How Solar-assisted Electric Boats can Empower Fishing Livelihoods

A Kerala Case Study

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Image: CEEW/Kartikeya Jain

Fisherfolk in Kerala using typical motorised boats and seine net for harvesting their catch.

Executive summary

Marine fishing is prevalent in all nine coastal states in India and has an annual harvestable potential of 53.1 lakh tonnes (Department of Fisheries 2019; National Fisheries Development Board 2020). In the financial year 2018 (FY18), India exported INR 45,100 crore (USD 7.08 billion) worth of marine products, registering a compound annual growth rate (CAGR) of 19 per cent over the previous five years (The Marine Products Exports Development Authority, n.d.). The maritime fishing sector is a significant economic contributor in India, with a share of about 6.8 per cent in the agricultural GDP and 1.07 per cent of the total GDP (Food and Agriculture Organization of the United Nations 2018). It is also a critical livelihood generator, supporting close to 16 million jobs in fisheries (Shyam S. Salim and Anuja A. R. 2022).

Despite the development of the marine fishing sector, the livelihoods of fisherfolk around India continue to suffer from challenges related to climate change, lack of formal financing, strenuous working conditions, and limited access to high-quality fishing craft and gear. Clean technology solutions – for example, solar-assisted electric boats (e-boat) – can assist in addressing many of these problems. A solar-assisted e-boat is a type of e-boat in which the electric motor that powers propulsion derives a part or all of the energy required from solar photovoltaic panels.

We conducted focus group discussions (FGDs) in 2021 in the fishing villages of Chellanam and Puthuvypin, Kochi, to understand the various challenges impacting the livelihoods of fisherfolk. Using the results of the FGDs and secondary literature, we classify the challenges as natural, financial, social, physical, and human capital, according to the sustainable livelihoods framework (SLF). Furthermore, we explore the potential of solar-assisted e-boats as a solution to the many problems affecting their livelihoods (Table ES 1).

Given that the idea of solar e-boats for the fishing sector is still in the nascent stages, we estimate the total cost of ownership (TCO) and analyse its impact on the finances of the fisherfolk. However, there is a need to back these estimates with on-ground trials of the technology to establish functional equivalence to conventional fuel–operated boats and validate real-world performance on energy costs.

Our analysis indicates that the adoption of clean technologies for the fishing sector will lead to several gains, with positive impacts on the identified challenges:

- **Natural capital**: As solar-assisted e-boats do not produce exhaust emissions, there is significantly lesser environmental pollution when compared to conventional fuel counterparts. Additionally, e-boats produce 25 per cent lower vibration and sound pollution than conventional vessels, with noise levels between 80 and 90 dB.
- **Physical capital**: Our study highlights that increasing access to the more energy-efficient and cleaner solar-assisted e-boats will enhance physical capital while reducing fisherfolk's dependence on fossil fuels, which are associated with high emissions and are expensive. There is also potential for further optimising the size and design of the ferry, new fuel and power technology integrated with sails, and add other modern safety and convenience features.
- **Financial capital**: We estimate that the TCO for solar e-boats is about 60 per cent lower than that for petrol boats. This would have a profound impact on improving fisherfolk's incomes and reducing their vulnerability to rising fuel prices. Providing low-interest loans to individuals and easy finance to co-operatives are necessary for quick penetration of clean technology.
- **Human capital**: A switch to solar-assisted e-boats will help reduce financial burden and aid in the improvement of human capital.
- **Social capital**: There is a need for regional-level interventions targeting each of the above capital assets to improve their livelihood.

Table ES1 Challenges identified under the SLF in Kerala's fishing villages of Chellanam and Puthuvypin

Sustainable Livelihoods Framework (SLF)					
Types of capital considered under SLF	**Natural capital** comprises the natural resource stocks that people can draw on for their livelihoods, including land, forests, water, air, etc	**Physical capital** comprises the basic infrastructure that people need to make a living and the tools and equipment they use	**Financial capital** comprises savings, in any form; access to financial services; and regular inflows of money	**Human capital** comprises skills, knowledge, the ability to work, and good health	**Social capital** comprises the social resources people draw on to make a living
Challenges	Climate change–related challenges severely impact fisherfolk in India. Some of these challenges include reduced fish catching and noise-related and pollution-induced disruptions from motorised fishing craft	Only a handful of fisherfolk in India own their fishing craft, and very few have access to motorised fishing boats	A significant portion of the fisherfolk's income from the catch has to be shared with the craft owners. Additionally, high fuel costs and maintenance costs add to the fisherfolk's woes	The challenges related to human capital arise as a result of strenuous working conditions, financial burden, and stress owing to reduced catch	—

Source: Authors' compilation

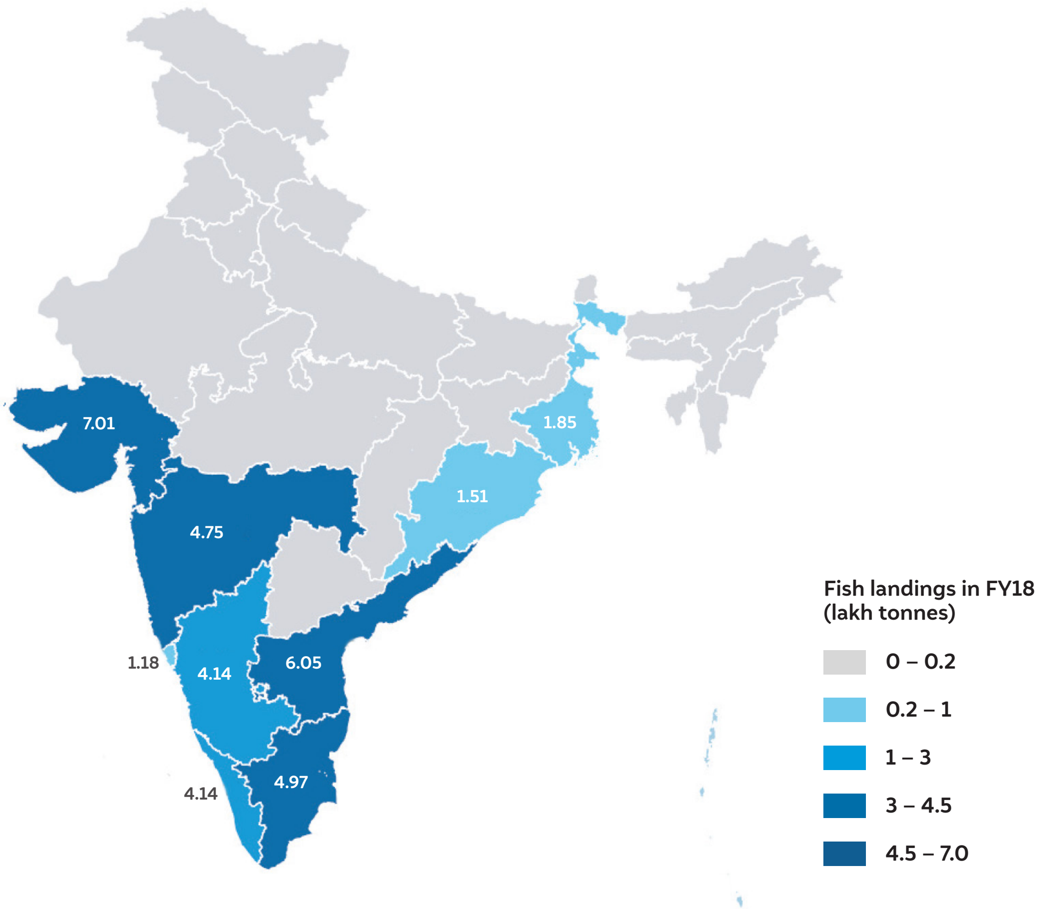
1. Introduction

Marine fishing refers to the capturing or culturing of the fish of the ocean and seas. India has an exclusive economic zone (EEZ) of 2.02 million square kilometres, but it utilises only 70 per cent of an estimated annual harvestable potential of 53.1 lakh tonnes (Department of Fisheries 2019; National Fisheries Development Board 2020). Marine fishing is prevalent in all nine coastal states of India and in four union territories (see Figure 1), and it is growing at a compound annual growth rate (CAGR) of 2 per cent. Gujarat and Andhra Pradesh were the top two marine fish–producing states in the financial year 2018 (FY18), producing about 7 lakh tonnes and 6 lakh tonnes, respectively, contributing to 37 per cent of India's total marine fish production.

Marine fishery resources in India comprise nearly 1500 species of fish and about 1000 species of shellfish. The essential varieties belong to the pelagic[1] groups, the demersal finfish[2] groups, crustaceans, and cephalopods. The availability of marine fishery resources varies seasonally and regionally (Seafood Exporters Association of India and Marine Products Export Development Authority 2010).

Although fishing evolved as a livelihood activity, the sector has undergone rapid changes to achieve its current status as a multi-billion-dollar industry. It contributes to large-scale employment generation, food and nutritional security, and exports. The total fish production in India in FY18 was 12.59 MMT (million metric tonnes), growing at a CAGR of 6.8 per cent over the past five years and recording an annual growth rate of 10 per cent year on year (Department of Fisheries 2019).

Figure 1 States carrying out marine fishing in India



Source: Department of Fisheries 2019.

1. Pelagic fishes inhabit the mid-water and upper layers of the oceans. Their habitat is extensive, occupying a wide variety of marine ecosystems, and they typically account for 20 per cent to 25 per cent of the total annual world fisheries catch (Stephenson and Smedbol 2019).
2. Demersal finfishes occupy the bottom of the oceans or seas. They are typically found in the continental shelves of coastal waters and constitute a large part of marine fish landings along the Indian coast (Rajan 2018).

The fisheries sector contributed INR 1,75,573 crore (1.03 per cent) to the country's GDP (National Fisheries Development Board 2020).

Although marine fisheries contributed only about 29 per cent to the total fish production in 2017–2018, it has a major share in foreign exchange earnings through exports. The export of marine products has grown by more than five times in 10 years from FY09 to FY19 (INR 46,590 crore worth); (Department of Fisheries 2019).

1.1 Fisheries-supported livelihoods

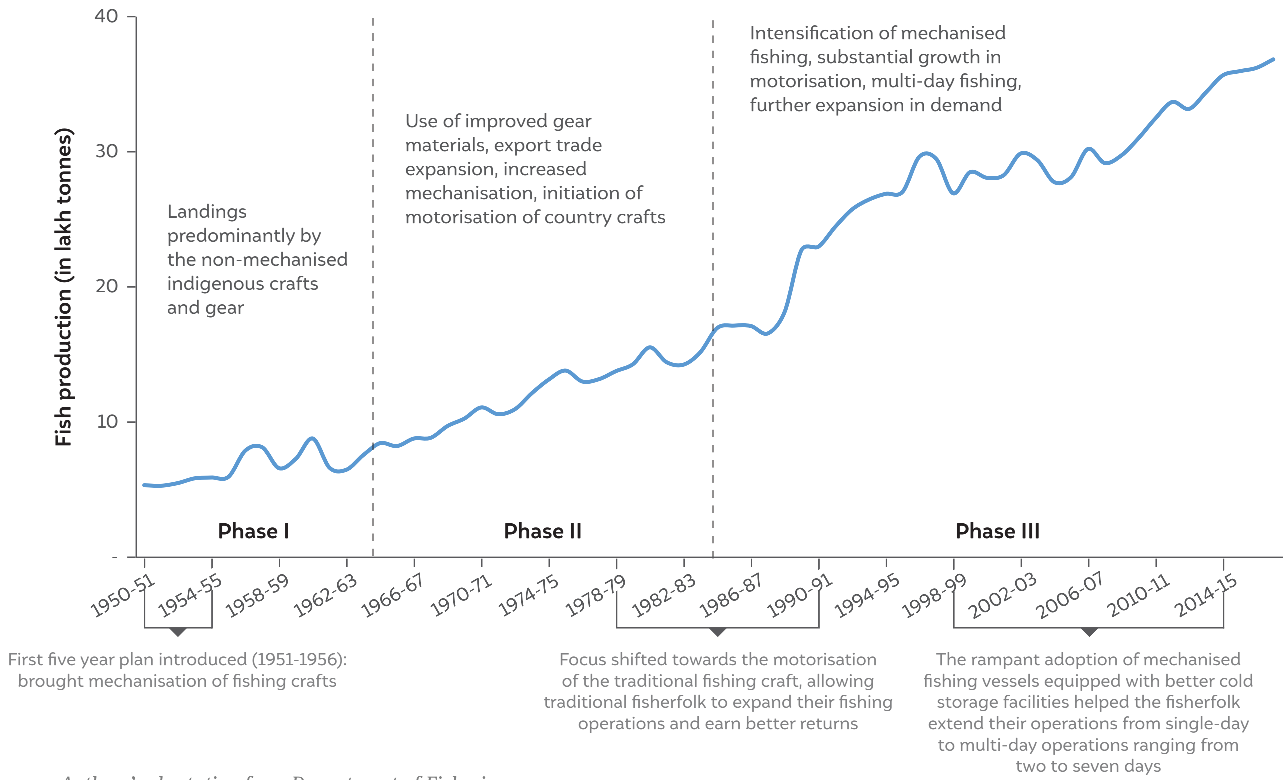
The marine fishing sub-sector is essential for rural economies along India's coast because it generates employment, livelihood opportunities, income, and food security for about 3.77 million people (Department of Fisheries 2019). The main stakeholders in the domestic marine fisheries value chain are classified into producers (fisherfolk), processors, traders, and ancillary and supplementary workers (Salim and Antony 2015).

It is estimated that for every fisher engaged in primary fishing activities, about four others get additional employment through post-harvest operations, fish marketing, and other allied activities (National Fisheries Development Board 2020). There are about 9.3 lakh active fisherfolk in India according to the *Marine Fisheries Census* 2016, of whom 81 per cent work full-time. Nearly 6 lakh (67.3 per cent) of the fisherfolk families in India are below the poverty line (Central Marine Fisheries Research Institute, Fishery Survey of India, and Department of Fisheries 2020).

A survey of fisher households[3] from different fishery states carried out in 2011 revealed that most fisherfolk have diversified their incomes and work in business, agriculture, labour services, and other services to supplement their livelihoods (Salim et al. 2013). Their income is the highest from marine capture (INR 6757 per month), but they have to depend on alternate jobs because of the uncertainty and risks involved.

Given the dependence on primary fishing activities for additional employment opportunities, it is critical to understand the various challenges faced by fisherfolk families. Relevant measures must be taken to address these challenges and improve their livelihoods. Thus, the **study focuses on the producer's segment (fisherfolk)** to build the snow-ball impact down the value chain.

Figure 2 **Motorised fishing craft create an opportunity for clean technology adoption**



Source: Authors' adaptation from Department of Fisheries 2019.

3. The survey was conducted among 4555 fisher households for different fishing sectors, across various states in India.

Historically, the mechanisation of fishing craft has played a critical role in improving fish production. Figure 2 highlights the three phases of mechanisation in the marine fishing sector and the subsequent growth in fish production. Beyond phase III, **the study explores the potential of using cleaner technologies** to reduce the reliance on fossil fuels for fishing craft and **estimates the benefits expected**. Cleaner technologies – namely, electric boats (e-boats) – have other multiple benefits in terms of emission, noise, and pollution reduction.

1.2 Dependence of livelihood of fisherfolk on vessels

More than 50 per cent of the vessels used for marine fishing comprise mechanised and motorised vessels (Zacharia n.d.). Medium trawlers, a type of mechanised vessel, are mostly used for multi-day operations targeting high-valued resources. The other smaller motorised and mechanised vessels are used for single-day operations. Ring seining is the most common seining method used to catch pelagics – especially small pelagics such as oil sardines, lesser sardines, anchovies, and mackerel along the Kerala coast. Figure 3 shows the economics of single-day fishing operations in seven maritime states disaggregated by major craft gear. It can be seen that estimates of net operating income and the incomes of vessel crew vary widely across craft gear categories and conditions.

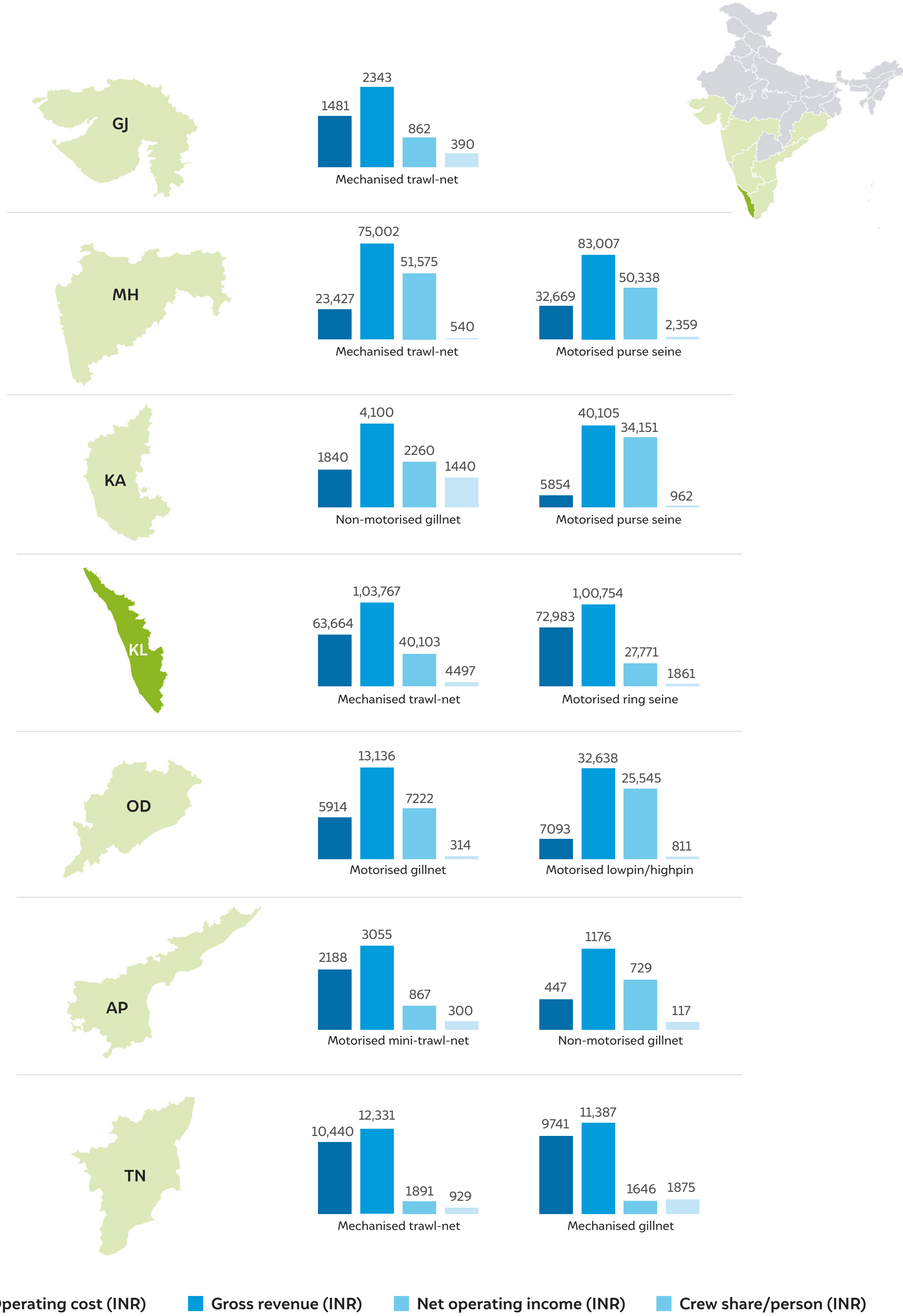
Kerala has the highest net operating income from the fishing sector; however, it also has the highest share of operating costs as observed in figure 3. The Indian Council of Agricultural Research–Central Marine Fisheries Research Institute (ICAR-CMFRI) conducted a survey in 2016 in nine coastal towns of different states and two union territories. From the CMFRI survey, we observe that, despite having the second-highest share of fishing craft among the coastal states, and the highest net operating income and gross revenue, Kerala has one of the highest shares of fisherfolk families who are below the poverty line (BPL) as observed in figure 4. We note that a major share of the net operating income of the fisherfolk in Kerala is spent on operating costs.

Hence, for this case study, we selected two typical fishing villages in Kerala. Our hypothesis is that most of the challenges related to the livelihood of fisherfolk can be addressed by making vessel operations efficient, leading to lower costs. The challenges are evaluated through multiple factors under the sustainable livelihoods framework (SLF). The study also examines if replacing conventional fuel–operated boats with clean technology boats such as solar-assisted e-boats could help mitigate some of the problems. After establishing the potential of solar-assisted e-boats in this regard, the study recommends strategies to enable faster uptake of these boats amongst fisherfolk.

Image: CEEW/Kartikeya Jain

A typical motorised boat used by the fisherfolk in Kerala being pulled on the shore after harvesting their catch.

Figure 3 Kerala has the highest net operating income amongst the seven maritime states



Source: Parappurathu et al. 2017a.

Note: The estimates of net operating income do not account for interest on working capital and depreciation of fishing vessels and equipment.

Figure 4 Characteristics of the fishing sector in Kerala

60%
Fisherfolk families are BPL

70%
Share of fishing crafts owned by the fisherfolk

Image: CEEW/Kartikeya Jain

22,000
Total number of fishing crafts

80%
Share of mechanised and motorised fishing crafts

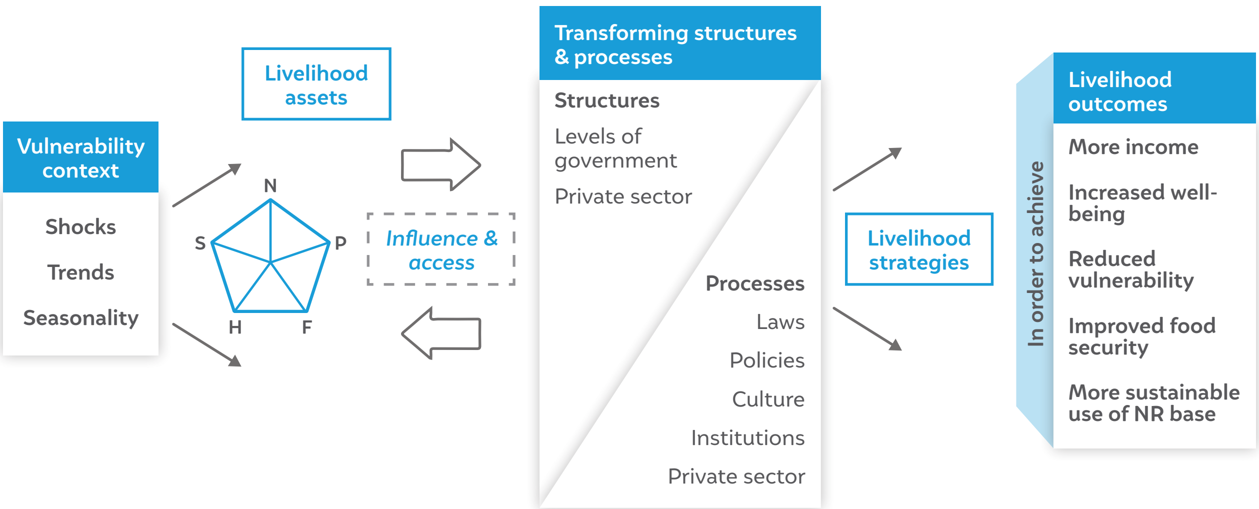
Source: Authors' adaptation from the Marine Fisheries Census 2016 – India

2. Challenges faced by fisherfolk: Lessons from Kerala

The SLF can be employed to gauge the impact of the relevant factors – namely, capabilities, assets, and activities – on the livelihood of the penurious. It is used for this analysis because it adopts a people-centric approach, using micro-level analysis to reveal the nuances of the assets. Essentially, poverty is not just a lack of income, but also the lack of access to assets imperative for sustaining an adequate income. These assets or capitals include natural, physical, social, financial, and human capital. Increased access to one type of capital may also lead to greater access to other capitals (School of Oriental and African Studies n.d.).

Comprehensive studies, involving nationally representative samples, regarding access to various assets are limited. Given the high share of operating costs pertaining to fishing craft in Kerala, we collated regional insights in the state to understand the various challenges faced by the fisherfolk in this region. We conducted focus group discussions (FGDs) in two villages in Kochi – Chellanam and Puthuvypin – to understand the current issues fisherfolk face and the challenges related to the operation of fishing craft. The sections 2.1 to 2.5 discusses the detailed insights obtained from the FGDs and secondary literature.
We use the SLF to understand how the livelihoods of fisherfolk are currently impacted. Figure 5 highlights the overview of the SLF framework that has been used in this study. Various issues are explored, and the use of solar-powered e-boats as a possible intervention is suggested, within the broader context of livelihood solutions. Table 1 summarises the findings from our FGDs and secondary literature. Further data obtained from the FGDs are discussed in the sections 2.1 to 2.5.

Figure 5 Overview of the sustainable livelihoods framework



N - Natural capital P - Physical capital F - Financial capital H - Human capital S - Social capital

Source: School of Oriental and African Studies (n.d.)

Table 1 Major challenges that impact Indian fisherfolk

	Challenges impacting fisherfolk
Natural capital	**Market challenges:** • Increased competition for fishing grounds • Over-capitalisation of fishing and post-harvest activities **Climate change–related challenges:** • Decline in marine fish landings across the western coast • Extended periods of monsoons and cyclones • Reduced fishing catch owing to noise generated from motorised fishing craft • Pollution from fossil fuel–operated motorised fishing craft
Physical capital	**Infrastructure-related challenges:** • Cold storage and transport • Poor access to piped water and sanitation • Poor cellular coverage for communication • Only a minor fraction of fisherfolk own fishing boats and fishing gear • Limited access to better technologies – namely, motorised fishing craft • Limited knowledge of maintenance of vessels and gear
Financial capital	**Formal financing-related challenges:** • Fisherfolk are unable to provide suitable collateral • Lack of awareness among fisherfolk about insurance premiums, resulting in reliance on informal moneylenders • Boat owners take a big share of the catch • The mechanisation of fishing craft results in higher upfront costs • Higher fuel costs and maintenance costs of the fishing vessels • Lack of low-cost formal loans for vessels/boats
Human capital	**Health-related challenges:** • Lack of occupational health services • Stress-induced reliance on smoking and alcohol • Strenuous working hours resulting in poor diet and nutrition • Lack of upskilling in tandem with the technological transition of the fishing industry
Social capital	**Fishing co-operatives related challenges:** • Disparities in the proper functioning of fishing co-operatives • Lack of regional-level interventions

Source: Authors' compilation

2.1 Natural capital

Natural capital comprises the natural resource stocks that people can draw on for their livelihoods, including land, forests, water, air, and so on. Evidence indicates that declining access to and availability of fish resources, increasing competition for fishing grounds in the marketplace, and over-capitalisation of fishing and post-harvest activities are critical sustainability issues (Salagrama 2006).

The impact of climate change has already started manifesting in the decline in marine fish landings on the western coast. The total estimated fish landings[4] decreased by 32 per cent, with Maharashtra witnessing the lowest annual catch in 45 years (Central Marine Fisheries Research Institute 2020). Additionally, Goa, Kerala, and Gujarat saw an annual decrease in marine fish landings in 2019, whereas Daman and Diu, West Bengal, and Andhra Pradesh have witnessed an increase in marine fish landings.

Researchers list extreme weather patterns, an extended monsoon period, and large-scale incessant exploitation of young fish as the primary reasons for low catches (Kajal 2020). A Council on Energy, Environment and Water (CEEW) analysis indicates that more than 55 districts have witnessed extreme floods post-2005, affecting 97.51 million people (Mohanty 2020). A study by the Central Marine Fisheries Institute concludes that unusual formations of frequent cyclones in the Arabian Sea have been a significant factor contributing to the decline in catches of common fish resources prevalent on the western coast (Central Marine Fisheries Research Institute 2020). Additionally, the extended monsoon has reduced the number of fishing days by 36 per cent (Central Marine Fisheries Research Institute 2020).

From our FGDs, it is clear that in Kerala, the depletion of fish resources remains a major concern for fisherfolk. This has been attributed to beach erosion and seawater incursion. Additionally, irregular rains and changes in monsoon patterns induced by climate change have also led to a depletion in marine fish landings across the western coast. Fisherfolk in Kerala have been hit hard by this because there has been a decline in their usual seasonal catch. Certain fish varieties have been majorly affected – for example, sardines have not been caught in over a year in these villages. The overall catch has reduced significantly as well, and they are able to get a decent catch only a few days a week. Additionally, they have to rely on this limited catch to clear off their debts and manage other expenses.

> **Owing to flexible repayment options, majority of small-scale fisherfolk rely on informal sources to avail loans.**

Fossil fuel–operated fishing vessels also cause other harms. Auditory systems are critical to aquatic life, which rely on them for communication, navigation, foraging, and reproduction (Stange 2019). Anthropogenic noise, including those from boats, can disrupt these processes, and therefore, noise reductions gained from the adoption of e-boats are valuable from an ecological standpoint. For instance, one study showed how noise pollution from vessels in the Ganges resulted in the doubling of metabolic stress in the endangered Ganges river dolphins (Dey et al. 2019). This is apart from the fact that the vibrations and noise levels create discomfort for human users as well. Fossil fuel–operated motorised fishing craft also cause water pollution, which results in a further decline in the fishing catch.

2.2 Physical capital

Physical capital comprises the basic infrastructure that people need to make a living and the tools and equipment they use – for example, transport and communication systems, shelter, water and sanitation systems, and energy.

Whereas coastal communities have good access to road infrastructure, health, and electricity, other forms of physical capital fall short of adequacy. Small-scale fisherfolk cannot get access to supporting infrastructure such as cold storage and transport, and this has a direct impact on the prices. Coastal fishing communities also lack proper piped water and sanitation facilities (World Bank 2010). Currently, communications infrastructure especially suited to the needs of fisherfolk is limited. Cellular coverage is available for only 12 to 15 km, but fisherfolk could go about 120 km from the shore into the sea (Rao, Ramesh, and Rangan 2016). In a study conducted in Trivandrum, it was found that while 75 per cent of fisherfolk own a house, 91 per cent did not own boats and only 10 per cent owned fishing gear (Shyam, Rahman, and Safeena 2017).

4. The fish catch that arrives at the port.

Our FGDs revealed several operational limitations, including limitations in the ability of the fishing crew to handle the outboard motors of fishing vessels, and erratic changes in the sea cause difficulties in steering. Additionally, littering of the canals has made it difficult to navigate to the sea, and the debris results in damage to property because it causes damage to the engine or the vessel. The high petrol prices are also a major obstacle because they need to spend close to INR 2000 just to navigate through the canals and reach the sea. This challenge is aggravated further because of the unavailability of petrol on credit.

Only a minor fraction of the fisherfolk own their fishing vessels and fishing gear. The manufacturing of new gear for smaller vessels has also been negligible because the market has seen an influx of demand for gear weighing more than 1000 kg. This is suitable only for bigger vessels, whereas fisherfolk using smaller vessels need gear weighing around 100 kg. Smaller gear also tend to get damaged frequently because there is limited knowledge about handling the equipment, and it takes longer to repair them when compared to their larger counterparts. This has also driven the manufacturers away from investing in the production of smaller fishing gear.

Although alternate fuel options such as LPG have been tested by the fisherfolk, the lack of compatible power has been a major disadvantage. The use of LPG also tends to heat the engines in the vessels, causing significant damage. They have also expressed concerns regarding reduced catches with the use of alternate fuels such as LPG.

Another major challenge that the fisherfolk face is getting insurance for their vessels and fishing craft. Private agencies have some insurance schemes, but the insurance provided is only for the craft and not the engine. In order to insure both the engine and the craft, the agency's condition has been to provide the craft as a collateral to which most of the fisherfolk are reluctant.

2.3 Financial capital

Financial capital comprises savings, in any form, access to financial services, and regular inflow of money. A study by Parappurathu et al. (2019) on fisherfolk across Kerala identified several formal and informal sources of credit. The formal credit sources include public sector banks, private banks, regional rural banks, co-operative banking institutions, and non-banking financial institutions. Historically, fisherfolk have had limited access to formal financing because of their inability to offer suitable collateral. The penetration of insurance for marine hulls, equipment, and gear has been limited as well. Lack of awareness and inability of fisherfolk to afford insurance premiums, perception of high risk, and low profitability in fisheries are among the reasons cited for this (Parappurathu et al. 2017a).

Informal financing is also common in the form of catch-/output-dependent deals (the creditor is an auctioneer/agent who will be the sole marketer of catch from the credit beneficiary). Sometimes fisherfolk also deal in third-party shares (shares available to those looking to invest in fishing), loans from private money lenders, and reciprocal loans from family and relatives (Parappurathu et al. 2019).

Table 2 Flexible repayment schedules and terms have led to fisherfolk favouring informal sources despite exorbitant interest rates in some cases (represents small-scale fisherfolk in Kerala).

Credit details of fisherfolk	Formal sources			Informal sources				
	Commercial banks	Co-operative banks	Matsyafed	Non-banking entities	Auctioneer	Private money lenders	Third-party shares	Friends and relatives
Average credit availed (lakh INR)	12.2	10.3	12	10.3	7.7	10.1	11.9	2.5
Average credit outstanding as a share of total (%)	57	73	65	90	96	90	90	80
Annual interest rate (%)	11-15	11-14	4-13	18-20	NA	24-60	NA	0
Loan term	2-7 years	2-7 years	2-7 years	2-7 years	Unspecified	Unspecified	Unspecified	1 year or less

Source: Adapted from (Parappurathu et al. 2018)

Macroeconomic factors may undermine the traditional structures and mechanisms that are used to protect fisherfolk's livelihoods (e.g., non-banking financial companies (NBFCs) have adapted to traditional money lending and savings, especially for fisherfolk). However, NBFC failures have become more frequent, affecting the livelihoods and savings of fisherfolk (Salagrama 2006).

Fisherfolk who cannot generate sufficient income or means of livelihood suffer from poverty and vulnerability. Boat owners take a more significant share of the catch, providing them with a buffer during lean periods and emergencies. The fishing crew, unlike boat owners, get a smaller share of the catch and do not have any assets for income security during emergencies. The fisherfolk's current level of revenues and wages leave very little room for surplus to support them beyond subsistence needs. During periods when the fishing season is disappointing and catches are low, the fishing households obtain credit at high rates of interest – pledging their future catch – trapping them in an endless cycle of debt. Up to 90 per cent of the households in typical fishing villages remain in debt for a good part of the year (Salagrama 2006).

The major challenges as identified in our FGDs are higher fuel costs and the limited subsidies on fuel from the government. The quota on subsidised petrol has undergone multiple iterations, and currently, the amount is 46 litres. This is barely enough for a single day's operation. Additionally, new engines do not have permits for subsidised fuels. Hence, fisherfolk are hesitant to change their engines even when their lifespan is over, which results in the consumption of more fuel owing to declining fuel efficiency. The increasing price of fuel further aggravates their situation. Kerosene has been used as an alternate fuel option; however, the limited subsidy available for kerosene forces them to resort to the black market for procurement.

A major share of the fisherfolk's income is directed to the high maintenance cost of the vessels and other equipment. Owing to all this, boat owners have negligible savings even if they manage to get a decent catch. Fisherfolk also end up paying more than INR 60,000 annually for repairing their fishing gear. Hence, they prefer to replace their vessels in two years rather than spend on maintenance. Additionally, the licence for operating the vessels has to be renewed annually, which amounts to INR 6000. Middlemen facilitate this renewal process, and the boat owners have to shell out money to them.

Fishing gear tend to get lost in rough seas and turbulent water, and fisherfolk usually borrow money to purchase new fishing gear, which along with other personal loans taken by them adds to their existing debts. Even though they are eligible for getting loans from the banks, they find it difficult to manage the collateral for availing the loan. Repayment is a concern amongst the fisherfolk as they need to pay back their loans even if their catch is not sufficient. Matsyafed, for example, has ceased to provide them with loans because of non-payment issues.

2.4 Human capital

Human capital comprises skills, knowledge, the ability to work, and good health. Although some measures have been taken to improve fisherfolk's safety at sea, there are no occupational health services for them. Documented evidence shows a high incidence of alcoholism and smoking among fisherfolk (Amit Bhondve et al. 2013). Strenuous working hours, inadequate diet and nutrition intake, stress, alcohol use, and tobacco use together lead to a high prevalence of oral mucosal lesions among fisherfolk (Anzil et al. 2016; Asawa et al. 2014).

Local ecological knowledge plays a vital role in the ability of fisherfolk to predict the weather and increase their yields by indicating the availability and location of fish (Pukkalla and Sharma 2021). Even in the transition from artisanal fishing to mechanised fishing and technology use, many implicit and embodied forms of knowledge remain relevant and can be gained through apprenticeship. With the modernisation of fishing, there has been a gradual erosion of navigational and fish-finding skills (Sundar 2018; Pukkalla and Sharma 2021). However, with the introduction of clean technologies, jobs in ancillary services pertaining to solar e-boats are set to increase.

Our FGDs with the fisherfolk from Chellanam and Puthuvypin reveal that the majority of them rely on fishing as their only source of income. Very rarely do

> **Fisherfolk pay a majority of their income on maintenance costs, hence they prefer replacing their vessels within two years.**

they have the knowledge or skills to work in any other sector along with fishing. This leads to stress when they are unable to get a decent catch because they still have the burden of loan repayment and other household expenses. Solar-assisted e-boats, owing to cheaper fuel costs, can potentially enhance their daily savings.

2.5 Social capital

Social capital comprises the social resources people draw on to make a living, such as relationships with either more powerful people (vertical connections) or with others like themselves (horizontal connections), or through membership in groups or organisations.

Fisherfolk co-operatives are critical to advancing the interests of fisherfolk and facilitating social connectedness. These include the national federation of fisherfolk co-operatives, the state federation of fisherfolk co-operatives, central fisherfolk co-operative societies, and primary fisherfolk co-operative societies. Their functions include procuring inputs and equipment, training, liaison with the government, raising capital for financing, marketing fish at fair prices, and processing fish, among others.

A review of various studies looking at the status of fisheries co-operatives in different regions revealed that few were well managed, actively monitored, and government supported. Several others were facing constraints arising from limited professional management skills and funding. In India, institutional mechanisms for managing risk and uncertainties in the fishing sector are limited. For instance, insurance in fisheries is significantly under-utilised when compared with other agricultural sub-sectors (Parappurathu et al. 2017b).

An inspection of the fisherfolk's community through the lens of the SLF and FGDs suggests that challenges exist in all asset dimensions. There is a need for regional-level interventions targeting each of the above capital assets to improve their livelihood.

This study explores solar-assisted e-boats, a physical capital that can potentially enhance incomes and avoid the ecological damage associated with fossil-fuelled vessels, which will enhance natural capital. Furthermore, the reduction in the costs of fuel will in turn enhance financial capital and human capital.

3. Role of clean technology in fisheries

Today, boats powered by solar energy and fuel cells are the main alternatives to fossil fuel–based boats. As observed across various case studies, the operational costs and maintenance costs for solar boats are low. E-boats vibrate less, and the sound pollution is also low, with decibel levels less than 60 dB, as compared to those of conventional vessels, whose noise levels are between 80 and 90 dB (Sharma and Kothari 2018).

Although solar boats will also incur costs associated with replacing batteries (every five to seven years), maintenance costs are lower when compared to internal combustion engines. For diesel engines, this includes replacing lube oil, filters, and engine repairs, which range from 3 to 7 per cent of the capital cost for regular maintenance (Thandasherry 2018).

Fuel prices disproportionately impact fisherfolk despite subsidies offered. This was especially exacerbated in the past couple of years owing to the increasing diesel prices, with fisherfolk demanding an increase in fuel subsidy (*The Hindu* 2020, 2021). Fisherfolk must be shielded against high fuel costs, given the precarious nature of their livelihood and lack of safety nets. Solar boats can address this issue by reducing fuel costs for fishing operations. This is evaluated in detail in the section 3.2.

Beyond using renewable energy (RE) to power the propulsion of fishing vessels, there is scope for using solar photovoltaic technology in other parts of the marine fishing value chain. It has found viable applications in auxiliary power consumption, lanterns to attract fish, active ventilation in traditional solar dryers, ice production, refrigeration, and powering entire fish processing units (Sunaryo, Syahrihaddin, and Imfianto 2019; Mills, Gengnagel, and Wollburg 2014; Tyona and Ojiya 2020; Huzayyin et al. 2018; Pandey et al. 2017; Widodo et al. 2018). Our consultations with various stakeholders also underscored the need to emphasise the use of low- or zero-carbon technology for post-harvest activities because this would help in increasing the income of fisherfolk.

> **Adoption of clean technologies in the fishing sector can reduce the reliance of fisherfolk on fossil fuels and enhance their daily income.**

Table 3 Case studies and examples of solar and electric boats worldwide

Name	Application	Length	Solar panel	Battery	Range	Speed
ADITYA **solar-powered boat**	Passenger ferry with a seating capacity of 75 passengers	20 m	18 kW (main) + 2 kW (auxiliary)	2 x 25 kWh li-ion phosphate for the main system; 2 x 5 kWh (lead–acid) for the auxiliary system	Six hours of cruising time	7.5 knots (14 km/h)
ELLEN **electric ferry**	Ferry service with a capacity of 31 cars or 5 trucks or 198 passengers	59 m	—	4.3 MWh Nickel Manganese Cobalt (NMC) battery	22 nautical miles	13–15.5 knots
SUNRIDER **solar-powered boat**	Ecotourism, 10 and 20 passengers	10 m (20 passengers); 6.5 m (10 passengers)	3.6 kWp (20 passengers); 1.8 kWhp (10 passengers)	40 kWh lead–acid battery (20 passengers); 20 kWh lead–acid battery (10 passengers)	—	7–9 knots
SOLARIS **solar-powered boat**	Ecotourism with a seating capacity of 28 passengers	15 m	8 kW	Energy for six hours cruising time after cut off from solar power	50 miles without solar power	8–10 knots
ECOCAT **solar vessel**	Passenger ferry with a seating capacity of 120 passengers	18 m	120 solar panels	8 x 30.5 kWh	Eight hours of cruising time without solar power	7 knots (13 km/h)
MOBICAT	Ecotourism with a seating capacity of 250 passengers	33 m	34 kWp	480 kWh lithium-ion battery	180 km	14 km/h

Source: Authors' compilation

3.1 Case studies of solar and electric boats

There has been an increase in the adoption of clean technologies in marine vessels and ferries. The technology used by e-boats has matured, and integration with RE, including solar power, has also been explored as highlighted in table 3. However, the adoption of clean technology has been limited to passenger ferries. The market potential of utilising cleaner technologies for the fishing sector is yet to be explored. Given the evolving market for motorised boats, it is imperative to assess the potential market for the use of cleaner technologies in the fishing sector.

ADITYA, a solar-powered passenger ferry in Vembanad backwaters, Kerala

ADITYA is a solar-powered catamaran ferry boat that was deployed in Kerala's Vembanad backwaters in 2017. Besides being India's first solar ferry, it is the first globally to draw more than 80 per cent of its energy requirements from solar energy. It has a seating capacity of 75 passengers and can cruise for more than six hours without the need for an external charge on a sunny day (NavAlt Boats n.d.). The boat makes 22 trips per day and saves 58,000 litres of diesel annually, translating to savings of INR 46,12,000 per year (Vishnu Varma 2020).

Ellen, an electric ferry connecting two Danish islands

Ellen is the world's largest e-ferry with the ability to carry 31 cars or 5 trucks or 198 passengers. It has 4.3 MWh of battery power on board. It is capable of conducting a round trip of 22 nautical miles at one go on a full charge – seven times what other ships have achieved so far (Tunnicliffe 2019; Dartford 2019). With a maximum speed range of 13 to 15.5 knots, it is capable of completing a single trip in 55 minutes as compared to the 70 minutes needed by a conventional vessel (Tunnicliffe 2019). The ferry has the potential to save 2000 tons of CO_2 emissions per year (Dartford 2019).

Sunrider, solar-powered boat in Kumarakom, Kerala

Set in Vembanad lake's backdrop, Kumarakom attracts several visitors for its famous backwater tourism. Conventional boats powered by diesel and petrol have been the primary mode of waterway transport since the early 1900s. Because of the growing popularity of ecotourism, TeamSustain designed and developed a solar-powered boat suited for the purpose. It now saves about 14,600 litres of diesel and 40 tons of CO_2 emissions annually (Trojan Battery Company 2018).

Solaris, a solar-powered boat on the Hudson River

Hudson River Maritime Museum has deployed *Solaris*, a solar-powered boat, to ferry passengers on a tour of the river. The boat was built by the museum's restoration crew (Spilman 2019). With a seating capacity of 28 passengers, the boat can travel up to 50 nautical miles on battery without solar power (Beacon 2019). In addition to providing ecotourism on the Hudson River, *Solaris* provides commuter ferry services between the two coasts on weekends (Beacon 2019).

EcoCat, a solar-powered vessel in Santander Bay

EcoCat is Europe's first solar-powered catamaran boat. The boat is 18 m long, propelled by 50-kW electric motors and eight 30.5-kWh batteries, with technology patented by BMW (creektech.net 2017). The boat can seat 120 passengers, including people with reduced mobility, and has a bathroom as well as parking space for bicycles (creektech.net 2017). The vessel can travel for eight hours on batteries alone, without recharging (PortNews 2018).

MobiCat, a solar-powered boat in lake Biel

Launched in 2000, *MobiCat* was advertised as the world's largest solar-powered catamaran boat. The boat has transported passengers on lakes Biel, Neuchatel, and Murten (Swissinfo.ch 2001). Since it started operations in 2001, the boat has ferried more than 40,000 passengers, covering 20,000 km (Schweiz Tourismus n.d.). The manufacturers have increased the capacity of the battery and solar cells by 2.5 times in their 2018 model. The complete system has been redesigned to create the first grid storage system at sea on a solar catamaran. The model now carries a 34-kWP solar power plant and a 480-kWh battery providing 14 hours of travel time and a range of 180 km (Lithium System n.d.).

3.2 Impact of solar-assisted electric boats on fisherfolk's income

We estimated the total cost of ownership (TCO) over five years of petrol boats and solar boats, accounting for both fixed and variable costs. We assumed that the motorised fishing boat and solar-assisted e-boat cover a round-trip distance of 100 km on a single day's fishing trip and carry out 150 trips annually (Radhakrishnan et al. 2018). The solar-assisted e-boats considered for the analysis were the NavAlt boats. NavAlt is the first manufacturer of solar-assisted electric ferries in India and is exploring the construction of solar-assisted electric vessels that can be used for fishing. The assumptions used for the TCO calculations are listed in Table 4.

Table 4 Assumptions for the TCO calculations

Variables	Units	Petrol boat	Solar assisted e-boat	Source
Distance travelled per trip	km	100	100	
Number of trips annually	Number	150	150	(Radhakrishnan et al. 2018)
Fixed cost assumptions				
Upfront cost	INR	5,00,000	10,00,000	
Borrowed percentage	%	80	80	
Rate of interest	%	10	10	
Repayment period	Years	5	5	
Insurance	INR	700	700	
Registration fees	INR	700	700	FGDs with boat owners and officers from NavAlt solar electric boats
Annual renewal fee	INR	250	250	
Licence fees	INR	6000	6000	
Annual renewal fee	INR	1500	1500	
Depreciation rate	%	5	5	
Fixed cost assumptions				
Fuel cost	INR/litre or INR/kWh	90	5	Price in Kerala as of July 2021
Fuel economy	km/litre or km/kWh	4.94	2	Detailed in the Annexure 2
Annual performance loss	%	1.5	1	
Annual price escalation	%	4	2	(Thandasherry 2021) and primary survey of boat owners
Share of other expenses	% of fuel expense	5	10	

Source: Authors' compilation

Table 5 Description of the variables used for the TCO calculation

TCO components	Description
Upfront cost and cost financing	
Upfront cost	Capital cost of the vehicle
Interest on the borrowed amount	Interest paid for the loan taken towards the purchase of the boat
Overheads	
Registration fees	Expenses for registering the boats
Insurance	Premium paid by the fisherfolk against the insurance of their vessels or gear
License fees	Fees for the renewal of the licence of the boats
Salvage value	Amount obtained for the boat at the end of its lifespan
Operational costs	
Fuel expenditure	Fuel expenses involved in the operation of the boats
Maintenance expenses	Regular maintenance expenses of the boats

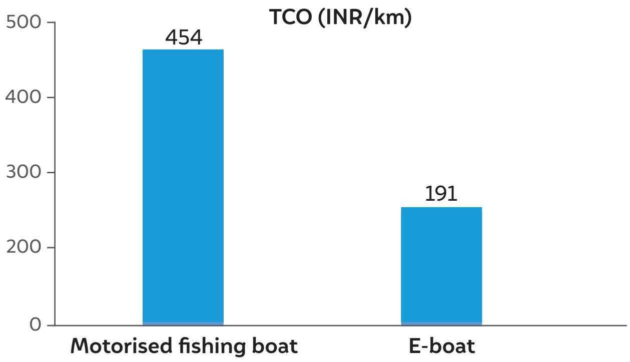
Source: Authors' compilation

Table 5 shows the list of expenses covered by the TCO analysis. We considered similar operational characteristics for both kinds of boats.

We find that the TCO of the petrol boat is INR 454/km compared to INR 192/km for solar boats (see Figure 6). Thus, despite the higher upfront purchase cost of the solar-assisted e-boat, the TCO of the solar-assisted e-boat is 58 per cent lower than that of a conventional motorised boat. A large part of this reduction is achieved through lower annual costs for fuel. The following factors bring about this decrease in the fuel expenses:

- **Greater efficiency of the solar fishing boat compared to the marine fishing boat**: The fuel economy of the conventional motorised boat is 4.94 km/litre, while that of a solar-assisted e-boat is 1.32 km/kWh.[5] The energy content of diesel and electricity are 36.9 MJ/litre and 3.6 MJ/kWh, respectively (European Automobile Manufacturers' Association 2016). So, in energy terms, a conventional motorised boat consumes 7.47 MJ of energy per kilometre, whereas a solar-assisted e-boat consumes 2.73 MJ of energy per kilometre. The energy consumed by solar motorised boats is about 63 per cent lower than that consumed by conventional motorised fishing boats, for the same distance covered.
- **Lower fuel cost:** In addition to being energy efficient, the cost of fuel – that is, electricity – is 43 per cent lower (INR 2.44/MJ) than that for diesel (INR 1.39/MJ).[6]
- **Lower fuel consumption owing to solar panels**: Solar-assisted e-boats use solar power for charging on-board batteries and for propulsion. This reduces the need for electricity consumption at the shore to charge the batteries. Based on the data available for *ADITYA* (the solar passenger ferry), about 80 per cent of the energy is generated from solar panels. Therefore, only about 20 per cent of the energy consumed by the boat on the trip is consumed at the shore.

Figure 6 The TCO of a solar assisted e-boat is around 60 per cent lower than that of a petrol boat



Source: Authors' analysis

5. This mileage was calculated based on various technical parameters available in the literature. Please see Annexure 2 for details on assumptions and calculations.
6. A diesel price of INR 85.50/litre in Kerala, as of 28 April 2021, and a subsidy of INR 1.50/litre was assumed for the analysis (ET 2021; DAHDF n.d.). The price of electricity used for the analysis was INR 7.50/kWh (Thandasherry 2020).

The savings on fuel expenses for marine fishing operations have the potential to increase the income of fisherfolk significantly. We further analyse the impact on the fisherfolk's income earned per day by replacing conventional motorised fishing boats with solar-assisted e-boats.

On-ground observations in Kerala show that around 13 people are involved in the operation of the vessel and handling the fishing catch: 5 to 6 people work on board the vessel, 3 to 4 help on the ground, and 2 to 4 are hired labour to assist with various activities. For our calculations, we assume an on-board crew of five for both the motorised fishing boat and the solar-assisted e-boat. The catches of the fisherfolk in Kerala also vary significantly, ranging from 150 kg to 800 kg on a good day, with a cost of between INR 20 and INR 50 per kg. For our analysis, we assume a catch of about 164 kg (Kumar et al. 2017; Thandasherry 2020) and an average price of a catch from their daily operations of INR 24 per kg.

We estimate that both conventional and solar-assisted e-boats generate a gross revenue of INR 3929 per trip. Deducting the fuel expenses from the gross revenue, the resulting net revenues are INR 2106 and INR 3879 in the case of petrol and solar fishing boats, respectively. The income per person among the crew is INR 421 and INR 776, for conventional and solar-assisted e-boats, respectively. The details of the cost estimation are presented in Table 6.

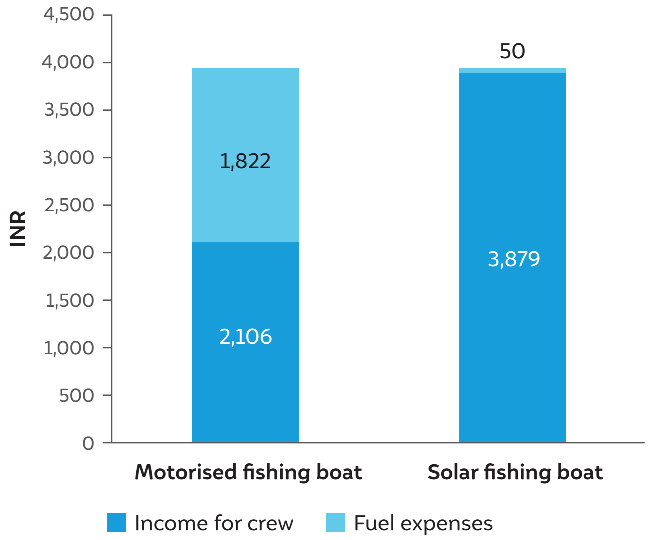
Thus, we observe an 84 per cent increase in the income of fisherfolk when they use solar-assisted e-boats. We have taken into account only fuel expenses under the operational costs of marine fishing operations for this analysis. However, more savings in operational costs are expected from reductions in maintenance and repair expenses.

Table 6 Adoption of solar assisted e-boats can increase the net income per person by almost two times

Items	Petrol fishing boat	Solar assisted e-boat
A Gross revenue	INR 3929	INR 3929
B Fuel expense	INR 1822	INR 50
C Net revenue [A – B]	INR 2106	INR 3879
E The amount available for crew share [C]	INR 2106	INR 3879
F Income per person	INR 421	INR 776

Source: Authors' compilation

Figure 7 The available income for the fishing crew can potentially increase by almost two times owing to lesser fuel expense



Source: Authors' analysis

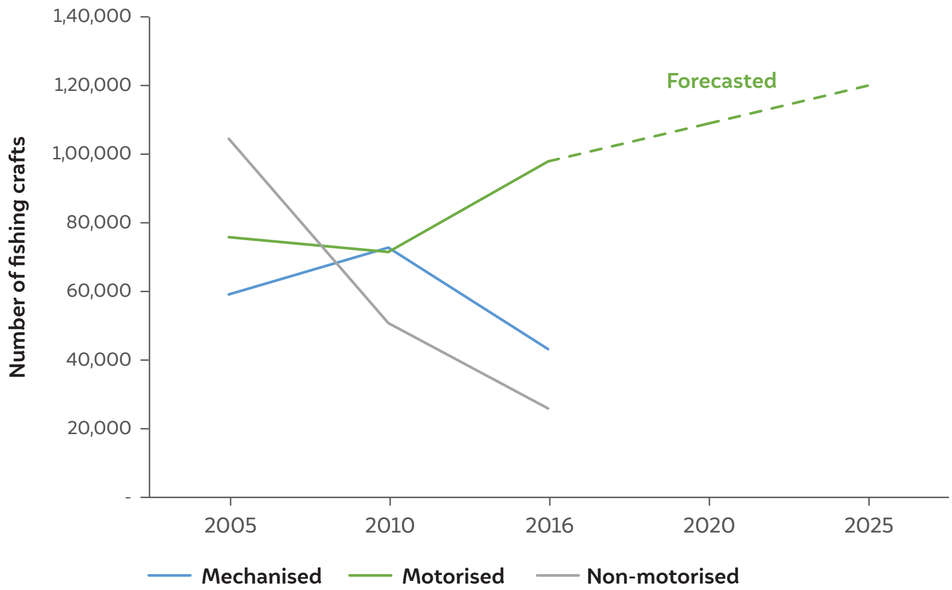
3.3 CO_2 emissions reduction

Solar-assisted motorised boats are associated with lower CO_2 emissions not only by being more efficient and using electricity, but also by using RE for on-board propulsion. Our analysis of CO_2 emissions in fishing boats using fuel CO_2 emission factors for fuel-related CO_2 emissions shows that one conventional motorised fishing boat emits about 0.46 kg CO_2/km, whereas a solar-assisted e-boat emits 0.08 kg CO_2/km (84 per cent lower).[7]

According to the Marine Fishing Census, the marine fishing fleet size has steadily declined between 1961 and 2016. In 2005, a total of 2.38 lakh marine fishing boats were in operation, and this number went down to 1.94 lakh in 2010 and 1.66 lakh in 2016, registering a 3.2 per cent CAGR decline over 11 years (Central Marine Fisheries Research Institute, Fishery Survey of India, and Department of Fisheries 2006, 2012, 2020). A more detailed count by different kinds of fishing craft showed that the fleet size of both mechanised and non-motorised boats has been shrinking over the years. On the other hand, the number of motorised fishing boats increased at a CAGR of 2.4 per cent between 2005 and 2016 (see Figure 8).

7. Detailed calculations and assumptions are included in Annexure 3.

Figure 8 **Motorised fishing craft are projected to grow by 1.6 times in 2025 from the 2005 baseline**



Source: Central Marine Fisheries Research Institute, Fishery Survey of India, and Department of Fisheries (2006, 2012, 2020). Marine Fisheries Census – India; authors' analysis

Assuming that all the outboard motorised fishing boats in 2016 (the latest marine fisheries census) were solar-assisted e-boats, about 560,000 tonnes of CO_2 emissions could be abated at a minimum. Additionally, these 97,659 solar-assisted e-boats would create a market size of INR 6625 crore.

4. Recommendations and the way forward

Marine fishing is a pivotal contributor to the country's economic growth, accounting for 7 per cent of the total agricultural GDP (1.07 per cent of the total GDP). Whereas on the one hand the marine fishing sector has evolved into a multi-billion-dollar industry, on the other, the fisherfolk face several challenges related to natural, financial, social, physical, and human capital. Technological advances, such as the introduction of motorised boats, have been instrumental in addressing these constraints. The mechanisation of the marine fishing sector has improved annual fish production by almost 117 per cent from 1986–1987 to 2016–2017.

However, this mechanisation poses several threats to the environment. Poor engine and fuel efficiencies of the boats contribute to water pollution, and the related noise pollution has significant adverse effects on aquatic life. A technology shift to greener alternatives would reduce various forms of pollution and make the fisheries sector more sustainable. We explored the possibility of using solar-operated boats in the fisheries sector in this study. Our analysis indicates that the TCO of an e-boat is around 60 per cent lower than that of a petrol-operated boat, with the possibility of a reduction of 560,000 tonnes in CO_2 emissions.

Despite an attractive TCO, fisherfolk have been hesitant to explore solar-assisted e-boats as a potential substitute, for various reasons. Based on our FGDs, we put forward the following recommendations to increase the uptake of solar-assisted e-boats:

1. **Awareness gaps and addressal:** Currently, fisherfolk are sceptical about solar-assisted e-boats. Their main concern is regarding the design of the boats – they feel that e-boats are not as sturdy as existing traditional vessels. A majority of their operations are in turbulent water, and their apprehension is that the material used to construct these boats is too fragile to withstand such conditions. Beach landings tend to damage fibreglass or wooden boats, and hence they would prefer that more robust materials are used for the construction of e-boats. Therefore, manufacturers could explore other, more sturdy materials for the construction of e–boats. Alternatively, there is a need for awareness campaigns to help disseminate the fears regarding the materials used. This will also help the fisherfolk adapt better to the technology of e-boats and start using them for their fishing activities.

2. **Suitable financing options**: A majority of fisherfolk are concerned about the high upfront costs of e-boats. Currently, even the price of traditional vessels is considered rather steep, which means that e-boats, which cost almost twice as much, are seen as prohibitively expensive. Hesitancy towards providing collateral prevents them from availing of formal loans and makes them rely on informal sources. The government can introduce schemes for the uptake of cleaner technologies, similar to the FAME scheme for electric vehicles. Additionally, banks can consider providing green loans at cheaper interest rates for e-boats.

3. **Renewable energy integration**: Integration of RE with e-boats provides an opportunity for the manufacturers to effectively design their vessels to reduce dependence on grid electricity. Given the intermittency of RE sources, it is imperative for manufacturers to design robust auxiliary systems that can power the e-boats in the absence of RE power. Fisherfolk tend to spend around eight hours sometimes at sea to get a decent catch. Hence, the manufacturers need to design the energy storage and power systems of the e-boats keeping this operational pattern in mind. This will further encourage a one-to-one replacement of conventional vessels with e-boats.

4. **Leveraging data for safety and resource efficiency**: Most of the vessels used for marine fishing purposes are informal. Given the use of materials such as fibreglass, it becomes imperative to ensure that the boats are properly disposed of when they are scrapped. The Information Technology and Management Services (ITMS) system present in the solar-assisted e-boats can help the government track the location of the e-boats and ensure that they are adequately disposed of and that the critical materials used in the e-boats are properly recycled at the end of their lifespan.

The ITMS system can also assist fisherfolk in keeping track of the vessels as well as ensuring their safety in case of emergencies. Currently, contacting the shore or the coast guard is a major concern for the fisherfolk during emergencies, but with the ITMS, this challenge can be overcome.

The existing policies, programmes, and schemes focus on various aspects to improve the livelihoods of fisherfolk, but the use of clean technologies is still missing from the discussion. The current policies and schemes can, however, be revamped to enable the adoption of clean technologies. Some of these policies and schemes are discussed below.

4.1 National policies

National Fisheries Policy (FY21–FY26)

Livelihood areas covered: productivity, diversification of income, marketing of catch, safety, and health

Integrating the National Policy on Marine Fisheries, 2017 (NPMF), the draft National Inland Fisheries and Aquaculture Policy (NIFAP), and the draft National Mariculture Policy (NMP), the Government of India introduced a comprehensive National Fisheries Policy (draft NFP) in February 2020 (PIB 2020b). The policy objectives include making fish products globally competitive while ensuring sound management of resources, meeting food and nutritional security of the fishing communities, and building resilience. The NFP focuses on regulatory and institutional reforms to promote various fisheries-related activities.

Currently, because fuel remains a major expense for the fisherfolk, a transition to cleaner technologies will help them increase their daily savings. These savings can then be used to purchase better fishing gear to increase their catch. Hence, the NFP policy can be amended to include the adoption of cleaner technologies to enhance the economic benefits for the fisherfolk.

4.2 Programmes and schemes

Pradhan Mantri Matsya Sampada Yojana (PMMSY; FY21–FY25)

Livelihood areas covered: Fish productivity, welfare, access to technology, post-harvest infrastructure

The PMMSY aims to address gaps in fish productivity, quality, technology post-harvest infrastructure and management, modernisation and strengthening of vessels and other assets, traceability and safety through better telematics, establishing a robust fisheries management framework, and fisherfolk welfare.

> Creating awareness, enabling suitable finance, integrating renewable energy and ITMS system would help catalyse the clean technology adoption.

The scheme has an estimated investment of INR 20,050 crore under the *Atmanirbhar Bharat package* (PIB 2020a). Although the PMMSY adequately addresses the need for modernising the craft, promoting the adoption of clean technologies could further help in reducing emissions and increasing savings for fisherfolk.

Fisheries and Aquaculture Infrastructure Development Fund (FY19–FY23)

Livelihood areas covered: Infrastructure

The government of India encourages private entrepreneurs and fish farmers to build fisheries infrastructure facilities. The Fisheries and Aquaculture Infrastructure Development Fund was created with an estimated fund outlay of INR 7522.48 crore to achieve 20 million tonnes of fish production by 2022–2023. Solar-assisted e-boats can play a critical role in achieving this target (Department of Fisheries 2015).

Kisan Credit Card Scheme (ongoing from FY20)

Livelihood areas covered: Access to credit

In 2019, the government extended the Kisan Credit Card scheme to fisherfolk. Under this scheme, fisherfolk can avail support for their short-term working capital needs.

Inclusion of clean technologies in the existing policies would help expedite the adoption of these technologies.

The credit limit is INR 2 lakh, and interest subvention is available at 2 per cent per annum, with an additional subvention of 3 per cent per annum in the form of a prompt repayment incentive (PIB 2019). The credit scheme can be extended by the government to promote cleaner technologies by increasing the credit limit for the purchase of e-boats.

Although there are clear economic and environmental benefits associated with the transition to cleaner technologies, support in terms of schemes and policies will further fast-track the transition. Going forward, the impact of solar-assisted e-boats can be further explored by conducting pilots to identify any key barriers that may arise in their operations. Furthermore, an impact study can be conducted to analyse the impact on the livelihood of fisherfolk when they adopt cleaner technologies. With proper support from the government and regional fishing co-operatives, the technology transition to greener alternatives will improve fisherfolk's livelihoods and help reduce emissions from the marine fishing sector.

Image: CEEW/Kartikeya Jain

CEEW team on ground collecting evidence and stakeholders' perspectives on the use of e-boats for potential enhancement of their livelihoods.

References

Amit Bhondve, Hemant Mahajan, Bhuwan Sharma, and Abhiram Kasbe. 2013. “Assessment of Addictions among Fishermen in Southern-East Costal Area of Mumbai, India.” *IOSR Journal of Dental and Medical Sciences* 6 (6): 71–79. https://doi.org/10.9790/0853-0667179.

Anzil, Ksa, J Mathews, Ag Sai, M Kiran, S Kevin, and S Sunith. 2016. “Prevalence of Deleterious Oral Habits and Oral Mucosal Lesions among Fishermen Population of Mahe, South India.” *The Journal of Contemporary Dental Practice* 17 (9): 745–49. https://doi.org/10.5005/jp-journals-10024-1923.

Asawa, Kailash, Piyush Pujara, Mridula Tak, Ramesh Nagarajappa, Pankaj Aapaliya, Nikhil Bhanushali, Prashant Mishra, and Abhishek Sharma. 2014. “Oral Health Status of Fishermen and Non-Fishermen Community of Kutch District, Gujarat, India: A Comparative Study.” *International Maritime Health* 65 (March): 1–6. https://journals.viamedica.pl/international_maritime_health/article/view/37754.

Beacon. 2019. “Solar Boat Solaris to Sail Hudson River between Cities of Newburgh and Beacon.” *The Photo News*, September 25, 2019. http://www.thephoto-news.com/news/local-news/solar-boat-solaris-to-sail-hudson-river-between-cities-of-newburgh-and-beacon-GY526901.

CMFRI. 2020. “Marine Landings in India 2019.” 24/2020. Kochi: Central Marine Fisheries Research Institute. http://eprints.cmfri.org.in/14325/1/Marine%20Fish%20Landings%20in%20India_2020_CMFRI.pdf.

Central Marine Fisheries Research Institute. 2020. “Marine Landings in India 2019.” http://eprints.cmfri.org.in/14325/1/Marine%20Fish%20Landings%20in%20India_2020_CMFRI.pdf.

Central Marine Fisheries Research Institute, Fishery Survey of India, and Department of Fisheries, Ministry of Fisheries, Animal Husbandry and Dairying, Government of India. 2006. “Marine Fisheries Census 2005 – India.” http://eprints.cmfri.org.in/8998/.

———. 2012. “Marine Fisheries Census 2010 – India.” http://eprints.cmfri.org.in/8998/.

———. 2020. “Marine Fisheries Census 2016 – India.”

creektech.net. 2017. “*Ecocat*, The First European Catamaran Powered By Solar Energy Launched In Santander.” 2017.

DAHDF. n.d. “Centrally Sponsored Scheme on Development of Marine Fisheries, Infrastructure and Post-Harvest Operation.” Department of Animal Husbandry, Dairying and Fisheries. Accessed April 28, 2021. http://www.dahd.nic.in/related-links/centrally-sponsored-scheme-development-marine-fisheries-infrastructure-and-post.

Dartford, Katy. 2019. “The World’s Largest E-Ferry, Connects Two Islands without Emmiting CO2.” Euronews. November 25, 2019. https://www.euronews.com/2019/11/25/meet-ellen-the-world-s-largest-e-ferry-connecting-two-danish-islands-without-emitting-any.

Dey, Mayukh, Jagdish Krishnaswamy, Tadamichi Morisaka, and Nachiket Kelkar. 2019. “Interacting Effects of Vessel Noise and Shallow River Depth Elevate Metabolic Stress in Ganges River Dolphins.” *Scientific Reports* 9 (1): 15426. https://doi.org/10.1038/s41598-019-51664-1.

Department of Fisheries. 2015. “Continuation of Centrally Sponsored Scheme on Development of Marine Fisheries, Infrastructure and Post-Harvest Operation during 2015-16.” Department of Fisheries. http://dof.gov.in/sites/default/files/2020-01/Continuation%20of%20Centrally%20Sponsored%20Scheme%20on%20Devpl%20of%20Marine%20fisheries%2CInfrastructure%20and%20Post%20Harvest%20Operation%20during%202015-16%20%20%202.pdf.

———. 2019. “Handbook on Fisheries Statistics 2018.” Mumbai: Ministry of Fisheries, Animal Husbandry & Darying. http://dof.gov.in/sites/default/files/2020-08/HandbookonFS2018.pdf.

European Automobile Manufacturers’ Association (ACEA. 2016. “Differences Between Diesel and Petrol | ACEA - European Automobile Manufacturers’ Association.” European Automobile Manufacturers’ Association (ACEA). 2016. https://www.acea.be/news/article/differences-between-diesel-and-petrol.

ET. 2021. “Diesel Price in Kerala | Check Latest Diesel Rates in Kerala.” The Economic Times. April 28, 2021. https://economictimes.indiatimes.com/wealth/fuelprices/fuel-diesel,citystate-kerala.cms.

Food and Agriculture Organization of the United Nations. 2018. “The State of World Fisheries and Aquaculture: Meeting the Sustainable Development Goals.” Rome.

Huzayyin, O. A., M. S. El Morsi, M. A. Serag-Eldin, and M. F. El-Bedaiwy. 2018. "Prototype for Solar Powered Chip-Ice Production Facility." In . American Society of Mechanical Engineers Digital Collection. https://doi.org/10.1115/IMECE2017-72510.

Kajal, Kapil. 2020. "How Climate Change Is Affecting Maharashtra Fish Catch." Mongabay-India. August 3, 2020. https://india.mongabay.com/2020/08/low-fish-catch-along-indias-western-coast-hints-at-impacts-of-climate-change/.

Kumar, R. Narayana, Shyam S. Salim, P. Shinoj, and C. Ramachandran. 2017. "Methodological Tools for Socioeconomic and Policy Analysis in Marine Fisheries." Special Publication 127. Kochi: ICAR-Central Marine Fisheries Institute. http://eprints.cmfri.org.in/12736/1/CMFRI%20Special%20Publication%20127.pdf.

Lithium System. n.d. "MobiCat - The Ship of the Future." *Lithium System GmbH* (blog). Accessed April 11, 2021. https://lithiumsystem.ch/projects/mobicat/?lang=en.

Mills, Evan, Tim Gengnagel, and Philipp Wollburg. 2014. "Solar-LED Alternatives to Fuel-Based Lighting for Night Fishing." *Energy for Sustainable Development* 21 (August): 30–41. https://doi.org/10.1016/j.esd.2014.04.006.

Mohanty, Abinash. 2020. "Preparing India for Extreme Climate Events: Mapping Hotspots and Response Mechanisms," December, 68.

Navalt Boats. n.d. "Introduction to India's First Solar Ferry." Navalt. Accessed April 1, 2021. https://navaltboats.com/navalt-first-solar-ferry-introduction/.

NFDB. 2020. "National Fisheries Policy 2020." https://dof.gov.in/sites/default/files/2020-12/Policy_0.pdf.

Pandey, Gayatri, CV Raju, Jag Pal, Shobha Rawat, and Mahesh Chand Sonwal. 2017. "Comparative Study of Changes in the Quality Attributes of Indian Mackerel (Rastrelliger Kanagurta) and Pink Perch (Nemipterus Japonicus) Stored in Solar Operated Refrigerated Fish Vending Unit." *Journal of Entomology and Zoology Studies*, 4.

Parappurathu, Shinoj, C. Ramachandran, K. K. Baiju, and Xavier Antony Kurisunkal. 2018. "Some Insights into the Credit Transactions of Small - Scale Fishers along the Kerala Coast, India." Marine Fisheries Information Service; Technical and Extension Series, no. 236: 16–21.

Parappurathu, Shinoj, C. Ramachandran, K. K. Baiju, and Antony Kurisunkal Xavier. 2019. "Formal versus Informal: Insights into the Credit Transactions of Small-Scale Fishers along the South West Coast of India." *Marine Policy* 103 (May): 101–12. https://doi.org/10.1016/j.marpol.2019.02.032.

Parappurathu, Shinoj, C Ramachandran, A Gopalakrishnan, K Mohammed Koya, R Narayanakumar, K P Salini, and P V Sunil. 2017. "Marine Fisheries Insurance in India: Status and Prospects," no. 233: 6.

Parappurathu, Shinoj, C. Ramachandran, A. Gopalakrishnan, Dilip Kumar, M. K. Poddar, Manas Choudhury, R. Geetha, et al. 2017. "What Ails Fisheries Insurance in India? An Assessment of Issues, Challenges and Future Potential." Marine Policy 86 (December): 144–55. https://doi.org/10.1016/j.marpol.2017.09.023.

PIB. 2019. "Credit Cards for Fishermen." 2019. pib.gov.in/Pressreleaseshare.aspx?PRID=1576660.

———. 2020a. "PM to Launch Pradhan Mantri Matsya Sampada Yojana on 10th September." Press Information Bureau. September 9, 2020. pib.gov.in/Pressreleaseshare.aspx?PRID=1652573.

———. 2020b. "National Fisheries Policy (2020)." Press Information Bureau. September 15, 2020. pib.gov.in/Pressreleaseshare.aspx?PRID=1654543.

PortNews. 2018. "Torqeedo Receives European Commercial Marine Award for Maritime Sustainability." 2018. https://en.portnews.ru/news/261084/.

P.U. Zacharia. n.d. "Present and Future Scenario of Indian Marine Fisheries." CMFRI, Cochin. Accessed November 24, 2022. https://www.cmfri.org.in/uploads_en/divisions/files/Present%20and%20future%20scenario%20of%20Indfian%20marine%20fisheries.pdf.

Pukkalla, Dalibandhu, and Sharma BV. 2021. "Transmission and Erosion of Local Knowledge Practices in a Fishing Village in South India." *Journal of Ecological Anthropology* 22 (1): 34–42. https://doi.org/10.5038/2162-4593.22.1.1238.

Radhakrishnan, Kalidoss, S. Prakash, R. Narayanakumar, M. Krishnan, M.S. Madan, and N.R. Kumar. 2018. "Economic Analysis of Marine Fishing Crafts in Thoothukudi Province, Tamil Nadu." *Indian Journal of Geo Marine Science* 47 (3): 653–59.

Rajan, Punnakulam T. 2018. "Marine Fishery Resources and Species Diversity of Tropical Waters." In *Biodiversity and Climate Change Adaptation in Tropical Islands*, 323–54. Elsevier. https://doi.org/10.1016/B978-0-12-813064-3.00011-9.

Rao, Sethuraman N, Maneesha Vinodini Ramesh, and Venkat Rangan. 2016. "Mobile Infrastructure for Coastal Region Offshore Communications and Networks." In *2016 IEEE Global Humanitarian Technology Conference (GHTC)*, 99–104. https://doi.org/10.1109/GHTC.2016.7857266.

Salagrama, Venkatesh. 2006. *Trends in Poverty and Livelihoods in Coastal Fishing Communities of Orissa State, India*. FAO Fisheries Technical Paper 490. Rome: Food and Agriculture Organization of the United Nations.

Salim, Shyam S, and Bindu Antony. 2015. "Marine Fisheries Trade in India: Perspectives and Paradigms." CMFRI. http://eprints.cmfri.org.in/10407/1/02_Shyam_S_Salim3.pdf.

Salim, Shyam S., R. Sathiadas, R. Naraynakumar, P.K. Katiha, M. Krishnan, R.S. Biradar, Nikita Gopal, Nagesh Barik, and B. Ganesh Kumar. 2013. "Rural Livelihood Security: Assessment of Fishers' Social Status in India." *Agricultural Economics Research Review* 26: 21–30.

SEAI and MPEDA. 2010. "Souvenir 2010." Chennai. http://eprints.cmfri.org.in/8714/1/Souvenir_2010.pdf.

Sharma, A. K., and D. P. Kothari. 2018. "Solar PV Potential for Passenger Ferry Boats in India's National Waterways." In *2018 2nd International Conference on Inventive Systems and Control (ICISC)*, 120–30. https://doi.org/10.1109/ICISC.2018.8399035.

Shyam, S. Salim, M. Ramees Rahman, and P. K. Safeena. 2017. "Assessing the Socioeconomic Profile of a Vulnerable Coastal Fishing Village in India." Asian Academic Research Journal of Multidisciplinary 4 (2): 98–127.

Shyam S. Salim and Anuja A. R. 2022. "Indian Fisheries Outlook 2022: Priming Indian Fisheries in Attaining Sustainable Development Goals." Kochi - 682 018, Kerala, India: ICAR- Central Marine Fisheries Research Institute. http://eprints.cmfri.org.in/15861/1/Indian%20Fisheries%20Outlook_2022_Shyam%20Salim.pdf.

School of Oriental and African Studies. n.d. "The Sustainable Livelihoods Framework and the Asset Pentagon." Accessed August 4, 2021.

Spilman, Rick. 2019. "Solaris, Solar-Powered Tour Boat to Ply the Hudson." *Old Salt Blog* (blog). October 11, 2019. http://www.oldsaltblog.com/2019/10/solaris-solar-powered-tour-boat-to-ply-the-hudson/.

Stange, Emma. 2019. "Acoustic Assault: How Anthropogenic Noise Pollution Affects Marine Ecosystems." https://utampa.dspacedirect.org/handle/20.500.11868/679.

Stephenson, R. L., and R. K. Smedbol. 2019. "Small Pelagic Species Fisheries." In *Encyclopedia of Ocean Sciences (Third Edition)*, edited by J. Kirk Cochran, Henry J. Bokuniewicz, and Patricia L. Yager, 2:503–9. Oxford: Academic Press. https://doi.org/10.1016/B978-0-12-409548-9.11491-5.

Sunaryo, Aldy Syahrihaddin, and Pradhana Shadu Imfianto. 2019. "Solar Energy for a Traditional Coastal Fishing Platform." *Journal of Marine Science and Application* 18 (3): 366–71. https://doi.org/10.1007/s11804-019-00087-5.

Sundar, Aparna. 2018. "Skills for Work and the Work of Skills: Community, Labour and Technological Change in India's Artisanal Fisheries." https://journals.sagepub.com/doi/10.1177/0973174118804449.

Swissinfo.ch. 2001. "Switzerland Builds World's Largest Solar Powered Boat." SWI Swissinfo.Ch. January 10, 2001. https://www.swissinfo.ch/eng/switzerland-builds-world-s-largest-solar-powered-boat/1832258.

Thandasherry, Sandith. 2018. "Economics of ADITYA - India's First Solar Ferry." https://sandith.in/wp-content/uploads/2018/11/economics-of-aditya-ieee-vol-13-jul-sep-2018.pdf.

———. 2020. "Solar Panels-On Boat or Shore?," April. https://doi.org/10.13140/RG.2.2.17118.79688.

———. 2021. *Solar-Electric Boats: Life Story*. Kochi: Navalt Solar and Electric Boats.

The Hindu. 2020. "Protection from Imports Time Bound, Says NITI Aayog Vice-Chairman," October 30, 2020, sec. Industry. https://www.thehindu.com/business/Industry/govt-to-provide-production-linked-incentives-to-more-sectors-says-niti-aayog/article32982855.ece.

———. 2021. "Rising Diesel Prices Worry Fishers," February 14, 2021, sec. Chennai. https://www.thehindu.com/news/cities/chennai/rising-diesel-prices-worry-fishers/article33832892.ece.

The Marine Products Exports Development Authority. n.d. "Annual Report 2017-18." https://mpeda.gov.in/wp-content/uploads/2020/11/1550120514MPEDAAR201718.pdf.

Tourismus, Schweiz. n.d. "Sustainability in Public Transport." Switzerland Tourism. Accessed April 11, 2021. https://www.myswitzerland.com/en-in/planning/about-switzerland/sustainability/sustainable-travel-by-public-transport/.

Trojan Battery Company. 2018. "Case Study: Solar-Powered Boat." https://mdplglobal.com/wp-content/uploads/2018/12/SunRider_Solar_Boat_CS.pdf.

Tunnicliffe, Andrew. 2019. "Ellen E-Ferry: The World's Glimpse of the Future of Ferries." *Ship Technology* (blog). March 9, 2019. https://www.ship-technology.com/features/ellen-e-ferry/.

Tyona, M. D., and E. D. Ojiya. 2020. "Design, Fabrication and Characterization of a Solar Fish Dryer." *NIGERIAN ANNALS OF PURE AND APPLIED SCIENCES* 3 (3b): 156–74. https://doi.org/10.46912/napas.183.

Vishnu Varma. 2020. "India's First Solar-Powered Ferry Aditya Wins Global Honour." *The Indian Express*, July 27, 2020. https://indianexpress.com/article/india/indias-first-solar-powered-ferry-aditya-wins-gustave-trouve-award-6525729/.

Widodo, S. B., Hamdani, T. A. Rizal, and N. A. Pambudi. 2018. "Techno-Economic Analysis of Solar Photovoltaic Power Plant for Small Scale Fish Processing in Kota Langsa - a Case Study." *IOP Conference Series: Materials Science and Engineering* 308 (February): 012025. https://doi.org/10.1088/1757-899X/308/1/012025.

World Bank. 2010. "Indian Marine Fisheries." https://openknowledge.worldbank.org/bitstream/e/10986/3002/542590ESW0whitories0Report00PUBLIC0.pdf?sequence=1&isAllowed=y.

Zacharia. P. U. n.d. "Present and Future Scenario of Indian Marine Fisheries." CMFRI, Cochin. Accessed November 24, 2022. https://www.cmfri.org.in/uploads_en/divisions/files/Present%20and%20future%20scenario%20of%20Indfian%20marine%20fisheries.pdf.

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