Just Transition Pathways for Small-Scale Fisheries: A Carbon Footprint and Socio-Economic Assessment in Sindangan, Zamboanga del Norte

ABSTRACT

This study examines the socio-demographic, livelihood, governance, and carbon-emission characteristics of small-scale fisheries across three coastal barangays in Sindangan, Zamboanga del Norte, empirical findings within social well-being, gendered livelihood, and fisheries sustainability frameworks. Results reveal gender-based labor roles, age and education-based differentiation in fishing participation, and widespread dependence on rented and non-registered vessels, reflecting structural constraints rather than individual choice or non-compliance. These conditions shape material, relational, and subjective well-being, reinforcing economic vulnerability and limited access to assets, governance mechanisms, and livelihood diversification. Analysis of fuel use and *CO_2 emissions* shows substantial site-level variation in carbon efficiency despite similar gears, vessels, and fishing distances, with trip frequency and operational practices emerging as key drivers of emissions intensity. Overall, the findings highlight the importance of integrated, locally grounded fisheries policies that address social equity, governance barriers, and operational efficiency to enhance both livelihood resilience and climate sustainability in small-scale fisheries.

1. INTRODUCTION

1.1 Small-scale Fisheries in the Philippines

Marine capture fisheries are central to Philippine food security, employment, and cultural identity. The country's archipelagic geography enables fisheries to support the livelihoods of 2.29 million fisherfolks (FishR, 2023; Philippine Fisheries Profile, 2023) and sustain protein intake for coastal and inland populations alike. Fisheries production in the Philippines includes municipal, commercial, and aquaculture sectors. Preliminary data in 2022 indicated that municipal fishing shared 25.8% of the total production of 4.3 million MT compared to other sectors (BFAR, 2023; Ferrer., et.al., 2023).

The municipal fishers in the country are those fishing without or with boats within the 12 km – 15 km from the shoreline and expectedly capable of three (3) GT and below fish catch using active or passive gears (Ferrer., et.al., 2023; RA 10654). They are commonly viewed as small-scale fishers (Ferrer., et.al., 2023). Globally, small-scale fisheries contribute about half of fish catches. When considering catches destined for direct human consumption, the share contributed by the small-scale fisheries increases to two-thirds (FAO, Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries, 2015).

However, contemporary fisheries are increasingly dependent on fossil fuel propulsion, particularly diesel and petrol engines used in both municipal and registered commercial fleets (Sarmiento, et.al., 2021; Smith, et.al., 1982; Maiti, et.al, 2005). As a result, fishing activities contribute to national greenhouse gas (GHG) emissions, linking local livelihood practices to global climate challenges (Teh & Sumaila, 2007).

The Philippines has committed to reducing GHG emissions. However, the national decarbonization agenda has largely ignored the fishing industry, in part because of a lack of carbon accounting data and worries that its policies might negatively impact the livelihoods of fishermen. Fuel price volatility, overfishing and the degradation of marine ecosystems (Mualil, et.al., 2014) have already made fishing households more economically vulnerable, especially small-scale and municipal fishermen (Salayo, et al., 2012). According to research, fishing effort and fuel consumption rise as fish biomass decreases, increasing carbon emissions per unit of catch (Ferrer et al., 2022; World Bank, 2017). As a result, emissions reduction and ecological conservation are closely related rather than distinct issues.

Conversely,making sure that decarbonization in fisheries is socially-justbecomes a challenge. A shift that lowers emissions, but compromises livelihood security runs the risk of perpetuating poverty, inequality, and food insecurity which are outcomes that are at odds with the more general goals of sustainable development.

1.2 Carbon Emissions Intensification and Fisheries Fuel Use

Iribarren et al., (2010) and Dineshbabu et al., (2024) in their study reveals thatfossil fuel combustion from fishing operations constitutes most emissions in capture fisheries, often accounting for 70–95% of total life-cycle carbon footprint. The absence of standardized carbon footprint accounting methodologies like the use of fuel logs and GPS monitoringis the gap which is pronounced in small-scale or artisanal fishing(Brewer, 2008). Also, some studies suggest that carbon accounting helps you find your hot spots and pinpoint where to target reductions (Ferrer, et.al., 2022; Salayo, et.al., 2012; Brewer, 2008; Iribarren, et.al., 2010).

The depletion of fish biomass below biologically optimal levels increases fishing effort, fuel consumption, and subsequent carbon emissions (World Bank, 2017). Ferrer et al. (2022) empirically demonstrated that small-scale fisheries exhibit significantly higher carbon intensity when operating in overfished waters, revealing an inherent ecological-economic-climate feedback loop.

Resource state dependent effects also operate through their influence on fisher fuel use and gear type that affect the amount of carbon released per unit fishing effort. Increased emissions and decreasing distributions seasonal of these resources strengthen a livelihood vulnerability, particularly for small-scale fishers whose ability to adapt is limited due to lack of financial resources and ecological variability. These pressures shape governance responses such as regulation, capacity building and incentives for low-carbon technologies which influence these communities trajectories of social-ecological change (Allison, et.al., 2001; Bennett, et.al., 2015; Cinner, et.al., 2018; Geels, et.al., 2011; Kroodsma, et.al., 2018; Mahon, et.al., 2020; Ostrom, et.al., 2009; Parker, et.al., 2018; Sala, et.al., 2018; Zhou, et.al., 2010).

Results from the study of Agosto, et.al., (2024), *Assessment on the Marine Capture Fisheries of Sindangan, Zamboanga Del Norte: Vessels, Gears And Species Caught*, (*unpub.*) found out that 93% of fisherfolk utilize motorized boats, while only 7% operate non-motorized boats in the three (3) barangays of Zamboanga del Norte namely Gampis, Lawis, Bantayan.

According to Sarmiento, et., al. (2021), motorized boats are typically preferred due to their improved mobility, efficiency, and range, which allow fishermen to go farther into offshore fishing grounds and increase their CPUE. By cutting down on travel time and providing access to more varied and abundant fish stocks, motorization in small-scale fisheries greatly improves income generation (Smith, et.al., 1982). And this causes depletion of nearshore fish stocks (Pauly, 1997).

However, reliance on motorized boats may have environmental implications. Extended fishing range enabled by engines may contribute to overfishing if not regulated, and the use of gasoline or diesel-powered engines contributes to marine pollution and carbon emissions (Teh & Sumaila, 2007).

1.3 Socioeconomic Vulnerability

Small-scale fishers often experience limited access to capital, unstable earnings, exposure to climate hazards, and weak bargaining power in markets (Salayo et al., 2012; Sadekin,et.al.,2018).

Income levels also reflect the degree of exposure to livelihood risks. According to Pomeroy and Andrew (2011), small-scale fisherfolk are particularly vulnerable to economic shocks due to the seasonality of fish catch, natural disasters, and policy shifts in fisheries governance.Low income among fisherfolk is a common issue in small-scale fisheries associated with limited access to modern fishing equipment, lack of post-harvest facilities, fluctuating fish prices, overfishing, and environmental degradation (Béné, 2006; Allison & Ellis, 2001).

Salayo et al. (2012); Ferrer, et.al., (2022), further highlight that small-scale fisheries generally including the Philippines are not only biologically overexploited but also socio-economically vulnerable, making the balance between conservation and livelihood particularly delicate.

1.4 Just Transition in Decarbonization

Co-management organizations, community quota systems, and targeted subsidies can support fair low-carbon transitions, as demonstrated by comparative examples from Japan, Korea, India, and the UK (Tsurita., et.al., 2018; Kim, et.al., 2023). These highlight the necessity of transition frameworks in fisheries governance that are phased, financially supported, and participatory.

For Philippine fishing vessels, particularly at the municipal level, there is presently no standardized carbon emission profiling system. There are currently no institutional support systems, community engagement frameworks, or livelihood safeguards in place to encourage low-carbon transitions in fisheries. The mitigation may come with increased operating costs, exclusion from fishing grounds or dropping fishing revenues in the absence of a Just-transition framework.

Decarbonization failure, however, constitutes long term erosion of livelihood as well as increased carbon intensity and ecological decline.This research contributes to Sustainable Development by linking carbon accounting (SDG 7,13,14), livelihood resilience (SDG 8), and just transition governance (SDG 10) within the fisheries sector. It provides empirical evidence for policymakers and resource managers to design decarbonization strategies that are not only environmentally sound but also socio-economically just. The findings can directly inform BFAR policy programming, strengthen the implementation of FishR and BoatR, LGU coastal resource management planning, fisher cooperatives' fuel and gear investments, and climate adaptation initiatives in coastal zones.The aim of this study is therefore to quantify fuel consumption and calculate carbon emissions, to assess demographic and socio-economic conditions among fishing households, then finally proposing a Just- transition pathway for Philippine fisheries based on empirical emission patterns, socio-economic conditions, and governance feasibility.

2. MATERIALS AND METHODS

2.1 Study Site and Data Collection

Sindangan is characterized by high fisheries dependence, fluctuating catch volumes, limited livelihood diversification, and observable effects of fuel price volatility on fishing effort. The research was conducted in barangayGampis, Lawis, and Bantayan, Sindangan, Zamboanga del Norte (*Figure 1*).

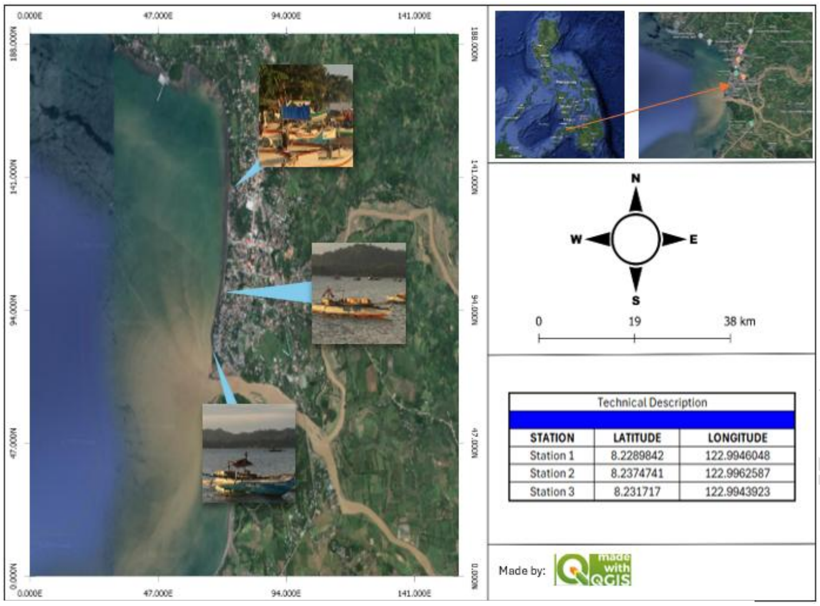

Figure 1. Map showing the locations for the focused areas.

Data on socio-economicinformation in the study siteswere collected using the Guidelines on the Collection of Demographic and Socio-economic Information on Fishing Communities for Use in Coastal and Aquatic Resources Management of the Food and Agriculture Organization (FAO). The study surveyed the family structure and dynamics, age, education, fishing vessel ownership/rent, and registration status.Moreover, carbon emission calculation explored the 2006 Intergovernmental Panel on Climate Change's (IPCC). IPCC Energy units were used in the calculation (*Table 1*).

Table 1. IPCC Energy Units

	NCV, TJ/Gg	Carbon content, kg/GJ	Default CO_2 EF, kg/TJ
Biomass (wood)	15.6	30.5	112 000
Peat	9.76	28.9	106 000
Lignite	8.9	27.6	101 000
Anthracite	26.7	26.8	98 300
Coking coal	28.2	25.8	94 600
Residual fuel oil	40.4	21.1	77 400
Diesel oil	43	20.2	74 100
Motor gasoline	44.3	18.9	69 300
Natural gas	48	15.3	56 100

Participants were given a matrix and recorded their fuel use and trip activity. This provided a powerful lens for understanding the intertwined ecological and carbon implications of small-scale fisheries.

Furthermore, carbon efficiency was calculated following the works of Zeigler, et.al., 2013 and 2019, it provided the relationship of fish catch and carbon emission, and fishing gears were identified using the classification and illustrated definition of fishing gears of FAO and the Field Guidebook on Philippine Fishing Gears by Monteclaro, et.al., 2017, this supported the assumption on catch per unit effort.

3. RESULTS

Family structure and dynamics are fundamental to small-scale fisheries, as fishing households function as integrated social and economic units where labor allocation, decision-making, and risk management are embedded in kinship relations (FAO, 2015; Allison & Ellis, 2011; Bene, et.al., 2007).

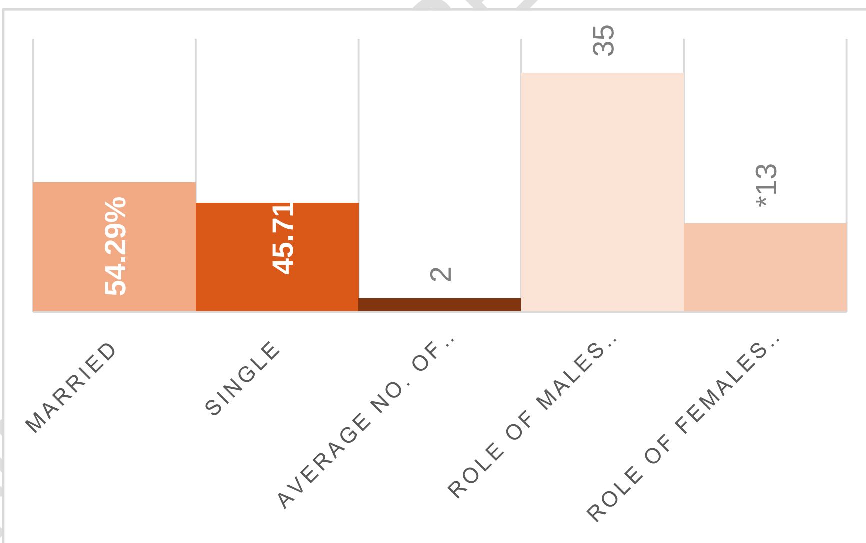

Figure 2. Family structure and dynamics surveyed in Gampis, Lawis, and Bantayan.

**Perceived role of females based on the demographic and socio-economic survey questionnaire.*

Figure 2 presents a demographic and role-based view of a surveyed group, revealing a community where marriage is slightly more common than being single, as indicated by the 19 married versus 16 single respondents. The average family size is compact, with 2 children per household. The primary responsible for fishing are assumed by males (35 individuals), while females (13) are perceived to primarily engaged in domestic and caregiving roles.

Age-disaggregated profiling enables more accurate socio-economic analysis, targeted policy and development interventions, and a clearer understanding of intergenerational continuity and sustainability in small-scale fisheries (FAO, 2015; BFAR, 2024).

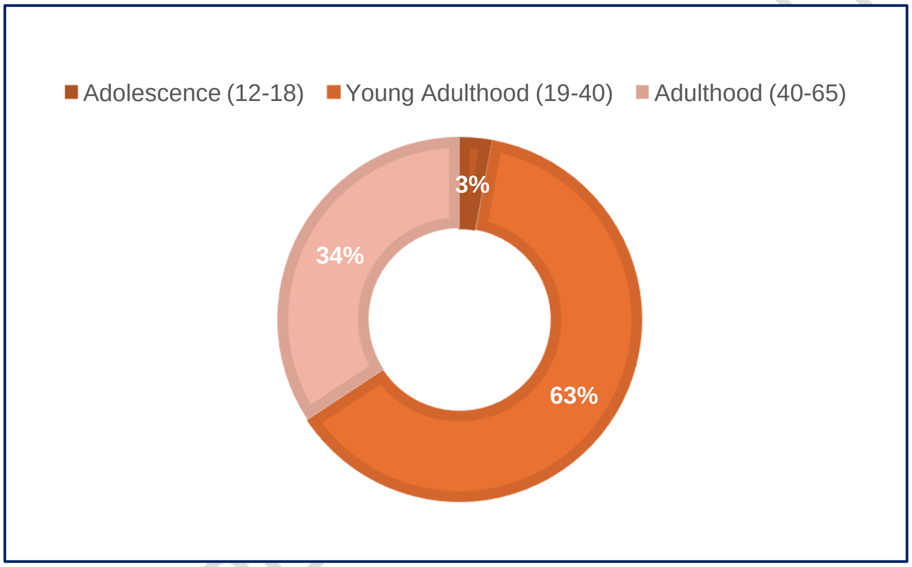

Figure 3. Age profile categorized as adolescence, young adulthood, and adulthood.

The data shows a concentration in Young Adult (19-40), which comprises the majority with 22 individuals, suggesting this is the primary productive and physically demanding cohort. The presence of 12 individuals in the Adulthood bracket (40-65) indicates experienced fishers continue in the occupation. The near absence of adolescents (1) could reflect legal working age restrictions, a cultural shift toward education over early entry into fishing, or a lack of youth engagement, posing concern in the transfer of intergenerational knowledge.

Profiling educational attainmentacross different levels enables policymakers and development practitioners to tailor extension services, co-management strategies, and livelihood programs according to learning capacities and aspirations, supporting sustainability, resilience, and inclusive development in small-scale fisheries (FAO, 2015; Pomeroy & Andrew, 2011; FAO, 2018; Chuenpagdee, et.al., 2006).

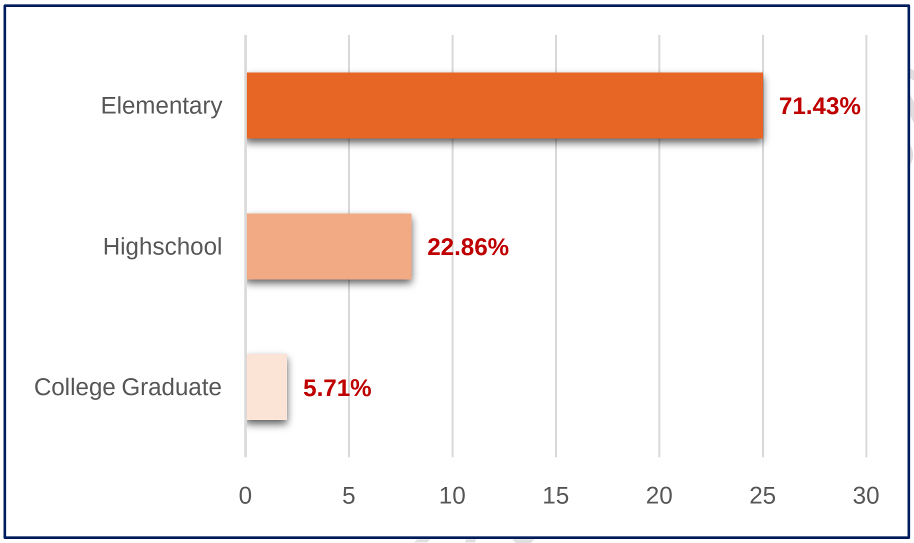

Figure 4. Educational background.

This data reveals a significant educational disparity within small-scale fisheries, with the vast majority (71.4%) of individuals possessing only an elementary-level education, followed by a modest segment (22.9%) who have completed high school, and a very small minority (5.7%) who are college graduates. The low percentage of college graduates highlights a critical gap in higher-level technical, business, or scientific expertise within the community, potentially hindering innovation, advocacy, and sustainable practices.

As emphasized in key references like FAO's SSF Guidelines (2015) and analyses by Bene (2003) and Crona, et.al., (2010), detailed ownership and rental data is foundational step toward implementing context-sensitive management that balances ecological resilience with social justice in small-scale fisheries. Owners retain a larger share of catch profits and have greater access to fishing grounds, while renters or laborers face economic dependency and limited capital accumulation (Muslim, et.al., 2023; Arias-Schreiber, et.al., 2018).

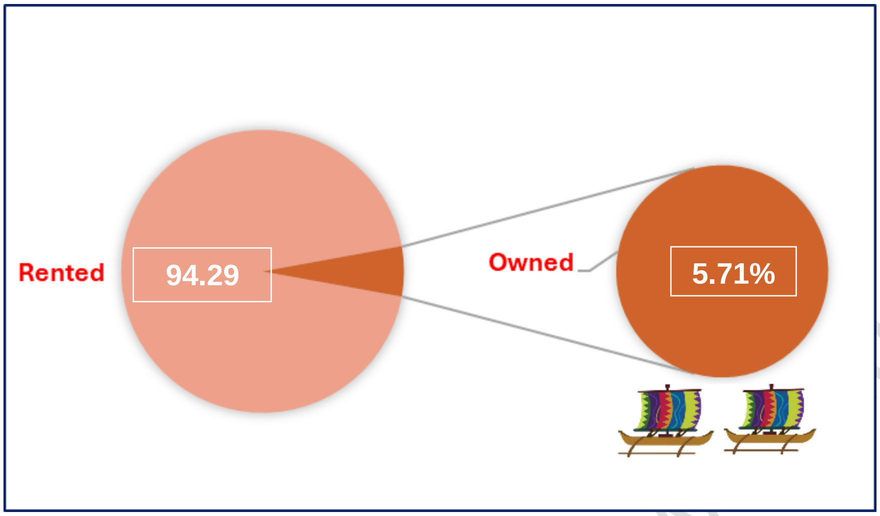

Figure 5. Fishing vessel ownership and rent.

The data indicates33 vessels (approximately 94.3%) are rented, while only 2 vessels about 5.7% are owned, yielding a rental-to-ownership ratio exceeding 16:1. This strong predominance of vessel rental suggests a structural preference for minimizing capital investment and maintaining operational flexibility.

Fishing vessel registration in small-scale fisheries is essential for sustainable management, legal recognition, and improved livelihoods. It provides an official record of all operating vessels, enabling authorities to monitor fishing effort, enforce regulations, and provide accurate information. Which are critical for ecosystem-based fisheries management (FAO, 2015; Allison, et.al., 2012; RA 10654; Bene, et.al., 2016).

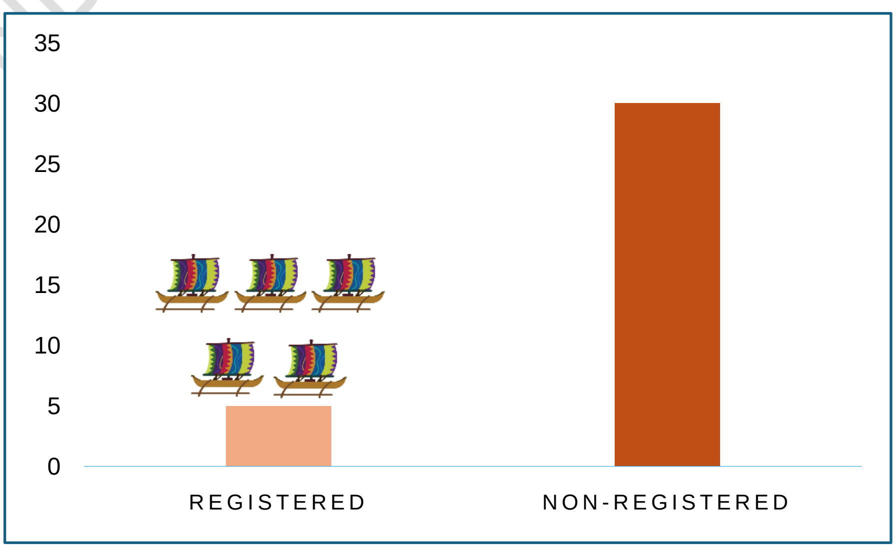

Figure 6. Fishing vessel registration status.

Based on the data, non-registered fishing vessel constitutes30 vessels making up approximately 85.7% of the total and only 14.3% with fishing vessels that are registered. This suggests a large informal or unregulated sector operating outside official oversight, which can undermine sustainable fisheries management, compromise crew safety and labor rights and lead to inaccurate catch data that hinders effective resource conservation.

Table 2. *CO_2 emissions in* kg CO_2 *for 15 km.*

Sampling Sites	*Fuel type*	*Distance*	*Fishing Gear*	**Average Fuel Consumption/ L**	**Average Trips**	**CO_2 Emissions for 15 km**
Brgy. Gampis*(n=10)*	Gasoline	12-15 km	Gillnets *(pukot)*	10 L	1	***22.7 kg CO_2***
Brgy. Bantayan *(n=10)*	Gasoline	12-15 km	Gillnets *(pukot)*	10.3 L	1	***23.4 kg CO_2***
Brgy. Lawis*(n=15)*	Gasoline	12-15 km	Gillnets *(pukot)*	20.47 L	3	46.5 kg CO_2 x 3 = ***139.5 kg CO_2***

**CO_2 emissions = amount of fuel (L) x Gasoline EF(2.27 kg CO_2 per liter)*
**1 trip = 15 km (municipal waters)*

*Table 2*illustrates the calculated *CO_2 emissions* from small-scale fishing operations across three barangays, revealing significant variation primarily driven by differences in the volume of fuel consumed per trip and the frequency of trips. While all sampled fishers used gasoline-powered boats to travel 12-15 km into municipal waters using gillnets, the average fuel consumption per trip varied notably from 10 liters in Brgy. Gampis to over 20 liters in Brgy. Lawis. Consequently, the *CO_2 emissions* for single 15 km trip, calculated using standard gasoline emission factor, ranged from approximately 22.7 kg to 46.5 kg. The most substantial total emissions, however, came from Brgy. Lawis, where an average of 3 trips per reporting period multiplied its per trip emissions of 46.5 kg *CO_2* to a total of 139.5 kg*CO_2*, demonstrating that trip frequency is a critical multiplier in the overall carbon footprint of these fishing activities.

Table 3. Carbon efficiency *(fish to emission ratio).*

Samling Sites	CO_2 Emissions for 15 km	Average Catch/kg	Carbon Efficiency
Brgy. Gampis*(n=10)*	***22.7 kg CO_2***	39 kg	*1.72 kg fish/kg CO_2
Brgy. Bantayan *(n=10)*	***23.4 kg CO_2***	63 kg	*2.7 kg fish/kg CO_2
Brgy. Lawis*(n=15)*	***139.5 kg CO_2***	22.27 kg x 3 = 66.81 kg	*0.48 kg fish/kg CO_2

*Carbon efficiency = $\frac{\text{Catch (kg)}}{CO_2 \text{ emissions}}$

Table 3 compares the carbon efficiency of 3 fishing sites, showing that Brgy. Bantayan is the most efficient, producing 2.7 kg of fish per kg of CO_2 emitted, due to a high average catch of 63 kg with relatively low emissions of 23.4 kg CO_2.Brgy. Gampis is moderately efficient (1.72 kg fish/kg CO_2), while Brgy. Lawis is the least efficient (0.48 kg fish/kg CO_2), as it emits substantially more CO_2 (139.5 kg) for a catch of 66.81 kg, indicating a much higher carbon footprint per unit of fish harvested.

4. DICUSSIONS

4.1 Demographic and socio-economic Profile

The demographic and role-based trendsshown in ***Figure 2*** can be better understood when viewed through the lens of Coulthard, et.al., (2011) social well-being framework and Weeratunge, et.al., (2010) gendered livelihoods perspectives. The clear division, with men primarily engaged in fishing and women focused on domestic and caregiving roles, highlights how small-scale fisheries livelihoods are shaped by culturally defined gender norms rather than solely by economic factors. The slightly higher proportion of married respondents (54.29%) and small average household size (average of 2 children) further emphasize the relational aspect of well-being, this suggests that household cooperation and gender-based division of labor play a key role in building resilience amidst livelihood uncertainty (Coulthard, et.al., 2011; Weeratunge, et.al., 2010; Kleiber, et.al., 2013).

Age-disaggregated profiling provides a more precise socio-economic analysis, enabling targeted policy and development interventions, while offering a better understanding of intergenerational continuity and sustainability in small-scale fisheries

(FAO, 2015; BFAR, 2024).Adolescents (3%)are ofteninvolved in family-based fishing, gleaning, or post-harvest activities, making age data crucial for understanding transfer across generations, balancing education and work, and addressing child labor concerns (FAO, 2015; Fry, et.al., 2021). Young adults form the backbone of the labor forcedriving innovation, adaptation, and livelihood diversification. As shown in ***Figure 3***, they make up 63% of the workforce**,**meaning their age-specific involvement significantly impacts fishing efforts, productivity, and resilience to environmental and economic challenges (Arulingam, et.al., 2019; Suh, et.al., 2023). Meanwhile, adults (34%)in the three barangays,possess accumulated ecological knowledge and take on leadership roles in household and community governance, influencing co-management, compliance, and long-term resource stewardship (FAO 2015; Reis-Filho, et.al., 2025).

With similar importance, fishers with only elementary-level education (71.43% according to***Figure 4***) often rely on traditional ecological knowledge and family-based fishing practices.While these are vital for local resource stewardship they may limit access to written regulations, formal training, and alternative livelihood opportunities (Allison & Ellis, 2001; Bene, et.al., 2016). Those with a high school education (22.86%)typically have a better understanding of fisheries policies, are more likely to adopt improved fishing gear and post-harvest technologies,andtend to engage in community-based management and cooperatives (FAO, 2015; Pomeroy & Andrew, 2011). College educated individuals, though fewer in the three barangays (5.71%), play a crucial role in leadership, enterprise development, value-chain enhancement, and connecting fishing communities with government agencies, NGOs, and markets.They are also more likely to diversity their livelihoods, which helps alleviate on fishery resources (FAO, 2018; Chuenpagdee, et.al., 2006).

Ownership status plays a significant role in fishers' income, economic security, and resilience.Vessel owners typically retain a larger share of catch profits and have better access to fishing grounds, while renters or laborers are more economically dependent and face challenges in accumulating capital (Muslim, et.al., 2023; Arias-Schreiber, et.al., 2018).The overwhelming reliance on rented fishing vessels (94.3%) compared to owned vessels (5.7%) in ***Figure 5*****,**suggests that the fleet is shaped more by capital constraints than by ownership preference. This aligns with finding by Muslim, et.al., (2023), which show that limited vessel ownership is linked to lower net incomes and on going poverty among small-scale fishers, as rental arrangements increase operating costs and restrict limit asset accumulation. Viewed through the social well-being framework of Voyer, et.al., (2017), this pattern has broader implications than just by income. From a material well-being perspective, dependence on rented vessels indicates weak livelihood security and diminished long-term resilience.Relationally, it creates a dependence on vessel owners of financiers, reducing autonomy and bargaining power. Subjectively, it can erode perceptions of stability and future prospects. Therefore, the dominance of rented vessels highlights a structural vulnerability that limits both economic performance and overall fisher well-being. This underscores the need for fisheries policies that promote equitable access to productive assets and ensure long-term livelihood sustainability.

On a sustainability note, data from registered vessels support scientific research and policy planning by providing accurate information on fleet composition, capacity, and spatial distribution, which is critical for ecosystem-based fisheries management.Building the discussions from the findings of Peralta-Milana, et.al., (2012), the data based on ***Figure 6*,**provides strong empirical support for interpreting the high proportion of non-registered fishing vessels (85.7%) as a manifestation of structural and governance constraints rather than simple non-compliance. The study shows that when fisheries registration and licensing were centralized at the municipal level, compliance was extremely low due to transportation costs, time burdens, literacy limitations, and mistrust, especially fears that registration would lead to taxation or increased surveillance (Peralta-Milana, et.al., 2012; Digal & Palencia, 2017). The absence of registration also excludes fishers from formal markets, licensing-based incentives, and conservation program, reinforcing cycles of informality and marginalization (Digal & Palencia, 2017).

4.2 Carbon emissions and Efficiency

Consequently, the data on fishing vessel ownership and registration is part of the equation to the calculated CO_2 *emissions*from small-scale fishing operations across the three barangays which reflect patterns consistent with broader assessments of fisheries' reliance on fossil fuels, where direct fuel use constitute the dominant source of energy consumption and emissions (Tyedmers, et.al., 2005; Crona, et.al., 2023). Despite operating similar gasoline-powered boats, traveling comparable distances (12-15 km), and using the same fishing gear (gillnets), substantial variation in fuel consumption per trip was observed, ranging from approximately 10 liters in Brgy. Gampis to over 20 liter in Brgy. Lawis. Such variability in ***Table 2,*** parallels global findings that fuel-use intensity can differ markedly among fisheries with similar targets and technologies, reflecting differences in operational efficiency and fishing effort (Tyedmers, et.al., 2005; Nooraiepour, et.al., 2025; Sumaila, R.U., 2024). Importantly, the results demonstrate that trip frequency acts as a critical multiplier of emissions, as evidenced by Brgy. Lawis, where higher per-trip fuel consumption combined with an average of three trips per reporting period produced the highest cumulative emissions (139.5 kg CO_2). This supports evidence that increasing fishing effort, rather than distance alone, drives importance of managing fuel use and trip frequency even within small-scale municipal fisheries (Tyedmers, et.al., 2005;Mahon, et.al., 2020; Ferrer, et.al., 2022; Zeigler, et.al., 2019; Sarmiento, et.al., 2021).

Moreover, the carbon efficiency differences observed among the three fishing sites ***Table 3*** are consistent with broader findings in fisheries emissions research, particularly regarding the strong influence of operational practices on fuel use and carbon intensity. Brgy. Bantayan's high carbon efficiency (2.7 kg CO_2) reflects a favorable balance between catch volume and fuel-related emissions, aligning with evidence that fisheries achieving higher catch rates with relatively low fuel inputs exhibit substantially lower carbon footprints per unit of harvest. In contrast, Brgy. Lawis demonstrates markedly lower efficiency (0.48 kg fish per kg CO_2), emitting more than five times the CO_2 of Bantayan for a comparable catch. This pattern mirrors findings highlighted by *Ziegler, et.al., 2013 and 2019,* who emphasize that fuel use and emissions are poorly predicted by effort alone and are instead strongly shaped by how engines are operated, fishing methods employedand contextual factors such as gear type (Parker, et.al., 2015), and stock conditions. High emissions relative to catch in Brgy. Lawis may therefore indicate inefficient operational profiles such as longer engine run times, higher fuel consumption per fishing trip, or less effective harvesting strategies rather than differences in catch volume (Tyedmers, et.al., 2005; Freon, et.al., 2014).

The intermediate efficiency observed in Brgy. Gampis (1.72 kg fish per kg CO_2) further supports the argument that fisheries performance exists along a spectrum rather than fitting into simplistic categories. The site-level variation evident ***Table 3*** reinforces the value of localized, data-driven assessments of carbon efficiency rather than relying solely on generalized effort-based or sector-level models.Overall, the results underscore that improving carbon efficiency in fisheries is not solely a matter of increasing catch, but of optimizing fuel use relative to harvest outcomes (Avadi, et.al., 2013). As emphasized in the works of *Zeigler, et.al.*, strategies such as reducing unnecessary engine operation, improving gear efficiency, and aligning fishing effort with stock availability are critical to lowering emissions intensity. The contrast between Brgy. Bantayan and Brgy. Lawis illustrates how site-specific practices can lead to substantially different climate impacts, even where total catches are similar.

5. CONCLUSIONS

This study demonstrates that livelihood structures, assets access, governance arrangements, and carbon efficiency in small-scale fisheries are significantly linked and socially embedded. However, this study is not conclusive to its objectives since there were only 35 respondents who consented to participate but can best reflect in a case study. The researcher recommends bigger sample size and longer sampling duration; and further exploration on stock conditions, fishing methods, types of gear used and engine operations.

Gender-based division of labor, age-specific roles, and education levels shape not only fishing practices but also the distribution of risks, benefits, and adaptive capacity within households and communities. The dominance of rented and unregistered vessels reflects structural constraints such as capital limitation, governance barriers, and institutional exclusion rather than individual non-compliance, reinforcing economic vulnerability and limiting long-term resilience.

The observed variation in fuel use and carbon efficiency across barangays further highlights that emissions in small-scale fisheries are driven less by technology alone and more by operational practices, access to assets, and local ecological conditions. These differences underscore the need for place-based, data-driven interventions that reduce emissions without undermining livelihoods. Importantly, the findings show that increasing fishing effort can exacerbate both economic precarity and carbon intensity, revealing a critical intersection between social well-being and environmental sustainability.

Taken together, the results point toward the necessity of Just Transition pathways that simultaneously address climate mitigation, livelihood security, and social equity. Such pathways should prioritize equitable access to productive assets, simplified and inclusive vessel registration systems, gender-responsive and age-sensitive livelihood support, and capacity-building aligned with educational realities. Supporting fuel efficiency, operational optimization, and livelihood diversification particularly for young adults and women who can reduce emissions while strengthening resilience. A Just Transition in small-scale fisheries, therefore, mut move beyond technological fixes to comfort structural inequalities, ensuring that climate action enhances, rather than compromises, the social well-being and dignity of fishing-dependent communities.

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