		Mean	Std.	Mean	Std.	Mean	Std.					Mean	Std.	Mean	Std.
1. Firewood	143	2939.58	1264.17	2012.89	1030.48	969.58	558.15	0.56	4.04	1.83	0.32	3.41	0.31	3325.88	1968.48
2. Wild vegetables	50	30.00	25.72	11.20	9.46	18.75	17.13	0.42	2.17	1.67	0.23	23.69	4.59	401.08	366.86
3. Common pastures															
4. Watering points															
5. Fish	50	60.80	46.65	14.76	10.11	30.90	35.61	0.58	6.96	2.02	0.52	91.69	9.54	2955.83	3455.24
6. Thatch grass	36	371.94	112.45	174.29	68.27	196.94	73.87	1.00	5.97	2.53	0.14	10.47	1.75	2027.22	753.46
7. Wild fruits	40	35.93	48.88	13.94	11.69	33.81	58.92	0.50	3.26	1.71	0.32	25.04	5.81	707.86	942.08
8. Poles/timber	23	478.70	167.01	183.00	588.58	328.26	126.87	0.09	5.87	2.39	1.00	28.04	2.84	924.57	370.40
9. Bushmeat	39	45.38	25.52	15.97	10.70	29.21	19.85	0.33	3.81	1.57	0.93	104.00	10.21	3060.18	2121.92
10. Insects	42	45.60	47.11	12.51	12.70	34.61	42.25	0.43	3.93	2.05	0.26	33.49	5.96	1078.33	1144.88
11.Palm/marula wine	62	75.72	89.43	17.35	14.39	56.92	75.98	0.97	14.90	1.69	0.76	32.48	4.11	1774.23	2186.91
12. Hats	35	32.89	13.86	3.40	1.06	29.66	13.36	0.17	52.66	1.11	0.69	61.37	6.62	1846.29	896.01
13. Mushroom	16	15.29	8.46	6.00	3.12	9.88	5.94	0.42	6.08	1.33	0.25	72.19	5.47	1057.81	643.32
14. Brickmaking	14	4800.00	3097.39	2800.00	1243.99	3000.00	1792.72	1.00	14.64	2.50	0.43	0.93	0.15	2103.40	1323.37
15. Farm implements	16	43.13	16.62	3.50	1.15	39.63	15.86	0.25	29.06	1.19	1.00	36.94	6.01	1409.81	485.78
16. Charcoal	17	234.71	120.78	68.24	24.81	160.59	86.13	0.94	12.35	4.18	0.47	23.88	1.54	3775.29	1855.90
17. Wild honey	13	23.85	24.42	3.22	2.32	19.86	23.51	0.64	2.36	1.91	0.91	100.94	18.56	1866.28	1899.59
18. Wild birds	10	21.80	14.38	5.75	4.96	13.17	10.19	0.10	3.70	1.70	0.70	53.75	8.29	726.25	552.62
19. Medicines	6	15.08	16.19	5.17	7.41	9.92	10.44	0.67	6.50	1.00	0.83	69.17	28.88	492.50	508.47
20. Household utensils	11	48.64	18.99	3.82	1.40	44.82	18.27	0.36	32.73	1.36	1.00	16.09	2.26	727.73	330.44
21. Mats	9	13.00	5.41	3.11	0.60	9.89	5.09	0.00	22.67	1.00	0.11	31.67	4.33	311.67	160.08
22. Furniture	8	12.75	4.27	2.88	1.25	9.88	3.72	0.25	23.11	1.25	1.00	218.75	68.13	2270.00	1297.38
23. Baskets	10	22.50	12.25	2.60	1.07	19.90	12.45	0.30	28.20	1.40	0.30	67.00	11.60	1281.00	744.06
24. Manure/mulch	2	200.00	141.42	100.00	141.42	100.00	-	-	6.50	1.00	0.00	2.50	0.71	250.00	70.71
25. Reptiles	3	50.00	40.93	10.29	7.23	29.38	27.18	0.33	7.67	2.00	1.00	57.50	8.45	1637.50	1386.80
27. Flavour/spices	2	6.25	5.30	3.00	2.83	3.25	2.47	-	3.50	1.00	-	37.50	3.54	126.25	104.30
28. Natural pesticides															
29. Amphibians	10	20.20	7.77	5.30	1.77	14.90	7.23	0.20	4.60	1.90	0.40	23.50	4.12	338.00	148.68
30. Fibres/rope	2	2.50	2.12	4.00	-	2.00	2.83	0.50	13.00	1.00	0.00	80.00	14.14	250.00	155.56
31. Sculpture/carving	5	20.00	17.31	-	-	20.00	17.31	0.80	53.00	1.25	1.00	290.00	41.83	5550.00	4171.93
32. Pottery	3	76.67	25.17	4.33	1.15	73.33	22.55	0.00	103.3	2.33	0.00	133.33	28.87	9416.67	1876.39
33. Livestock fodder															
34. Livestock medicines															

Source: Household survey (2022/23)

Table A15: Quantity bought, perception of source, allowed, frequency, gender and income

Resource processed	Obs.	Purchased	Source (1 =PA)	Allowed (1=Y)	Purchase freq.		Qnty. bought		Purchase Price		Total Expenditure		Total consumed	
					Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
1. Firewood	241	21.75	26.86	23.14	3.79	1.40	1367.44	772.10	1.36	0.13	1871.80	1093.29	1961.59	987.88
2. Wild vegetables	113	10.20	31.25	86.61	3.63	2.55	3.23	2.23	16.52	4.04	53.32	39.68	5.41	7.86
3. Common pastures														
4. Watering points														
5. Fish	118	10.65	13.33	79.17	5.40	4.09	7.18	5.34	51.87	12.44	363.85	289.35	7.29	5.44
6. Thatch grass	24	2.17	33.33	83.33	1.71	1.00	75.63	23.00	6.58	1.91	495.21	195.87	75.61	23.00
7. Wild fruits	103	9.30	24.27	82.52	4.53	2.09	5.44	3.15	20.83	4.32	112.53	65.98	6.36	4.33
8. Poles/timber	18	1.62	55.56	16.67	1.78	1.17	30.22	67.64	15.94	3.73	265.22	180.62	29.39	67.81
9. Bushmeat	96	8.66	28.13	30.21	3.99	3.23	5.89	4.74	54.47	33.51	290.62	217.68	7.57	11.11
10. Insects	115	10.38	14.91	91.23	4.18	2.48	6.51	4.52	22.52	4.77	139.84	88.38	7.03	5.07
11.Palm/mmarula wine	15	1.35	0.00	100.00	34.20	67.31	51.73	74.91	107.60	251.43	307.83	447.56	284.86	867.95
12. Hats	5	0.45	50.00	80.00	1.40	0.89	1.60	0.89	43.00	14.83	103.33	45.09	2.00	1.00
13. Mushroom	56	5.05	37.50	89.27	2.00	1.06	2.38	0.97	45.59	10.31	109.71	47.49	2.59	1.13
14. Brickmaking														
15. Farm implements														
16. Charcoal	26	2.35	33.33	46.15	3.77	2.20	53.08	26.65	13.69	3.12	684.23	280.33	53.46	26.22
17. Wild honey	17	1.53	23.53	94.12	2.24	1.95	1.12	0.67	64.41	7.88	76.62	46.16	1.12	0.67
18. Wild birds	4	0.36	0.00	100.00	6.50	6.35	3.50	4.51	102.00	139.71	52.50	98.45	4.00	4.32
19. Medicines	5	0.45	20.00	80.00	0.80	0.45	1.21	1.08	15.00	19.69	113.00	217.22	1.26	1.25
20. Household utensils	8	0.72	0.00	87.50	1.00	-	7.25	4.95	39.38	58.76	152.50	154.55	3.00	2.67
21. Mats	11	0.99	0.00	90.91	1.27	0.65	2.27	1.74	70.00	30.41	115.91	82.18	1.90	1.66
22. Furniture	2	0.18	0.00	100.00	1.00	-	1.00	-	1500	-	1500	-	1.00	-
23. Baskets	5	0.45	20.00	80.00	1.00	-	1.20	0.45	95.00	80.31	135.00	86.31	15.00	30.75
24. Manure/mulch	1	0.09	0.00	100.00	1.00	-	50.00	-	15.00	-	750.00	-	50.00	-
25. Reptiles	15	1.53	47.06	17.65	2.06	1.20	3.21	1.55	59.41	7.48	188.38	86.71	2.85	1.39
26. Natural resins/glue														
27. Flavour/spices	3	0.27	0.00	33.33	7.67	4.04	13.33	7.64	25.00	5.00	188.33	98.28	58.33	79.74
28. Natural pesticides														
29. Amphibians	32	2.89	28.13	93.75	2.19	1.06	3.11	2.49	25.72	13.97	109.77	255.94	3.36	2.73
30. Fibres/rope	1	0.09	0.00	100.00	2.00	-	18.00	-	10.00	-	180.00	-	18.00	-
31. Sculpture/carving														
32. Pottery														
33. Livestock fodder														
34. Livestock medicines	5	0.45	0.00	100.00	1.00	-	2.80	2.49	86.00	20.74	208.00	116.49	2.80	2.49

Source: Household survey (2022/23)

APPENDIX B: FULL METHODOLOGY

SAMPLING, SAMPLE SIZE & DATA COLLECTION

B1: Study site

Figure 1 shows the map of the study site, and here we describe its major characteristics. The Great Limpopo Transfrontier Conservation Area (GLTFCA) is a vast and ecologically significant region that spans parts of southern Mozambique, northeastern South Africa, and southeastern Zimbabwe. It includes core conservation zones such as Limpopo National Park (Mozambique), Kruger National Park (South Africa), and Gonarezhou National Park (Zimbabwe), along with surrounding communal areas and buffer zones. Geographically, the GLTFCA lies roughly between 22° and 25° South latitude and 30° and 33° East longitude, covering a combined area of over 100,000 square kilometres. The population living in and around the GLTFCA is predominantly rural, with communities engaged primarily in subsistence agriculture, livestock rearing, small-scale fishing, and informal trade, alongside increasing dependence on natural resources for livelihoods.

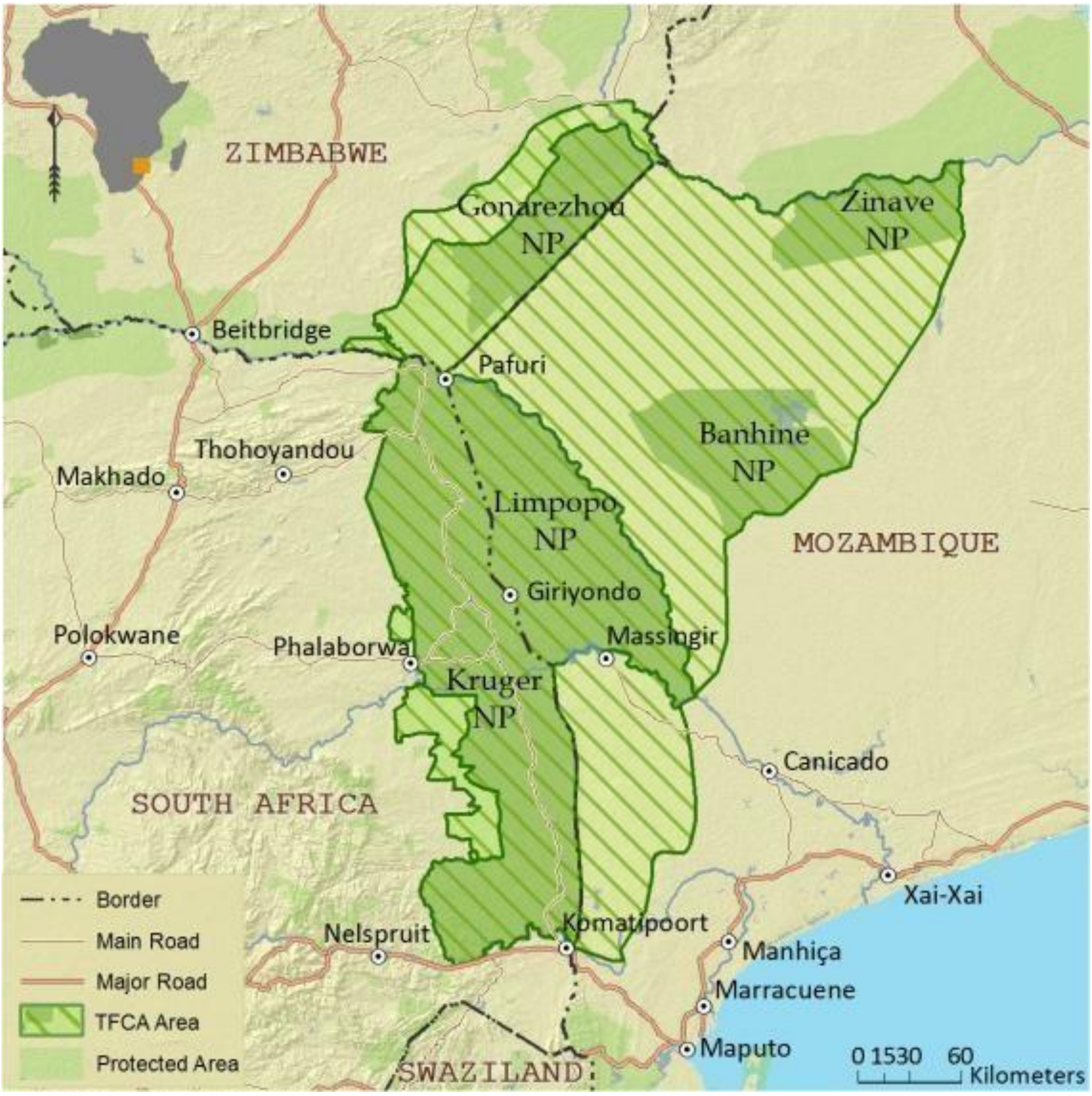

Figure 1: RP-PCP (2025)

Source: https://www.rp-pcp.org/study-sites/great-limpopo

The region experiences a semi-arid to sub-tropical climate, characterized by hot, wet summers (November to March) and cool, dry winters (May to August). Annual rainfall varies from 300 mm in drier lowlands to over 700 mm at higher altitudes, with Mozambique and Zimbabwe typically receiving less precipitation than South Africa. Despite its rich biodiversity and conservation value, communities across the GLTFCA face persistent challenges such as climate variability, human-wildlife conflict, limited access to basic services, and economic marginalization. In recent years, the GLTFCA has gained strategic importance, not only in terms of transboundary conservation efforts but also as a platform for integrated development and cross-border cooperation among the three countries, aiming to balance biodiversity protection with community welfare.

B2: Sampling methods and sample size

Simple random sampling in the GLTFCA is challenging due to the arrangement or setup of rural households in African communities, and thus requires innovation. Often, a sampling frame is unavailable in rural communities and new households emerge during the fieldwork, complicating the sampling process. An initial sampling frame showing a list of households in each community was generated with help from local authorities, such as local government structures at the district level and municipalities, chiefs, and village heads, where appropriate. The use of simple random sampling based on the sampling frame, although methodologically robust, was constrained by the survey budget, given the large communities in the GLTFCA and the spatial distribution of households, which made it financially and logistically challenging to implement a fully randomized sampling approach. As a result, the sampling strategy had to balance methodological rigor with practical feasibility, ensuring adequate representation while remaining within the resource constraints of the study.

The random sampling of households was done in two steps based on a systematic random sampling procedure. First, the household list was used to compute a sampling interval (n). The household list captured the head of the household in each community. Households not on the list were verified, added, and recruited into the sample. The sampling interval was computed by dividing the population size in each community by the desired sample size in that community. The number of sampled households from each community was calculated as a proportion of the total sample size in each country.

Second, respondents randomly chose a starting point and direction from the centre of the community by tossing a coin and a six-sided die simultaneously. The starting point was selected if the coin landed on heads, while the numbers 1 – 4 on the die represented North, West, South, and East. The enumerator moved to a different household if the coin landed on the tail and numbers 5 or 6 appeared on the die. Once the direction and a starting point had been identified, the enumerator would skip n households to select the next respondent. This process would continue until either the required sample size had been achieved or all households in that direction were exhausted. If households were exhausted in one direction, the enumerator would move to a new location and start the process again. Enumerators were spaced sufficiently to avoid collision of paths. The same sampling method was used in all three countries to ensure consistency in the sampling procedure and a demographically representative sample of the households.

The study recruited a total of 1,108 households in the GLTFCA. The survey, which focused on exploring local perceptions of the governance of the conservation areas, had 322 respondents from Zimbabwe, 374 from South Africa, and 412 from Mozambique, located in 40 villages with traditional authorities inside or on the border areas of the National Parks. Through face-to-face structured interviews, the authors conducted the survey in three rounds, one per country. The first round was conducted in December 2022 in South Africa, the second round in July 2023 in Zimbabwe, and the third and final round was completed in December 2023 in Mozambique.

B3. Data collection procedure

To ensure that the data collection procedure followed sound practices consistent with ethical social sciences standards, the questionnaire underwent a rigorous evaluation exercise by the Ethics Committee at the Faculty of Commerce at the University of Cape Town. The study recruited and trained undergraduate and postgraduate students from local communities in the GLTFCA as enumerators for primary data collection. For more information about the protocols followed before data collection, enumerator recruitment, and training, kindly refer to Appendix A. The researchers applied for research permits from responsible authorities in South Africa, Zimbabwe, and Mozambique. Permission to enter the communities and conduct interviews was ultimately granted by the chiefs and village heads responsible for local management structures on the ground.

The study recruited undergraduate and postgraduate students from the communities as enumerators to collect the primary data in the GLTFCA. The same enumerators were used in all the communities and countries to reduce enumerator bias, while at the same time increasing data quality or accuracy and efficiency. The enumerators were trained for three days before they practiced with actual respondents. During the first day, the enumerators went through the research instruments, discussing each question thoroughly to understand the intention behind each question so that they could ask it accurately in the local language. During the second and third days, enumerators took turns asking each other questions to familiarise themselves with the questionnaire and questions. On the third day, a pilot study was conducted in each country as enumerator training. The enumerators were allowed to go into the field to practice with actual respondents. The researchers and enumerators discussed the enumerators' experiences in the field on the final training day and adjusted the instrument accordingly. Once the researchers were satisfied with the progress and applicability of the instrument under different contexts, the actual fieldwork started.

B4. Conceptual framework

Figure 1 presents a conceptual framework linking the welfare effects and gender dynamics of the GLTFCA's biodiversity economy. The biodiversity economy within the GLTFCA encompasses a range of both licit and illicit nature-based economic activities that rely on the region's rich natural capital, including wildlife, forests, and water resources. These activities include ecotourism, conservation agriculture, sustainable harvesting of natural products, and wildlife-based enterprises such as game ranching and safari hunting. While the biodiversity economy presents significant opportunities for promoting sustainable livelihoods, enhancing rural incomes, and conserving ecosystems, its benefits are not evenly distributed. The welfare effects vary across communities and households, influenced by factors such as land tenure, access to markets, and the regulatory environment. Illicit activities, such as poaching or unregulated harvesting, often emerge in contexts of poverty, exclusion, and weak governance, creating both risks and coping mechanisms for local populations.

Welfare impacts of biodiversity-based livelihoods are multifaceted. On the one hand, these activities can contribute to poverty reduction, food security, and resilience against economic and climate shocks, especially when communities are integrated into formal value chains and receive tangible benefits from conservation efforts. On the other hand, conservation restrictions, human-wildlife conflict, and elite capture of ecotourism revenues can undermine local welfare, leading to economic displacement and social tensions. The conceptual framework therefore considers both the positive and negative externalities associated with biodiversity conservation and resource use, and the institutional arrangements that mediate these outcomes. It also highlights the role of policies and benefit-sharing mechanisms in enhancing or constraining the welfare gains of rural households in the GLTFCA.

Gender dynamics further shape how individuals and households engage with and benefit from the biodiversity economy. Women and men often play distinct roles in natural resource use and management, yet women are frequently underrepresented in decision-making processes and face barriers to accessing land, capital, and markets. These structural inequalities can limit women's participation in conservation programs and their ability to benefit from biodiversity-based livelihoods. At the same time, women often bear a disproportionate share of the costs associated with conservation restrictions or increased labour burdens from environmental degradation. By integrating a gender lens, this framework emphasizes the importance of equitable access, representation, and benefit-sharing to ensure that the biodiversity economy contributes not only to conservation goals but also to inclusive and just development across the transboundary landscape of the GLTFCA.

Figure 1: Conceptual framework of biodiversity economy, welfare and gender (Haverhals et al., 2016).

The biodiversity economy has the potential to significantly contribute to the achievement of several Sustainable Development Goals (SDGs), provided that the natural resources within TFCAs are managed sustainably. This requires a deliberate balance between social objectives, such as poverty reduction and gender equality; economic goals, including job creation and inclusive growth; and the preservation of ecological infrastructure, such as healthy ecosystems and biodiversity. When managed holistically, the biodiversity economy can support SDG 1 (No Poverty), SDG 5 (Gender Equality), SDG 8 (Decent Work and Economic Growth), SDG 13 (Climate Action), and SDG 15 (Life on Land), among others. Achieving this balance calls for integrated policy frameworks, inclusive governance structures, and community participation to ensure that conservation efforts generate equitable and long-term benefits for both people and nature.

MATHEMATICS BEHIND THE MODELS

B.5 Propensity score matching

4.2.1 Theoretical and analytical framework

The theoretical framework is based on Roy (1951) and Rubin (1974), where the decision of households to participate in the biodiversity economy depends on the expected benefits, such as per capita income or expenditure in park-adjacent communities. The focus is on the Average Treatment Effect on the Treated (ATT), which measures how participation in the biodiversity economy affects the welfare of households within TFCAs. Since it is not possible to observe outcomes without the treatment for those who participate, non-beneficiaries of the scheme are used as counterfactuals. Given that participation is non-random, there is a risk of selection bias. To address this, the study uses the PSM technique to estimate the mean impact on household welfare.

4.2.2 Identification strategy

The analysis assumes that a set of observable covariates X, which are unaffected by the treatment (participation in the biodiversity economy), are independent of the treatment assignment, known as the Conditional Independence Assumption (CIA). This assumption is strong and requires justification based on data quality. In addition to independence, the analysis requires a common support or overlap condition, which ensures that households with the same values of X have a positive probability of being both participants and non-participants in the biodiversity economy (Heckman et al., 1999). This overlap condition is represented as

$$0 < P(X) < 1 \tag{1}$$

The effectiveness of the Propensity Score Matching (PSM) method relies on having a substantial region of common support (Khandker et al., 2010). For estimating the Average Treatment Effect on the Treated (ATT), the assumption can be relaxed to $P\ (T = 1 \mid X\ ) < 1$.

4.2.3 Estimation Strategy

If the CIA holds and there is sizable overlap (Heckman et al., 1999), then the next step is to find the PSM estimator. PSM was undertaken in two steps. The first step was generation of propensity scores from a probit model using the household socio-economic and demographic characteristics, community level characteristics, and other controls. The score indicates the probabilities of respective households participating in the scheme. From the scores, we constructed a control group by matching beneficiaries to non-beneficiaries according to their propensity scores by comparing various methods of matching.

The second stage involved computation of the ATT of households and CFAs benefiting from incentives on household welfare and forest cover, respectively, using the matched observations.

B.6 Model specification

The PSM estimator for the ATT is specified as the mean difference in Y (per capita household income or expenditure over common support), weighting the comparison units by the propensity score distribution of participants. The cross-section estimator is specified as:

$$\tau_{ATT}^{PSM} = E(T = 1)\{E[T = 1, P(X)] - E[T = 0, P(X)]\} \quad (2)$$

where Y (1) and Y (0) represents per capita household income or expenditure beneficiary and non-beneficiary households, respectively. $T = 1$ indicates treated or beneficiary households, while $T = 0$ indicates control or non-beneficiary households. The PSM estimator is thus given by the mean difference in outcomes over the common support, weighted by the propensity score distribution of participants (Caliendo and Kopeinig, 2008). According to Caliendo and Kopeinig (2008), inclusion of non-significant variables cannot lead to inconsistent or biased results. We thus used all the variables in the PSM probit in the outcome analysis. Because of the restrictive identification condition, selection issues, and potential endogeneity, the study also employed the use of the conditional QTE model under the endogeneity assumption described in the next section.

B.7 Quantile Treatment Effects Model

The quantile treatment effects (QTE) model estimates the causal effect of a binary treatment on an outcome variable and can identify the distributional effects. To determine the distributional impact of the scheme on household welfare, the study employed the parametric conditional QTE model under endogenous assumption following Abadie et al. (2002) and Chernozhukov and Hansen (2008).

4.4.1 Conceptual Framework

Given a continuous outcome variable Y, we consider the effect of a binary treatment variable D. We let Y_i^1 and Y_i^0 be the potential outcomes of household i that is per capita monthly income or expenditure. Hence, Y_i^1 would be realized if household i participated in biodiversity economy and Y_i^0 would be realized otherwise. We define Y_i as the observed outcome, which is $Y_i = Y_i^1 D_i + Y_i^0(1 - D_i)$, and estimate the entire distribution functions of Y^1 and Y^0 (Frölich and Melly, 2010).

We then define QTE conditionally on the covariates as we deal with the endogenous treatment choice, since in our case, selection is unobservable, meaning that treatment assignment is non-ignorable. Participation in the biodiversity economy is also potentially endogenous to per capita income or expenditure. The traditional quantile regression may therefore be biased, hence the need for an instrumental variable (IV) to recover the true effects. Key concerns with respect to instrumental variables are weak instruments and over-identification. A 2SLS that contains weak instruments is not identified, thus the instruments treatment effect is not valid (Stock and Yogo, 2005). In addition, if the instruments affect participants in different ways, interpreting the resulting treatment effects may be complicated, that is treatment effects heterogeneity (Frölich and Melly, 2010). The exclusion restriction is, however, difficult to test, as it is in all IV applications.

Assuming we observe a binary instrument Z, we define two potential treatments denoted D_z. We then make use of the following assumptions underlying the potential outcome framework for IV with probability one, as in Abadie et al. (2002).

1. Independence: Y^0, Y^1,D_0, D_1 is jointly independent of Z given X
2. Exclusion: $Pr(Y^1 = Y^0|X) = 1$
3. Non Trivial Assignment: $0 < Pr(Z = 1|X) < 1$
4. First Stage: $E[D_1|X] = E[D_0|X]$
5. Monotonicity: $Pr(D_1 \geq D_0|X) = 1$

The first assumption is the standard IV assumption of exclusion restriction. It claims that the exclusion restriction and non-confoundedness of IV is only possible if the instrumental variable is conditioned on covariates (Abadie et al., 2002). It implies that, if conditioned on a set of covariates, the instrumental variable should not affect the outcome of individual i but rather the treatment channel. However, the monotonicity assumption requires that the treatment variable D either increases or decreases weakly with Z for all i. The third assumption requires that propensity scores of instrumental variables exist. In addition to these assumptions, individuals with $D_1 > D_0$ are referred to as compliers.

Treatment can be identified only for this group, since the "always" and "never" participants cannot be induced to change treatment status by hypothetical movement of the instrument (Frölich and Melly, 2010). Following Abadie et al. (2002), the conditional QTE δ^τ for the compliers is estimated by the weighted quantile regression:

$$(\beta_{IV}^\tau, \delta_{IV}^\tau) = argmin \sum W_i^{AAI} \cdot \rho_\tau(Y_i - X_i\beta - D_i\delta)$$

$$W_i^{AAI} = 1 = \frac{D_i(1 - Z_i)}{1 - Pr\ (Z = 1|X_i)} - \frac{(1 - D_i)Z_i}{Pr\ Pr\ (X_i)} \quad (3)$$

To implement the estimator, we first need to estimate $Pr(Z = 1|X_i)$. $\rho_\tau(u)$ as the check function, where $\rho_\tau(u) = u \times \{\tau - 1(u < 0)\}$. This is estimated using the *ivqte* command in stata, since it produces analytical standard errors that are consistent even in case of heteroscedasticity (Frölich and Melly, 2010). Given that some weights may be negative or positive, the *ivqte* stata command uses the local logit estimator and implements the AAI estimator with positive weights. An alternative provided by Abadie et al. (2002) shows that the following weights can be used as an alternative to W_i^{AAI}, where

$$W_i^{AAI+} = E[Y_i, D_i, X_i] \quad (4)$$

which are always positive. The *ivqte* command uses the local linear regression to estimate W_i^{AAI}. The passage explains the use of an instrumental variable to estimate the QTE in a model. The instrument used is whether a household member was born in the village, which is assumed to influence their intention to participate in the biodiversity economy but not directly affect household income or expenditure. The rationale is that locals, having grown up with the natural resources, may take them for granted and prefer other income sources, while outsiders are more likely to value and engage with these resources. However, distance to the forest can also influence participation and income, so the analysis controls for this and other covariates to ensure the instrument's validity.

B.8 Inverse Probability Weighting Regression Model

This passage explains that the Inverse Probability Weighting (IPW) regression model is used to address selection bias by reweighting the data. It assumes that, given certain covariates, treatment (e.g., adoption of CSA technology) does not affect the outcome distribution. The goal is to estimate the ATE on the treated by using propensity scores to create a control group that closely resembles the treated group. IPW simulates this matching process by adjusting the weights of observations, making the distribution of beneficiaries and non-beneficiaries more comparable. However, identification of the average effect of beneficiaries within this framework requires both strict ignorance of the treatment ($Y_{1i,} Y_{01} \perp D_i \backslash P(X_i)$) and the propensity score overlap, $0 < P(X_i) < 1$ (Dehejia *et al.,* 2002; Rosenbaum *et al.,* 1983). Another assumption is common support, in which similar individuals have a positive probability of being both beneficiaries and non-beneficiaries (Heckmann *et al.,* 1999). The IPW regression model, where the probability is derived from a logit model in line with the propensity scores, is specified as follows:

$$Prob\ (X_i) = \wedge\ (X\Gamma) \tag{4}$$

Farm, distance to market, and household socioeconomic and demographic characteristics are other controls included in the model. The IPW regression model where the propensity scores are used to reweight the data was applied. In the model, propensity scores are estimated first to create the weights and define overlaps between comparison and control groups, and then the weighted regression is estimated (Cameron *et al.,* 2005; Wooldridge, 2003).

The estimated model is a standard treatment effects regression, wherein the outcome variable of interest is regressed on the treatment together with controls from the propensity score regression presented in equation (1) (Cameron *et al.,* 2005; Wooldridge 2003; Dehejia *et al.,* 2002; Heckmann *et al.,* 1999; Rosenbaum *et al.,* 1983). This is done to control for any lingering covariate imbalance that could influence the estimates.

B.9 Theory behind IV estimation with heteroscedasticity-based instruments

Lewbel (2012) presents the theory that allows the identification and estimation of "endogenous regressor models" by exploiting heteroscedasticity-based instruments. Identification is achieved in this context by having regressors that are uncorrelated with the product of heteroscedastic errors, a feature of many models where error correlations are due to an unobserved common factor. Using this method, instruments are constructed as simple functions of the model's data (Baum et al., 2013). In the following specification:

$$y_1 = y_2\beta_1 + X\beta_2 + \varepsilon \qquad [5]$$

X is a vector of exogenous variables, and y_2 the endogenous variable (namely institutions in the case of this paper). The first-stage equation is given by

$$y_2 = Z\gamma_1 + X\gamma_2 + \mu \qquad [6]$$

where Z comprises excluded exogenous instruments, which cannot be observed in our case. According to Lewbel (2012), the key identifying assumptions for coefficients, especially β_1, are that some variables Z_2, which may be variables in X, exist such that:

$$E(W\varepsilon) = 0 \qquad [7]$$

$$E(W\mu) = 0 \qquad 8]$$

$$E((Z_2 - \mu_2)\mu\varepsilon) = 0 \qquad [9]$$

$$E((Z_2 - \mu_2)\mu^2) \neq 0 \qquad [10]$$

where $W = [X, Z]$ are the available exogenous variables and Z_2 is a subset of W. Equations [7] and [8] are from the exogeneity assumptions of W. Equation [9] requires zero expectation for the product of errors $\mu\varepsilon$ and demeaned Z_2. This condition fundamentally requires that covariance between μ and ε conditional on Z_2 does not depend on Z_2, since

$$E\big((Z_2 - \mu_2)\mu\varepsilon\big) = E\big((Z_2 - \mu_2)cov(\mu, \varepsilon|Z_2)\big) = E\left((Z_2 - \mu_2)\sigma_{\mu,\varepsilon}(Z_2)\right),$$

which is zero when $\sigma_{\mu,\varepsilon}(Z_2)$ is a constant. Equivalently, any heteroscedasticity related to Z_2 cannot enter through the correlated component or common factor of the error terms. The condition in Equation [10] requires that the first stage error μ is heteroscedastic in demeaned Z_2. Conditions [9] and [10] imply that $(Z_2 - \mu_2)\,\mu$ can be used as an instrument for y_2.