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Impact of Carbon Trading Schemes on Mangrove Forest Ecosystem Services and Household Welfare

Evidence from Kenya's Coastal Communities

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Keywords: Mangrove, carbon trading, welfare, ecosystem services.

JEL Code: Q2, Q5, I3.

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1.0 Introduction

Mangrove forests are distributed throughout the tropical and sub-tropical coastal areas of the globe (Ho et al. 2021). Mangrove forests provide a myriad of ecosystem services that are of economic, ecological, and environmental significance, both globally and to local coastal communities (Ewel et al. 1998; Nagelkerken et al. 2008; Lang'at et al. 2013). Mangrove forests also play a significant role in the sequestration of carbon, storing up to five times more carbon per hectare than terrestrial forests (Donato et al. 2011). They provide a habitat and breeding ground for juvenile fish and other fauna, and also play an important role in protecting the shoreline; waste assimilation; the provision of medicine, low-cost firewood, food (fish), timber, nutrients, and fodder for livestock; and the development of rural areas through the provision of Non-Timber Forest Products (NTFPs) (Taylor et al. 2003; Taylor et al. 2018; Steften et al. 2015; Enchelmaier et al. 2020; Hussain et al. 2010; Barbier, 2016; Barbier et al. 2011; Aye et al. 2019; Ameen et al. 2020; Olesen et al. 2022**;** Gbetnkom, 2009; Baudron et al. 2017; Amadu & Miller 2024; Fungo et al. 2016; Karki et al. 2018). The mangrove ecosystems are also a critical factor in reducing vulnerability to natural disasters and economic crises (Soanes et al. 2021; Begum et al. 2021). They are therefore of vital importance in addressing various dimensions of poverty such as income generation, subsistence for forest-dependent coastal communities, and environmental protection.

Compared with other types of forests, mangroves are rare, representing less than 1% of tropical forests and 0.4 % of global forest areas (FAO 2007). However, mangrove forests are more threatened by the effects of climate change and anthropogenic factors than other forest types (Ghosh et al. 2015). About 1.04 million hectares of mangrove forest were lost between 1990 and 2020, creating negative repercussions for the provision of ecosystem services to local communities (Nyangoko et al. 2022). In the East African region, especially Kenya and Tanzania, mangroves are utilized by local coastal communities for furniture and ornate doors, shipbuilding, firewood, building poles, and charcoal. The forests here have become endangered as a result of overexploitation of wood products, coupled with increasing pressure from the growing population in the East African region. Salt extraction has also led to the loss of mangroves, causing hyper-salinity in adjacent areas (Lang'at et al. 2013). In addition, poor land use practices in the hinterland have increased sediment loads into the mangroves, leading to siltation of the breathing roots of the trees and their eventual death. The projected rise in sea level along the East African coast due to climate change also poses a threat to mangrove forests.

The conservation and management of mangroves thus requires a multisectoral, collaborative, and landscape approach rather than the standard top-down approaches (Friess et al. 2016). In response to the loss of inherent mangrove goods and services, government and development partners implemented a range of initiatives to reverse the trend, such as creating awareness about the importance of mangroves; capacity-building in mangrove area restoration and management; and participatory forest management through community forest associations - an arrangement whereby communities manage and benefit from the forest (Forest Act 2016; Okumu et al. 2020).

In the last decade, carbon markets, which rely on restoring or reforesting mangroves, have attracted growing interest (Buditama, 2016; Lovelock et al. 2014). In the East African region, the Kenyan government partnered with development partners to come up with carbon trading schemes. Community-based mangrove management programs that promote multiple uses of the mangrove environment have also been implemented. These programs include activities such as beekeeping, mangrove eco-tourism, and integrated aquaculture. In this study, we aim to analyze the impact of pilot carbon trading schemes implemented in Kenya's coastal regions over the past few years, specifically the "*Mikoko Pamoja*" ("mangrove together" in Swahili) and the Vanga Blue Carbon Forest Project in Kenya's Kwale County. These two carbon trading schemes are of interest to the study because they are the only carbon trading schemes implemented in the coastal region of Kenya that reduce mangrove forest deforestation, improve mangrove forest ecosystems, and provide financial incentives to local households.

Although interest in mangrove research has increased in recent years, an assessment of the ecological and economic roles that they play has hardly been done. Studies have shown that locals are incentivized to conserve forest resources by livelihood and economic benefits (Ha et al. 2014, Roy et al. 2016; Aheto et al. 2016). However, despite having being operational for over a decade, the impact of the carbon trading schemes on livelihoods and the provision of mangrove ecosystem services has hardly been assessed. Women in the coastal region are significantly more engaged in fishing than farming. Hence, it is important to understand the gender-differentiated impacts of the carbon projects, especially since they require 40% female representation. It would also be of inherent value to assess these schemes based not only on their efficiency and effectiveness in promoting equity and provision of ecosystem services, but also on the sustainability of the benefits they provide.

Since the projects are among the first in the East African region, the uncertainty surrounding the exact benefits provided by carbon trading needs to be unraveled. Assumptions of the expected environmental and economic benefits may not translate into actual achievements due to heterogeneous effects, the possibility of elite capture, and the high opportunity cost of restricting forest access. In addition, with respect to integrated forest management, access to forest resources should lead to economic empowerment (human wellbeing), mitigation of climate change effects, and environmental protection (forest cover), i.e. a win-win outcome (Sunderlin et al. 2005). Balancing socioeconomic and environmental demands thus remains a major challenge. Schemes such as carbon trading may only be viable if the economic value of the ecosystem service exceeds the opportunity cost of habitat conservation (Friess et al. 2016). The main challenge for policy makers is thus whether the carbon credits can be cascaded to other forests, leading to sustainable management of forest resources, effective balancing of socioeconomic and environmental demands, and distributional equity.

A number of studies have looked at various issues around mangrove forest conservation, however most have focused on Asian countries (see Roy et al. 2014; Ha et al. 2014; Gosh et al. 2015; Das et al. 2016; Friess et al. 2016; Abdullah et al. 2016; Bhomia et al. 2016; Sidik et al. 2018; Tran et al. 2019; Apipoonyanon et al. 2020; Begum et al.2022; Begum et al. 2024; Thuy et al. 2024). Most studies conducted in Africa have focused on the tropical or sub-tropical forests (see Manley et al. 2012; Gelo et al. 2014; Mazunda et al. 2015; Gelo et al. 2016; Tadesse et al. 2017; Okumu et al 2020; Loswaga, 2023; Luswaga, 2022 Mawa et al. 2022).

Studies that have tried to evaluate the impact of carbon trading on mangrove forest ecosystem services and the livelihood of local communities are quite scant. However, there are a few closely related studies from Asia (Yee 2010; An et al. 2021; Zhu et al. 2020; Yi et al. 2014; Aye et al. 2019; Ali et al. 2015; Yu et al. 2022) and some from Mexico (Jadin et al. 2022). In a more closely-related study in Kenya, Obegi et al. (2018) found that carbon trading improves the welfare of local communities. Huff & Tonui (2017) also demonstrated the significance of community-based participatory forest co-management with respect to the marketing of carbon credits under the *Mikoko Pamoja* project. Several factors have also been found to influence participation in forest conservation initiatives (see Roy et al. 2014; Jumnongsong et al. 2015; Tadesse et al. 2017; Tran et al. 2019; and Okumu et al. 2020; Apipoonyanon et al. 2020; Jadin et al. 2022; Ntibona et al. 2023; Thuy et al. 2024; and Begum et al. 2024).

The existing studies therefore vary in terms of methodological approaches, contextual factors, and applied definitions, making comparison difficult. The measurement of variables of interest are also varied and prone to measurement errors. This study thus broadens the scope of the existing literature by addressing the following questions: What is the overall impact of carbon trading on ecosystem services and household welfare? What is the gender-disaggregated impact of carbon trading on household welfare?

1.1 Setting the Context

Kenyan coastal communities rely heavily on mangrove forest ecosystem services as a source of income or livelihood. Artisanal and commercial fishermen source fish such as shrimp, crustaceans, and shellfish from the mangroves (Mutagyera, 1984; Ahmed et al., 2022). In addition, about 90 percent of the fish available at local markets come from mangrove creeks, estuaries, and nearby shallow waters. Animal and plant diversity are also important for ecotourism, specifically birdwatching and hiking in mangrove forests. Yet, despite their ecological and socioeconomic value, mangroves are among the world's most threatened forests globally. In Kenya, it is estimated that between 1985 and 2010, Kenyan mangroves were reduced in size by more than 18 percent (Kirui et al., 2013) due to anthropogenic activities.

According to the Kenyan National Mangrove Ecosystem Management (2017-2027), the four root causes of mangrove exploitation are ignorance, weak governance, poverty, and economic development. The continued destruction of mangrove forests not only disturbs habitats and damages biodiversity, but also leads to a decline in fishery yields in fishing communities, who rely on these yields as a source of income. It is thus important to balance the food chain and mangrove restoration. Accordingly, urgent intervention is required to ensure that the ecosystem services and non-market benefits are incorporated into policy and development initiatives. Several interventions have emerged as communities self-organize to form Community Forest Associations to manage the mangrove ecosystem. These interventions have mainly focused on mangrove reforestation, community-led partnerships, ecotourism, and mangrove restoration. We consider two unique carbon trading schemes: the *Mikoko Pamoja* and the Vanga Blue Forest Carbon Projects in Kwale County.

The *Mikoko Pamoja* and Vanga Blue Forest Carbon Projects

Mikoko Pamoja is a small-scale carbon offset facility in Gazi Bay that focuses on mangroves. The project commenced in 2010, has a total of 1,018 participating households, and was awarded the 2017 UN Equator prize. It is a community-led mangrove conservation and restoration project that was designed to provide long-term incentives for mangrove protection and restoration through community engagement and participation. This is achieved through conservation activities, awareness creation, and the sale of mangrove carbon credits. Revenue generated from the sale of carbon credits (US$24,000/annum) is used to support local development projects in water and sanitation, education, health, and environmental conservation. It also supports community development projects such as the construction of school buildings and the provision of clean drinking water and schoolbooks. By raising income from forest resources, including carbon credits and other income-generating activities such as beekeeping and ecotourism, the project safeguards these benefits for local communities and future generations. It is thus a triple-win project, as it addresses climate change, community welfare, and biodiversity conservation.

The project is managed by three groups: The *Mikoko Pamoja* Community Organization (MPCO), consisting of representatives of Gazi Bay, specifically Gazi and Makongeni villages; the *Mikoko Pamoja* Steering Group, which provides technical support to the MPCO; and the project coordinator, the Association for Coastal Ecosystem Services, a charity registered in Scotland. Beyond carbon, the project contributes to UN Sustainable Development Goals 1, 4[5], 5, 6, 13, 14, and 15[6]. As a result of the project's interventions, over 8,000 mangroves have been restored with the help of the local community, government institutions (KMFRI), local schools, and volunteers. The anticipated result of all these interventions is improved welfare for locals and enhanced provision of mangrove ecosystem services.

Following the success of the *Mikoko Pamoja* project in environmental conservation and community development through mangrove conservation, the Vanga community self-organized to protect their forest based on learnings from the *Mikoko Pamoja* project. The Vanga site is three times the size of the *Mikoko Pamoja* project site. It was launched in 2019, and the funds from the sale of carbon credits are used to conserve mangrove forests and provide social and economic benefits to communities, using the same strategies employed in *Mikoko Pamoja*. As a result, the project has supported the protection of 460 hectares of mangrove, and community development projects support the livelihood of close to 9,000 people in the three villages of Vanga, Jimbo, and Kiwegu, especially local fish farmers[7].

2.0 Description of the Study Area

The study was conducted in Kwale County, which is located on the southern tip of Kenya between the latitudes of 30.05^0 and 40.75^0 South and longitudes of 38.52^0 and 39.51^0 East. The county borders Taita Taveta County to the North West, Kilifi County to the North and North East, Mombasa County and the Indian Ocean to the East and South East, and the United Republic of Tanzania to the South West. It covers an area of 8,270.2 square kilometers, of which 62 square kilometers is water surface. This area excludes the 200-mile coastal strip known as the Exclusive Economic Zone (CIDP 2023-2027). The county has a total population of 866,820, of which 740,389 is rural, living on a land area of 8,191 square kilometers. The rural population mainly relies on agriculture as a source of livelihood. The county is divided into agro-ecological zones based on the land's agricultural potential. Moderate-potential and marginal lands constitute 15 percent and 18 percent of the total land area, respectively. The remaining 67 percent is arid and semi-arid land suitable for livestock and limited cultivation of

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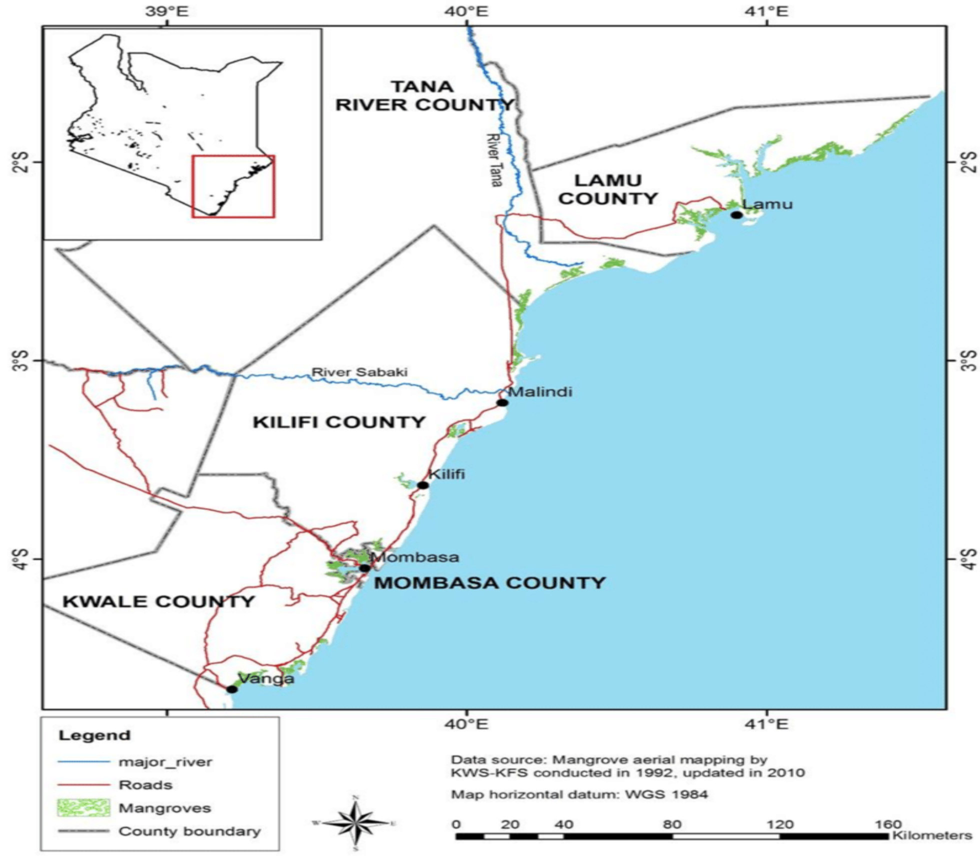
[5] Towards the realization of SDG Goal 1 (no poverty), a minimum of 70% of PES income is directly received by communities, and funds are democratically controlled by local people to meet local priorities. The project also contributes to SDG Goal 4 (quality education) by providing funds to supply village schools with equipment and school building repairs, while primary and secondary school children are educated on the importance of mangroves.

[6] Towards SDG Goal 5 (gender equality), the project requires that the community organization has a minimum of 40% representation by women. Towards SDG Goal 6 (clean water and sanitation), PES income from this project is used by participating communities to fund a water and sanitation project which already cleans water for two villages, reducing the instance of water-borne diseases. The project also contributes towards SDG Goal 13 (climate action) through carbon sequestration, and SDG Goal 14 (life below water) by developing the habitat for marine communities and enhancing fishery grounds. Towards SDG Goal 15 (life on land), the 5,614 mangrove seedlings planted to date are helping to stabilize the shoreline and reduce soil erosion. Towards the realization of these goals, the project conserves 117 ha of mangroves, and has been restoring 0.4ha annually.

[7] https://www.aces-org.co.uk/our-projects/vanga-blue-forest/

drought-resistant crops. The county has 30,000 hectares of terrestrial and mangrove forests along the coastal strip, spanning about 250 kilometers. According to the National Mangrove Ecosystem Management Plan, 45 percent of Kwale County's mangroves require rehabilitation. Since 2000, 20 percent of Kwale County's tree cover has disappeared. Figure 1 shows the map of Kwale County and other coastal counties with mangrove forests. Mangrove forests at the coast are managed by the Kenya Marine and Fisheries Research Institute (KMFRI). The forests are managed through 12 Community Forest Associations (CFAs), which fall under an umbrella body known as the Kwale Ecosystem Community Forest Association (KECOFA).

Figure 1: Map of Kwale County



2.1 Survey Design and Data Collection

2.1.1 Survey Design and Sampling

The study is based on cross-sectional data collected in the months of April and May 2024 from a random sample of 459 households in Kwale County in Kenya (149 project participants and 310 non-project participants). Data collection involved several steps. First, in consultation with KMFRI officials, we identified the two sub-counties in which the project villages were located, namely Lunga Lunga and Msambweni. A total of 22 villages were sampled, consisting of 221 households in Msambweni and 238 households in Lunga Lunga. The study employed systematic random sampling, where every third household was selected with the assistance of village elders and guides, based on a list of households obtained from the Chief's office. Data collected from the households included sociodemographic characteristics such as the age and gender of the household head, income sources, economic activities, and farming and fishing activities undertaken by households, among others. Due to the heterogeneous nature of the county, we looked at various welfare measures such as per capita monthly expenditure, household food security (proxied using the household dietary diversity index), and value of fish harvest (as a proxy for mangrove ecosystem services). The choice of consumption expenditure as a welfare measure was based on the fact that households are prone to underreporting their monthly income. Per capita expenditure is also easily interpreted and widely used (Skoufias & Kayama, 2011). Per capita expenditure also provides information about the consumption bundle that fits within the household budget. We aggregated expenditure on food supplies, education, farming, clothing and apparel, medical etc. Consequent to a rise in income, households are expected to be able to afford a wider variety of foodstuffs and hence become more food secure, leading to improved welfare with an increase in per capita expenditure and food security. In addition, we posit that with well-conserved mangrove forests, households reliant on fish for their livelihoods are expected to experience larger fish harvests, as the mangroves provide a good breeding ground for fish.

3.0 Empirical Approach

3.1 Econometric Framework

The framework is grounded in the Roy (1951) occupational choice model. We assume that households decide whether to participate in a carbon trading scheme based on utility maximization. If a household expects to benefit from participating in the scheme, then we assume that they will participate in carbon trading. Treatment assignment is therefore non-random. We define V_{ij} as the utility of household i=1, 2…n in treatment regime j= {0, 1}, with 1 representing participation in carbon trading and 0 representing non-participation. Therefore, $D_i = 1$ if $V_{i1} > V_{i0}$. Similarly, Y_{ij} is defined as a vector of the potential outcome variables (i.e., per capita monthly expenditure, household food security, and value of fish harvest) where Y_{i1} is the potential outcome for participants in carbon trading and Y_{i0} is the potential outcome for non-participants. The difference between Y_{i1} and Y_{i0} can therefore be used to measure the differential impact on the outcome variables. The utility gain from participation in carbon trading ($V^* = V_{i1} - V_{i0}$) can be expressed as a function of an observable vector of covariates (Z) in a latent model as follows:

$$V_{ij}^* = \alpha Z_i + \eta_i \, , V_i = 1 \; if \; V_i^* > 0 \tag{1}$$

where V_i is a binary variable equal to 1 if a household participates in carbon trading and 0 otherwise, α is a vector of the parameters to be estimated, and Z_i is a vector of household sociodemographic characteristics and farm-level attributes, whereas η_i is a random error term assumed to be normally distributed. Participation in carbon trading is assumed to affect household welfare outcomes and forest ecosystem services. We assume the outcome measures are a linear function of exogenous variables X_i and endogenous participation in carbon trading V_i such that

$$Y_{ij} = \beta X_i + \delta V_i + \epsilon_i \tag{2}$$

where Y_{ij} represents a vector of outcome variables, V_i is as previously defined, and β and δ are parameters to be estimated, while ϵ_i is an error term. If participation in carbon trading was purely random, then we would use the ordinary least square (OLS) method. However, since participation in the scheme was not random, OLS may yield biased estimates. According to Rubin (1973), program impact is the difference between the observed and the counterfactual outcomes. The main challenge is that the counterfactual is not observable, and an individual cannot be in both states at the same time. A quasi-experimental approach is therefore more appropriate for identifying the counterfactual, given that participation in carbon trading is non-random. Controlling for the participation decision is therefore an important factor in teasing out the impact of participation in carbon trading scheme. We consider that differences in the potential outcome variable for participants in carbon trading can be due to unobserved heterogeneity, reverse causality, simultaneity, and measurement errors. Failure to distinguish between the causal effects of participation in carbon trading and the effect of unobserved heterogeneity may lead to misleading conclusions and policy implications.

In this study, in order to assess the impact of participation in carbon trading schemes on household welfare and mangrove ecosystem services, we employ the Endogenous Switching Regression (ESR) model to control for endogeneity bias. To assess the gender-differential impact, we estimate the average and heterogeneous impact by estimating separate models for male- and female-headed households using the ESR model.

3.2 Endogenous Switching Regression Model

We estimate the impact of participation in carbon trading on household welfare and ecosystem services in two stages. The first stage is based on the decision to participate in carbon trading (equation 1). The second stage is concerned with estimating the two regimes' outcomes equations, one for participants and another for non-participants, as presented in equations (3) and (4).

$$Regime\ 1: Y_{1i} = \beta_1 X_i + \epsilon_{1i}\ if\ V_i = 1\ (Participants) \quad (3)$$

$$Regime\ 2: Y_{2i} = \beta_2 X_i + \epsilon_{2i}\ if\ V_i = 0\ (Non-Participants\ ) \quad (4)$$

where Y_1 and Y_2 represent the outcomes for participants (regime 1) and non-participants (regime 2); X_i represents the vector of covariates of farmer i; β_1 and β_2 are the parameters to be estimated; and ϵ_{1i} and ϵ_{2i} are error terms associated with the outcome variables. In the ESR framework, the error terms in the three equations (1, 3, and 4) are assumed to have trivariate normal distribution, with zero mean and a covariate matrix of the following form:

$$cov(\eta, \epsilon_1, \epsilon_2) = [\sigma_\eta^2\ \sigma_{\eta 1}\ \sigma_{\eta 2}\ \sigma_{1\eta}\ \sigma_1^2\ .\sigma_{2\eta}\ .\sigma_2^2\ ] \quad (5)$$

where σ_η^2 is the variance of the error term in the selection equation (1), and σ_1^2 and σ_2^2 are the variances of the error terms in the outcome equations 3 and 4. On the other hand, $\sigma_{1\eta}$ and $\sigma_{2\eta}$ are the covariances of $\eta, \epsilon_{1i}\ and\ \epsilon_{2i}$. Covariance between $\epsilon_{1i}\ and\ \epsilon_{2i}$ is not defined since Y_1 and Y_2 are not observed simultaneously (Maddala et al., 1986). The expected values of $\epsilon_{1i}\ and\ \epsilon_{2i}$ conditional on the sample selection are non-zero because the error term of equation 1 is correlated with the error terms of the outcome equations (3) and (4):

$$E[V = 1] = \sigma_{1\eta} \frac{(\emptyset(Z_i\alpha))}{(\Phi(Z_i\alpha))} = \sigma_{1\eta}\lambda_{1i} \quad (6)$$

$$E[V = 0] = \sigma_{2\eta} \frac{(\emptyset(Z_i\alpha))}{(1-\Phi(Z_i\alpha))} = \sigma_{2\eta}\lambda_{2i} \quad (7)$$

where $\emptyset(.)$ is the standard normal probability density function, $\Phi(.)$ is the standard cumulative density function, and $\lambda_{1i}\ and\ \lambda_{2i}$ are the Inverse Mills Ratios computed from equation 1 with $\lambda_{1i} = \frac{(\emptyset(Z_i\alpha))}{(\Phi(Z_i\alpha))}$ and $\lambda_{2i} = \frac{(\emptyset(Z_i\alpha))}{(1-\Phi(Z_i\alpha))}$, and are included in equation 3 and 4 to correct for selection biases resulting from unobservable factors. We thus have:

$$Y_{1i} = \beta_1 X_i + \sigma_{1\eta}\lambda_{1i} + \delta_{1i} \text{ if } V_i = 1 \text{ (Participants)} \quad (8)$$

$$Y_{2i} = \beta_2 X_i + \sigma_{2\eta}\lambda_{2i} + \delta_{2i} \text{ if } V_i = 0 \text{ (Non-participants)} \quad (9)$$

where δ_{1i} and δ_{2i} are error terms with conditional zero means. The full information maximum likelihood method is applied to obtain consistent estimates (Lokshin et al. 2004). From the ESR estimates, we compute the ATT and ATU following Carter et al (2006) and Di Falco et al., (2012) as follows:

Participants in carbon trading (observed in the sample)

$$E[V_i = 1] = \beta_1 X_i + \sigma_{1\eta}\lambda_{1i} \tag{10}$$

Non-participants in carbon trading (observed in the sample)

$$E[V_i = 0] = \beta_2 X_i + \sigma_{2\eta}\lambda_{2i} \tag{11}$$

Non-participants had they decided to participate (counterfactual)

$$E[V_i = 1] = \beta_2 X_i + \sigma_{2\eta}\lambda_{1i} \tag{12}$$

Participants had they decided not to participate (counterfactual)

$$E[V_i = 0] = \beta_1 X_i + \sigma_{1\eta}\lambda_{2i} \tag{13}$$

Equations (10) and (11) represent the actual expectations of the outcome variable observed from the sample, while equations (12) and (13) are the counterfactual expected outcomes. The effects of the treatment on the treated are thus computed as the difference between equations (10) and (11). The term λ is the selection term that captures all potential effects of differences in the unobservable variables. The effect of the treatment on the untreated is also computed as the difference between equations (12) and (13). The economic intuition is that the expected changes in the characteristics of participants and non-participants are similar, and thatthe term λ adjusts the effect of the treatment on the untreated for the effect of unobservable factors. The conditional expectations, treatment, and heterogeneous effects are presented in Table 1.

Table 1: Conditional Expectations, Treatment, and Heterogeneity Effects

Sub Samples	**Decision Stage**		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) $E[V_i = 1]$	(c) $E[V_i = 1]$	**TT**
Non-participant in carbon scheme	(d) $E[V_i = 0]$	(b) $E[V_i = 0]$	**TU**
Heterogeneity	**BH_1**	**BH_2**	**TH**

3.3 Identification Strategy

In the ESR model, we used awareness of the value of mangrove forests and access to electricity and water as instruments to measure intention to participate in the carbon trading scheme. These instrumental variables were measured as a dummy variable with values of 1 if a household was aware of the value of mangrove forests and had electricity and access to water, and 0 otherwise. The motivation for the use of this instrument is that knowledge of the value of mangrove forests, especially ecosystem services, can influence a household's decision to participate in the scheme but cannot directly influence household welfare and ecosystem services, except through participation in mangrove forest conservation and management. In addition, households with access to electricity or water are often affluent households and thus less likely to participate in the scheme, and having access to water or electricity cannot directly influence their welfare and ecosystem services. Affluent households are also more likely to participate in alternate income-generating opportunities and may thus find the opportunity cost of participating in the scheme to be high. Since the level of education in a household can also influence knowledge of the value of mangroves, we also control for years of education in the model.

3.4 Data, Variables and Descriptive Statistics

The summary statistics of the variables used in the study are presented in Table A1 in the Annex. As expected, the per-capita monthly expenditure and value of fish harvest for the project participants were higher than for the non-participants. As mentioned before, households are prone to underreporting their income, which could be the reason for the treatment group reporting a lower average income. In addition to the data collected, we constructed an additive index of social capital after verifying that membership in various groups was not correlated. The index was then factored into the model estimates to capture social capital. The same approach was also used to construct the coping strategy index.

4.0 Results and Discussion

This section reports the results of the impact of participation in a carbon trading scheme on household welfare (per-capita expenditure and food security, as measured by household dietary diversity) using ESR models. Lastly, the heterogeneous effects are analyzed and discussed.

4.1 Overall Impact of Participation in Carbon Trading Schemes: ESR Model Results

The ESR model results for per capita monthly expenditure, food security (household dietary diversity), and value of fish harvest as a proxy for household welfare and ecosystem services, are presented in Tables 2, 3, and 4 respectively. The ESR model was estimated using the Full Information Maximum Likelihood approach, as it presents both selection and outcome equations. For the outcome equations for participation and non-participation in the scheme, the first stage of the estimation of the ESR model is presented in column (1) and the second stage in columns (2) and (3), respectively.

Table 2: ESR for Per Capita Monthly Expenditure

VARIABLES	(1) select	(2) PCMonthlyExp1	(3) PCMonthlyExp0
Age of HH head	0.0851*	-257.4	85.43
	(0.0499)	(358.9)	(134.1)
Age of HH head squared	-0.000999*	3.055	-0.500
	(0.000546)	(3.898)	(1.454)
HH head is married	0.623**	2,234	-2,469***
	(0.264)	(1,892)	(709.2)
HH head is employed	-0.192	2,087	1,450**
	(0.257)	(1,473)	(674.6)
HH size	-0.0441	-979.7***	-633.0***
	(0.0411)	(269.6)	(116.6)
Years of education	-0.0559**	505.0***	331.3***
	(0.0257)	(155.0)	(71.78)
Social networks	0.312***	185.9	444.1*
	(0.0610)	(387.3)	(236.9)
HH CFA member	1.446***	2,223	52.84
	(0.259)	(1,624)	(1,543)
HH owns plot	0.683**	3,749**	-320.0
	(0.293)	(1,759)	(837.2)
HH coping strategy	-0.0675**	-182.2	-272.8***
	(0.0310)	(210.9)	(81.67)
HH experienced dry spell	-0.594**	-936.9	-914.4
	(0.236)	(1,526)	(727.7)
Source of information about mangrove conservation			
Baraza	0.843***	-930.6	-1,063
	(0.220)	(1,517)	(761.8)

Project official	1.391***	-500.2	1,799
	(0.270)	(1,781)	(1,307)
Community leaders	0.921***	-2,753	1,309*
	(0.235)	(1,996)	(683.4)
HH has electricity	0.422*		
	(0.239)		
HH has water	0.726**		
	(0.285)		
HH aware of value of mangroves	1.323***		
	(0.399)		
Constant	-5.706***	13,971	7,545**
	(1.268)	(8,537)	(3,068)
σ_0			0.301*(0.178)
σ_1		-0.299*(0.177)	
ρ_0			8.574***(0.036)
ρ_1		8.988***(0.036)	
Log likelihood	-4736.95		
Observations	459	149	310

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The results in Tables 2, 3, and 4 show that the exclusion restriction variables, namely knowledge of the value of mangroves, access to water, and availability of electricity are statistically significant for the per capita monthly expenditure, household dietary diversity (HDD), and value of fish harvested models. In addition, the coefficients of correlation ρ between participation in carbon trading scheme and per capita expenditure, HDD, and value of fish harvested are all positive and statistically significant for both participants and non-participants, implying that the hypothesis of selectivity bias in both models may not be rejected. Since ρ_0 and ρ_1 have the same sign, we can infer that participants in the carbon trading scheme have above average per capita monthly expenditure, food security and value of fish harvest whether they participate in the scheme or not, but are better off participating in the scheme.

Table 3: ESR for Household Dietary Diversity

VARIABLES	(1) select	(2) HDD1	(3) HDD0
Age of HH head	0.0898**	0.0526	0.0341
	(0.0401)	(0.0964)	(0.0653)
Age of HH head squared	-0.00101**	-0.000571	6.66e-05
	(0.000430)	(0.00105)	(0.000708)
HH head is married	0.526**	0.308	-0.191
	(0.232)	(0.530)	(0.355)
HH head is employed	-0.244	-0.596	0.187
	(0.209)	(0.413)	(0.328)
HH size	-0.0530	0.0371	-0.0304
	(0.0353)	(0.0755)	(0.0567)
Years of education	-0.0503**	0.124***	0.184***
	(0.0207)	(0.0411)	(0.0346)
Social networks	0.276***	0.168	0.224*
	(0.0529)	(0.116)	(0.118)
HH CFA member	1.213***	-1.201***	-3.168***
	(0.239)	(0.457)	(0.786)
HH owns plot	0.378	-0.158	-0.974**
	(0.233)	(0.486)	(0.400)
HH coping strategy	-0.0462*	-0.0879	-0.106***
	(0.0256)	(0.0562)	(0.0390)
HH experienced dry spell	-0.328*	1.995***	0.615*
	(0.198)	(0.409)	(0.360)
Source of information about mangrove conservation			
Baraza	0.598***	0.773*	-0.141
	(0.187)	(0.450)	(0.360)
Community leaders	0.953***	-1.186**	-1.695***
	(0.203)	(0.539)	(0.344)
HH has electricity	0.825***		
	(0.177)		
HH has water	0.820***		
	(0.248)		
HH aware of value of mangroves	1.105***		
	(0.321)		

Constant	-5.360***	6.050**	5.226***
	(1.026)	(2.390)	(1.489)
σ_0			-1.043***(0.368)
σ_1		-0.883**(0.344)	
ρ_0			0.972***(0.0491)
ρ_1		0.839***(0.0771)	
Log Likelihood	-1153.96		
Observations	459	149	310

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

The outcome equations from the ESR regression also show that household per capita monthly expenditure for participants is significantly influenced by household size and years of education, while HDD for participant households is influenced by years of education, membership in a CFA, access to information about mangroves through barazas and community leaders, and experience of dry spells. The value of fish harvested by participant households was found to be influenced by years of education, the type of floor material used in the household, and household coping strategies.

For non-participant households, the results reveal that per capita monthly expenditure is influenced by marital status, employment status, household size, years of education, social networks, coping strategies, and whether households received communication on mangroves from community leaders. HDD was, however, found to be influenced by years of education, membership in a CFA, ownership of plots of land, household coping strategies, experience of dry spells, and whether the household received information on mangrove conservation from community leaders. However, value of fish harvest was found to be influenced by years of education, experience of incidents of crop and animal disease, whether the household head is a native or not, and the presence of a marine management committee in the area.

Table 4: ESR for Value of Fish Harvest

	(1)	(2)	(3)
VARIABLES	select	FishHarvestVal1	FishHarvestVal0
Age of HH head	0.0841**	-399.7	11.49
	(0.0419)	(1,053)	(26.06)
Age of HH head squared	-0.00100**	12.16	-0.193
	(0.000460)	(11.45)	(0.284)
HH head employed	-0.136	2,982	-38.12
	(0.205)	(4,280)	(133.4)
HH size	-0.0369	324.2	22.86
	(0.0365)	(779.0)	(23.33)
Years of education	-0.0565***	1,499***	-26.53*
	(0.0217)	(463.2)	(15.22)
HH CFA member	1.532***	-975.8	-36.34
	(0.229)	(5,137)	(309.2)
HH has cement floor	0.429*	-11,424**	-48.57
	(0.225)	(5,359)	(154.0)
Existence of marine management committee	-0.00924	2,953	218.4*
	(0.212)	(4,790)	(130.6)
HH experienced crop disease outbreak	-0.226	-4,492	982.3***
	(0.273)	(6,375)	(189.4)
HH experienced animal disease outbreak	-0.229	1,531	-1,043***
	(0.260)	(6,146)	(191.8)
HH coping strategy	-0.0392	-1,364**	-3.294
	(0.0273)	(656.2)	(16.03)
HH member of FUGs	-0.257	-4,609	-385.0
	(0.433)	(6,990)	(407.8)
HH has access to agriculture extension	-0.0325	-5,948	85.70
	(0.205)	(4,508)	(150.2)
Social networks	0.336***	372.9	7.954

	(0.0561)	(1,260)	(52.44)
HH head is native	0.396	2,390	-400.7*
	(0.331)	(8,502)	(237.4)
HH owns a toilet	-0.229	-5,921	-175.0
	(0.233)	(4,710)	(156.2)
HH has electricity	0.467**		
	(0.229)		
HH has water	0.732***		
	(0.259)		
HH aware of value of mangroves	1.678***		
	(0.337)		
Constant	-5.045***	-7,336	588.8
	(1.100)	(24,080)	(647.6)
σ_0			0.0692(0.165)
σ_1		-0.0977(0.165)	
ρ_0			6.956***(0.0402)
ρ_1		10.04***(0.0163)	
Log Likelihood	-4436.43		
Observations	459	149	310

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

4.2 Conditional Expectations, Treatment, and Heterogeneity Effects

Table 5 presents the treatment and heterogeneity effects. Cells (a) and (b) present the expected treatment and heterogeneity effects. For instance, the expected per capita monthly expenditure for a household that participated in the scheme is Ksh 7,791, while it is about Ksh 7,275 for a household that did not participate in the scheme. However, it would be misleading to assume that, on average, the households that participated in the carbon trading scheme experienced improved welfare by about Ksh 516 (7.1 percent) more than non-participants. The last column in Table 5 presents the treatment effect of participation on household welfare. It shows that households that participated in the scheme would have experienced a reduction in expenditure of Ksh 2,141 (21.6 percent) compared to if they had opted not to participate in the scheme. In the counterfactual case, if households that did not participate in the scheme had participated, they would have experienced an increase in per capita expenditure of Ksh 1,479 (20 percent). The results thus imply that participating in the carbon trading scheme improved household welfare, but the effects were smaller for participant households compared to non-participant households had they participated, as reflected by the negative transition heterogeneity. Furthermore, the last row in Table 5, which adjusts for potential heterogeneity in the sample, reveals that households that participated in the carbon trading scheme tend to have above-average benefits whether they participate or not, but are better off participating in the scheme than not. The results align with findings by Abdullah et al. (2016); Luswaga & Nuppenau (2022); and Luswaga (2023). However, the results are contrary to the findings of Mazunda et al. (2015) and Ali et al. (2015).

Table 5: Average Treatment and Heterogeneity Effects - Per Capita Monthly Expenditure

Sub Samples	Decision Stage		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 7791.64	(c) 9932.55	**TT=-2140.91**
Non-participant in carbon scheme	(d) 8753.62	(b) 7275.07	**TU=1478.55**
Heterogeneity	**BH_1=-961.98**	**BH_2=2657.48**	**TH=-3619.46**

In terms of the effect on household dietary diversity, the last column in Table 6 shows that households that participated in the scheme experienced an increase in HDD of 3.5 points compared to if they opted not to participate in the scheme. In the counterfactual case, if households that did not participate in the scheme had participated, then they would have experienced an increase in HDD of 1.85 points compared to if they had opted not to participate. We can therefore infer that participation in the carbon trading scheme increases household food security as proxied by HDD, with higher effects for participating households compared to non-participating households had they decided to participate, as reflected by the positive transition heterogeneity. Similar findings have been echoed by other studies (see Gbetnkom, 2009; Baudron et al. 2017; Karki et al. 2018; Olesen et al. 2022; and Amadu & Miller 2024).

Table 6: Average Treatment and Heterogeneity Effects - Household Dietary Diversity

Sub Samples	Decision Stage		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 8.16	(c)4.66	**TT=3.50**
Non-participant in carbon scheme	(d) 9.81	(b)7.96	**TU=1.85**
Heterogeneity	**BH_1=-1.65**	**BH_2=-3.30**	**TH=1.65**

The results in Table 7 also show that households that participated in the scheme experienced an increase in value of harvested fish of KSh 2,776 compared to if they had opted not to participate in the scheme. In the counterfactual case, if households that did not participate in the scheme had participated, they would have experienced an increase in the value of fish harvest of Ksh 4,056 compared to if they had opted not to participate. We can therefore infer that participation in the carbon trading scheme increases access to mangrove ecosystem services as proxied by the value of the fish harvest, with higher effects for non-participating households had they decided to participate than for participating households, as reflected by the positive transition heterogeneity. The results lend support to the works of Taylor et al. 2018; Enchelmaier et al. 2020; and Hussain et al. 2010).

Table 7: Average Treatment and Heterogeneity Effects - Value of Fish Harvested

Sub Samples	Decision Stage		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 2977.65	(c) 201.77	**TT=2775.88**
Non-participant in carbon scheme	(d) 4205.93	(b) 149.21	**TU=4056.72**
Heterogeneity	**BH_1=-1228.28**	**BH_2=-52.56**	**TH=-1280.84**

4.3 Gender Impact of Participation in Carbon Trading Schemes: ESR Model Results

A gender-disaggregated analysis of the ESR model results for per-capita expenditure, food security as proxied by HDD, and value of fish harvested is presented in Tables A2, A3, and A4 in the Annex, respectively. The results largely reinforce findings from the previous ESR. In Table A2, for per capita monthly expenditure, the significance of ρ_1 and ρ_0 show evidence of selection bias for both female-headed and male headed households - an indication that both female- and male-headed households self-select themselves into participation in the scheme. The outcome equation also shows that per capita expenditure for female-headed participating households is influenced by age, marital status, years of education, household size, and plot ownership. However, per capita expenditure in non-participating female-headed households is influenced by marital status, household size, years of education, household coping strategies, and communication from community leaders. It was also noted that per capita expenditure in male-headed participating households is influenced by age, years of education, and household coping strategy. However, for non-participating male-headed households, per capita expenditure was influenced by marital status, employment status, years of education, and coping strategy.

In Table A3, the significance of ρ_1 and ρ_0 shows evidence of selection bias for both female-headed and male headed households. The results further show that the HDD for participating female-headed households is influenced by years of education, marital status, experience of dry spells, and communication regarding the carbon scheme through barazas. HDD in non-participating female-headed households was found to be influenced by years of education, the presence of a marine management committee, and communication regarding carbon schemes by community leaders. However, the HDD for participating male-headed households was found to be influenced by marital status, household size, experience of dry spells, presence of a marine management committee, and having slept without food. For male-headed non-participating households, HDD was found to be influenced by years of education, membership in a CFA, ownership of a plot, communication regarding carbon schemes through community leaders, regular attendance of meetings, and having slept without food.

In terms of mangrove ecosystem services, the results in Table A4 show that ρ_1 and ρ_0 are positive, revealing significant evidence of selection bias in both female-headed and male-headed households. The results show that the value of fish harvest for female-headed participant households is influenced by the household coping strategy and type of floor used in the main house. For female-headed non-participant households, the value of fish harvested was found to be mainly influenced by years of education and experience of crop and animal diseases. However, the value of fish harvest for male-headed participant households was found to be influenced by years of education, the type of floor material used in the main house, and the household coping strategy. The value of fish harvest for male-headed non-participant households was also found to be influenced by household size, type of floor material, experience of crop and animal diseases, and access to agricultural extension services.

4.4 Gender-Disaggregated Conditional Expectations, Treatment, and Heterogeneity Effects

The gender-disaggregated conditional expectations, treatment, and heterogeneity effects are presented in Tables 8 to 13. The results show that if female-headed households that participated in the scheme continued to participate, then they would experience a reduction in expenditure of Ksh 1,105 compared to non-participation in the scheme. In the counterfactual case, if female-headed households that did not participate in the scheme had participated, then they would have experienced an increase in expenditure of Ksh 9,564.48 compared to non-participation. This result implies that participation in carbon trading schemes by female-headed households increases welfare, but the effect is higher for non-participants than participants, as reflected by the negative transition heterogeneity (see Table 8). This can be attributed to the low-income levels of non-participants, meaning any slight intervention could improve their welfare, as opposed to the participants, who are expected to experience a slightly higher level of income.

Table 8: Average Treatment Effects - Per Capita Expenditure – Female-Headed Households

Sub Samples	**Decision Stage**		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 7897.48	(c) 9002.99	**TT=-1105.51**
Non-participant in carbon scheme	(d) 17087.54	(b) 7523.06	**TU=9564.48**
Heterogeneity	**BH_1=-9190.06**	**BH_2=1479.93**	**TH=-10669.99**

With regards to male-headed households, the results in Table 9 show that male-headed participant households would experience a reduction in per capita expenditure of Ksh 2,734.06 if they opted to continue participating in the scheme. However, in the counterfactual case, non-participant households would experience an increase in per capita expenditure of Ksh 1,242.22 if they opted to participate in the scheme compared to if they opted not to. This shows that the impact of participation in carbon trading for male-headed households is higher for non-participants than participants, as reflected by the negative transition heterogeneity. This can also be because non-participant households (both male- and female-headed) may find the opportunity cost of participating in the scheme to be high, and thus opt for alternate income-generating activities, and because the carbon credits are not provided to individual households directly.

Table 9: Average Treatment Effects - Per Capita Expenditure – Male-Headed Households

Sub Samples	**Decision Stage**		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 7684.52	(c)10418.58	**TT=-2734.06**
Non-participant in carbon scheme	(d) 7931.65	(b) 6689.43	**TU=1242.22**
Heterogeneity	**BH_1=-247.13**	**BH_2=3729.15**	**TH=-3976.28**

The study also reveals that participation in the carbon trading scheme had a positive effect on household food security, as measured by the HDD index (Table 10). In terms of the gender dimension, the study reveals that female-headed households participating in the scheme would experience an increase in HDD of about 2 points more than if they had not participated in the scheme. However, non-participating households would experience an increase of 1.88 points if they continued with non-participation. Thus, the positive transition heterogeneity also shows that participation in the scheme has a positive effect on household food security, but the effects are higher in participating households than in non-participating households.

Table 10: Average Treatment Effects - Food Security - Female-Headed Households

Sub Samples	**Decision Stage**		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 7.93	(c) 5.72	**TT=2.21**
Non-participant in carbon scheme	(d) 6.29	(b) 8.17	**TU=-1.88**
Heterogeneity	**BH_1=1.64**	**BH_2=-2.45**	**TH=4.09**

Participating male-headed households would also experience an increase in household food security of 3.6 points if they continued to participate, while non-participating households would experience an increase in food security of 4.4 points if they opted to participate in the scheme as opposed to not participating. The results are consistent with findings by Fungo et al. (2016). The negative transition heterogeneity also shows that participation in the scheme has a positive effect on household food security in male-headed households, but the effects are higher for non-participating households than for participating households if the non-participating households had opted to participate in the scheme, as shown in Table 11. This implies that non-participant households are better off participating in the scheme.

Table 11: Average Treatment Effects - Food Security - Male-Headed Households

Sub Samples	Decision Stage		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 8.32	(c) 4.70	**TT=3.62**
Non-participant in carbon scheme	(d) 12.21	(b) 7.81	**TU=4.40**
Heterogeneity	**BH_1=-3.89**	**BH_2=-3.11**	**TH=-0.78**

In terms of access to mangrove forest ecosystem services, the study reveals that participating female-headed households would also experience an increase in the value of fish harvest of Ksh 384.21 if they continued to participate, while non-participating households would also experience an increase in the value of fish harvest of Ksh 1,397.58 if they opted to participate in the scheme as opposed to not participating. The negative transition heterogeneity also shows that participation in the scheme has a positive effect on the value of fish harvest for female-headed households, but the effects are higher for non-participating households than for participating households if non-participating households opted to participate in the scheme (Table 12).

Table 12: Average Treatment Effects - Fish Harvest - Female-Headed Households

Sub Samples	Decision Stage		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 547.10	(c) 162.89	**TT=384.21**
Non-participant in carbon scheme	(d) 1539.90	(b) 142.32	**TU=1397.58**
Heterogeneity	**BH_1=-992.80**	**BH_2=20.57**	**TH=-1013.37**

Consequently, Table 13 shows that participating male-headed households would experience an increase in the value of fish harvest of Ksh 4,430.19 if they continued to participate, while non-participating households would also experience an increase in the value of fish harvest if they opted to participate in the scheme rather than not participating, but in the amount of Ksh 471.63. The positive transition heterogeneity also shows that participation in the scheme has a positive effect on the value of fish harvest for male-headed households, but as expected, the effects are higher in participating households than in non-participating households, mainly due to the physically intense nature of fishing, which is mainly dominated by males.

Table 13: Average Treatment Effects - Fish Harvest - Male-Headed Households

Sub Samples	Decision Stage		
	Participate	**Not to Participate**	**Treatment Effects**
Participant in carbon scheme	(a) 4856.14	(c) 425.95	**TT=4430.19**
Non-participant in carbon scheme	(d) 571.89	(b) 100.26	**TU=471.63**
Heterogeneity	**BH_1=4284.25**	**BH_2=325.70**	**TH=3958.56**

5.0 Conclusion and Policy Recommendations

The study set out to determine the overall and gender-differentiated impact of participation in carbon trading schemes on household welfare and forest ecosystem services. Using the ESR model, the results reveal that participants in the carbon trading scheme have above-average per capita monthly expenditure, food security, and value of fish harvest whether they participate in the scheme or not, but are better off participating in the scheme. However, it was also noted that non-participant households would be better off participating in the scheme than participant households when taking per capita expenditure and value of fish harvested into account. The effects on food security were found to be higher for participating households than for non-participating households, had the non-participating households decided to participate. The effects on value of fish harvest were also found to be higher for non-participating households than for participating households, had the non-participating households decided to participate. This result is mainly attributed to the opportunity costs associated with participation in the scheme.

In terms of gender, the results reveal that for both female-headed and male-headed households, participation in carbon trading schemes increases household per capita expenditure, but the effect is higher for non-participants than for participants. However, for female-headed households, the results reveal that participation in the scheme increased household food security, with greater effects for participating households than non-participating households. For male-headed households, participation in the scheme increased household food security, but the effects were greater for non-participating households.

In terms of access to ecosystem services such as fish, the results showed that participation in the scheme has a positive effect on the value of fish harvest for female-headed households, but the effects were greater for non-participating households than for participating households if non-participating households opted to participate in the scheme. Conversely, the effect of participation on male-headed households was found to be greater in participating households than in non-participating households, mainly because fishing is dominated by males. The results thus show that the scheme has the dual benefit of improving access to ecosystem services and increasing household welfare.

The study findings call for greater policy intervention in mangrove restoration, particularly with respect to increasing female participation in carbon trading schemes. In order to sustainably manage forests and increase participation in the scheme, policymakers need to explore ways of incentivizing communities to participate in mangrove restoration through the design of direct incentives to households over and above existing community-based incentives. There is also a need for increased community education on the value of mangroves and regeneration techniques. In addition, information on the actual value and state of mangroves should be disseminated through community leaders, barazas, CFAs and FUGs.

Limitations of the Study

One of the key limitations of this study is the sample size, i.e., the unequal proportion of the treatment and control groups. This limitation was not by design, but given the systematic random sampling approach adopted, the sample size for treatment turned out to be smaller than the control. The smaller number of participants in the carbon credit scheme is due to the fact that the scheme was a fairly new phenomenon. However, we believe the results still provide significant policy implications that can guide the rollout of the scheme in other forests.

Further research could consider examining a larger sample, and extending the study to take into account how long the two projects have been active and individual households have been members, in order to assess the heterogeneous effects.

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Data Availability Statement: Data used for this study is available on request.

Authors Contribution

Author 1: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Investigation, Project administration, Writing - original draft, Writing - review and editing, Software, Supervision, and Validation.

Author 2: Funding acquisition, Methodology, Investigation, Project administration, Supervision, and Validation.

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Annex

Table A1: Summary Statistics

	Whole Sample (n=459)				Treatment (n=149)				Control (n=310)			
Variable	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Dependent Variables												
Per capita Monthly expenditure	7442	7407	128.6	95000	7791	9216	575	95000	7275	6367	128.6	71500
Household Dietary Diversity	8.009	2.865	0	14	8.161	2.697	0	14	7.935	2.944	1	14
Value of fish harvest	1067	14289	0	300000	2977	24975	0	300000	149.2	1126	0	14000
Independent Variables												

HH sex	0.536	0.499	0	1	0.564	0.498	0	1	0.523	0.500	0	1
Age of HH head	41.05	12.47	19	88	43.18	11.76	22	82	40.03	12.69	19	88
MaritStat	0.719	0.450	0	1	0.819	0.386	0	1	0.671	0.471	0	1
Years of education	8.804	5.160	0	20	8.597	5.331	0	20	8.903	5.081	0	20
HH head employed	0.514	0.500	0	1	0.577	0.496	0	1	0.484	0.501	0	1
HH size	6.569	2.731	1	20	6.745	2.785	1	14	6.484	2.705	1	20
HH has electricity	0.525	0.500	0	1	0.564	0.498	0	1	0.506	0.501	0	1
HH has water	0.780	0.415	0	1	0.872	0.335	0	1	0.735	0.442	0	1
HH CFA member	0.242	0.429	0	1	0.617	0.488	0	1	0.0613	0.240	0	1
HH member of FUGs	0.0545	0.227	0	1	0.114	0.319	0	1	0.0258	0.159	0	1
HH owns plot	0.196	0.397	0	1	0.208	0.407	0	1	0.190	0.393	0	1
HH has access to agriculture extension	0.296	0.457	0	1	0.423	0.496	0	1	0.235	0.425	0	1
HH experienced crop disease outbreak	0.333	0.472	0	1	0.275	0.448	0	1	0.361	0.481	0	1
HH experienced animal disease outbreak	0.397	0.490	0	1	0.342	0.476	0	1	0.423	0.495	0	1
HH experienced dry spell	0.680	0.467	0	1	0.611	0.489	0	1	0.713	0.453	0	1
HH gone to bed without food	0.285	0.452	0	1	0.248	0.433	0	1	0.303	0.460	0	1
Existence of marine management committee	0.595	0.491	0	1	0.698	0.461	0	1	0.545	0.499	0	1
HH attended village meeting regularly	0.780	0.415	0	1	0.933	0.251	0	1	0.706	0.456	0	1
HH attended meeting last six months	0.290	0.454	0	1	0.114	0.319	0	1	0.374	0.485	0	1
Toilet	0.455	0.499	0	1	0.483	0.501	0	1	0.442	0.497	0	1
Social Networks	2.133	2.125	0	10	3.926	2.073	1	10	1.271	1.530	0	9
HH aware of value of mangrove	0.693	0.462	0	1	0.973	0.162	0	1	0.558	0.497	0	1
HH coping strategy	2.303	3.828	0	14	1.893	3.511	0	14	2.500	3.962	0	14
Source of information of mangrove conservation												
Community leaders	0.529	0.500	0	1	0.839	0.369	0	1	0.381	0.486	0	1
Social media	0.181	0.385	0	1	0.289	0.455	0	1	0.129	0.336	0	1
Baraza	0.366	0.482	0	1	0.651	0.478	0	1	0.229	0.421	0	1
Project official	0.181	0.385	0	1	0.409	0.493	0	1	0.0710	0.257	0	1

Table A2: ESR Model Results of Per Capita Expenditure by Gender of Household Head

	Female-headed households			Male headed Households		
	(1)	(2)	(3)	(1)	(2)	(3)
VARIABLES	select	PCMonthlyExp1	PCMonthlyExp0	select	PCMonthlyExp1	PCMonthlyExp0
Age of HH head	0.0670	-1,208	318.4	0.106	576.3**	116.9
	(0.0970)	(758.5)	(203.1)	(0.0650)	(288.8)	(208.9)
Age of HH head squared	-0.000842	15.21*	-3.347	-0.00105	-5.114*	-0.258
	(0.00111)	(8.886)	(2.422)	(0.000672)	(2.989)	(2.162)
MaritStat	0.774*	6,409*	-1,462*	0.596	-992.1	-4,337***
	(0.455)	(3,681)	(776.5)	(0.429)	(1,628)	(1,445)
HH head employed	-0.441	2,298	499.2	0.0959	1,377	2,359**
	(0.425)	(2,967)	(753.2)	(0.342)	(1,219)	(1,125)

HH size	-0.0976	-1,587***	-431.6***	-0.0142	-276.7	-808.4***
	(0.0822)	(540.8)	(130.9)	(0.0514)	(212.0)	(191.3)
Years of education	-0.0691	898.9***	342.4***	0.00534	451.9***	356.1***
	(0.0443)	(326.5)	(94.72)	(0.0328)	(106.5)	(107.2)
HH CFA member	1.757***	3,315	2,596	1.798***	825.6	-49.22
	(0.417)	(2,896)	(2,060)	(0.340)	(1,424)	(2,218)
HH owns plot	0.805	5,923*	-977.4	0.474	238.3	341.5
	(0.539)	(3,334)	(931.8)	(0.385)	(1,440)	(1,343)
HH coping strategy	-0.136**	-291.3	-246.1***	-0.0134	-260.3*	-273.8*
	(0.0590)	(479.6)	(85.92)	(0.0387)	(153.5)	(141.9)
HH experience dry spell	-0.887**	-1,155	-1,527*	-0.473	-865.0	-910.6
	(0.393)	(2,757)	(847.9)	(0.325)	(1,215)	(1,117)
Source of information of mangrove conservation						
Baraza	0.570	-1,709	-1,500	1.263***	-826.3	-163.8
	(0.380)	(3,058)	(917.4)	(0.304)	(1,320)	(1,192)
Project official	1.363***	-3,931	1,065	1.721***	1,627	3,775
	(0.446)	(3,432)	(1,356)	(0.357)	(1,497)	(2,415)
Community leaders	0.998***	-5,166	2,121***	0.756**	-2,367	585.2
	(0.379)	(3,467)	(800.8)	(0.338)	(1,790)	(1,080)
HH has electricity	0.523			0.203		
	(0.410)			(0.310)		
HH has water	0.722			0.672*		
	(0.498)			(0.399)		
HH aware of value of mangrove	1.536**			1.864***		
	(0.707)			(0.594)		
Social networks	0.433***					
	(0.114)					
Constant	-4.928**	34,604**	2,044	-7.451***	-6,666	8,033*
	(2.202)	(16,180)	(4,267)	(1.762)	(7,296)	(4,526)
σ_0			0.0992(0.355)			0.422*(0.232)
σ_1		-0.684**(0.315)			-0.299(0.298)	
ρ_0			8.308***(0.0487)			8.711***(0.0608)
ρ_1		9.226***(0.0394)			8.433***(0.0530)	
Log Likelihood		-2165.92			-2519.31	
Observations	213	213	213	213	246	246

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A3: ESR Model Results of Food Security by Gender of Household Head

	Female-headed households			Male-headed households		
	(1)	(2)	(3)	(1)	(2)	(3)
VARIABLES	select	HDD1	HDD0	select	HDD1	HDD0
Age of HH head	-0.0545	-0.00398	-0.0242	0.0869	0.173	0.0600
	(0.0713)	(0.168)	(0.121)	(0.0546)	(0.141)	(0.0926)
Age of HH head squared	0.000788	0.000212	0.000616	-0.000953*	-0.00181	-0.000162
	(0.000843)	(0.00197)	(0.00145)	(0.000560)	(0.00142)	(0.000954)
HH head is married	0.850**	1.387*	-0.162	0.708**	-1.446*	-0.208
	(0.348)	(0.790)	(0.502)	(0.347)	(0.824)	(0.629)
HH head is employed	-0.546	-1.011	0.120	-0.145	-0.983	-0.183
	(0.348)	(0.686)	(0.439)	(0.268)	(0.600)	(0.493)
HH size	-0.0431	-0.0934	-0.0384	-0.0335	0.203*	0.0809
	(0.0557)	(0.118)	(0.0775)	(0.0466)	(0.108)	(0.0853)
Years of education	-0.000823	0.141**	0.148***	-0.0230	0.0990	0.213***
	(0.0353)	(0.0684)	(0.0544)	(0.0260)	(0.0618)	(0.0476)
HH CFA member	2.005***	0.421	-1.345	1.734***	-1.205	-2.578**
	(0.384)	(0.967)	(1.653)	(0.294)	(0.752)	(1.069)
HH owns plot	0.111	0.263	-0.0822	0.367	-0.700	-1.841***
	(0.382)	(0.743)	(0.545)	(0.314)	(0.708)	(0.589)
HH experienced dry spell	-0.463	1.925***	0.276	-0.223	2.836***	0.555
	(0.345)	(0.599)	(0.517)	(0.278)	(0.600)	(0.484)
Source of information of mangrove conservation						
Baraza	0.613**	1.903***	0.526	0.713***	-0.0623	-0.730
	(0.283)	(0.698)	(0.546)	(0.258)	(0.894)	(0.519)
Community leaders	1.168***	0.421	-1.701***	0.907***	-1.324	-1.239**
	(0.307)	(1.058)	(0.559)	(0.300)	(0.827)	(0.595)
Existence of marine management committee	-0.424	-0.326	-0.972**	-0.292	-1.428**	-0.410
	(0.366)	(0.768)	(0.465)	(0.325)	(0.673)	(0.510)
HH attends village meeting regularly	0.216	-0.881	1.131**	0.326	0.224	1.143*
	(0.357)	(1.011)	(0.494)	(0.420)	(1.437)	(0.605)
HH gone to bed without food	-0.421	-0.425	-1.212***	0.313	-1.065*	-1.659***
	(0.335)	(0.785)	(0.446)	(0.273)	(0.628)	(0.513)
HH has electricity	0.683**			0.808***		
	(0.339)			(0.217)		
HH aware of value of mangrove	1.589***			1.276***		
	(0.586)			(0.377)		
Constant	-2.251	4.308	6.999***	-5.362***	6.752	3.877*
	(1.554)	(4.005)	(2.547)	(1.389)	(4.579)	(2.060)
σ_0			-0.570(0.788)			0.753(0.513)
σ_1		0.511(0.548)			-1.422*(0.839)	
ρ_0			0.870***(0.0872)			0.975***(0.0758)
ρ_1		0.790***(0.118)			0.917***(0.153)	
Log Likelihood	-533.70			-630.32		
Observations	213	213	213	246	246	246

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

Table A4: ESR Model Results of Fish Harvest by Gender of Household Head

	Female-headed households			Male-headed households		
	(1)	(2)	(3)	(1)	(2)	(3)
VARIABLES	select	FishHarvestVal1	FishHarvestVal0	select	FishHarvestVal1	FishHarvestVal0
Age of HH head	-0.00296	-216.5	13.42	0.107*	-235.6	-26.84
	(0.0775)	(194.3)	(60.19)	(0.0644)	(1,781)	(25.62)
Age of HH head squared	8.66e-06	3.630	-0.246	-0.00135*	12.08	0.196
	(0.000894)	(2.257)	(0.711)	(0.000719)	(18.57)	(0.274)
HH head employed	-0.280	-837.3	19.34	0.00556	7,380	20.10
	(0.335)	(690.2)	(238.4)	(0.300)	(8,397)	(143.7)
HH size	-0.0513	120.1	-12.99	-0.0701	931.5	62.12**
	(0.0577)	(131.3)	(40.31)	(0.0505)	(1,326)	(24.63)
Years of education	-0.0542	2.327	-51.90*	-0.0916***	2,156***	-3.185
	(0.0363)	(78.10)	(29.57)	(0.0324)	(761.8)	(15.54)
HH CFA member	1.591***	532.5	-104.4	1.887***	-955.5	139.9
	(0.346)	(762.4)	(633.5)	(0.356)	(8,981)	(303.1)
HH has cement floor	0.0829	-1,438*	109.7	0.672**	-20,528**	-377.1***
	(0.321)	(829.0)	(227.0)	(0.315)	(9,115)	(143.3)
HH experienced crop disease outbreak	0.289	-915.5	1,412***	-1.151**	-8,936	567.6***
	(0.396)	(948.2)	(327.8)	(0.482)	(15,486)	(206.6)
HH experienced animal disease outbreak	-0.156	356.1	-1,425***	-0.311	1,245	-655.8***
	(0.370)	(898.0)	(325.2)	(0.413)	(14,649)	(212.8)
HH coping strategy	-0.0976**	-336.0***	11.90	0.0389	-1,825*	-14.54
	(0.0461)	(122.8)	(27.26)	(0.0400)	(1,096)	(18.00)
Social networks	0.365***	-154.7	13.40	0.309***	1,162	-7.213
	(0.0875)	(220.6)	(100.1)	(0.0809)	(2,092)	(51.00)
HH attends village meeting regularly	0.462	-227.2	319.0			
	(0.423)	(1,105)	(237.5)			
HH experienced dry spell	-0.703**	-217.6	178.0			
	(0.325)	(723.0)	(276.1)			
HH has electricity	0.507			0.353		
	(0.351)			(0.326)		
HH has water	0.417					
	(0.418)					
HH aware of value of mangrove	2.027***			1.733***		
	(0.602)			(0.557)		
HH member of FUGs				1.128	-4,168	-292.0
				(0.716)	(10,877)	(496.3)
HH has access to agriculture extension				0.390	-12,220	347.2**
				(0.293)	(8,157)	(158.2)
HH attended meeting last six months				-0.0152	1,800	-206.8
				(0.360)	(11,490)	(146.4)
Constant	-2.884*	5,211	202.9	-4.333***	-18,706	892.3
	(1.749)	(4,071)	(1,283)	(1.585)	(42,629)	(607.8)
σ_0			0.00354(0.397)			0.323*(0.170)

σ_1		-0.435*(0.258)			0.0189(0.258)	
ρ_0			7.127***(0.0581)			6.673***(0.0573)
ρ_1		7.833***(0.0834)			10.29***(0.0114)	
Log Likelihood	-1920.06					-2362.22
Observations	213	213	213	246	246	246

Robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1

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