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The impact of low-cost technological innovations on sustainable fisheries for economic development in developing countries

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Abstract

Technological innovations have the potential to revolutionize small-scale fisheries and aquaculture, especially in developing countries where traditional methods face increasing pressures due to overfishing, resource depletion, and environmental degradation. Low-cost technologies, including mobile applications, IoT-based monitoring systems, and solar-powered fishing gear, offer accessible and scalable solutions to address these challenges. However, despite their promise, the adoption of these technologies in developing regions remains limited due to financial constraints, lack of technical expertise, and infrastructure gaps. This paper explores the impact of low-cost technologies on enhancing the sustainability, productivity, and profitability of fisheries and aquaculture in developing countries. Drawing on case studies from Africa, Asia, and Latin America, it evaluates the role of mobile apps for fisheries management, IoT-based monitoring systems in aquaculture, and solar-powered fishing gear in improving resource management, reducing operational costs, and fostering environmental sustainability. The paper discusses the significant benefits of these technologies, such as increased operational efficiency, cost savings, and enhanced livelihoods for small-scale fishers. However, it identifies key challenges hindering their widespread adoption, including financial barriers, infrastructure limitations, and technical skill gaps. In response, the paper offers recommendations for overcoming these barriers, including financial incentives, capacity-building initiatives, and investments in infrastructure. Ultimately, this paper emphasizes the importance of integrating low-cost technologies into fisheries and aquaculture development strategies. By addressing adoption barriers and leveraging these innovations, these technologies can contribute to sustainable food production, poverty reduction, and environmental conservation in developing countries, improving small-scale fishing communities' resilience and economic stability.

Keywords: Low-cost technologies; Fisheries; Sustainable development; IoT; Food security

1. Introduction

1.1. Background and Importance of Fisheries and Aquaculture

Fisheries and aquaculture are essential to global food systems, contributing significantly to human nutrition, livelihoods, and economic development, particularly in developing countries (Elegbede et al., 2025). According to the Food and Agriculture Organization (FAO), over 3 billion people rely on fish as their primary source of animal protein, with this dependency being most acute in regions such as sub-Saharan Africa and Southeast Asia, where alternative protein sources are often scarce (FAO, 2020). Beyond their nutritional value, fisheries support diverse socio-economic

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and cultural functions, employing over 56 million people globally in both capture fisheries and aquaculture (FAO, 2018). The value of fisheries extends to environmental services, such as maintaining aquatic biodiversity and providing livelihoods integral to coastal communities' cultural identity and heritage.

As global demand for fish continues to rise, driven by population growth, urbanization, and increasing incomes, the pressure on wild fish stocks and aquaculture systems has intensified (Saidu, 2025). The FAO has warned of stagnating wild fish catches, which have exacerbated global fisheries' challenges, environmental degradation, climate change, and overfishing (FAO, 2020). In response to these challenges, aquaculture has emerged as a critical solution for bridging the gap between supply and demand, contributing nearly half of the global fish supply for human consumption (Gleadall et al., 2024). However, despite the rapid growth of aquaculture, the sector also faces challenges related to resource management, environmental sustainability, and operational efficiency.

1.2. The Need for Low-Cost Technologies in Fisheries and Aquaculture

Low-cost technologies have become increasingly vital in addressing the challenges faced by small-scale fisheries and aquaculture Basurto et al (2025), particularly in developing. These technologies—such as mobile applications, Internet of Things (IoT)-based monitoring systems, and solar-powered fishing gear—offer affordable, scalable, and sustainable solutions to enhance the efficiency, productivity, and sustainability of fisheries and aquaculture systems. Small-scale fisheries, a livelihood source for millions in developing regions, often face barriers such as limited access to resources, market information, and technology. As traditional practices struggle to meet growing demand, these low-cost technologies provide essential tools for improving data collection, resource management, and operational practices without requiring significant capital investment (Finegold, 2009).

Mobile applications have revolutionized fisheries management by providing real-time access to market data, fishing conditions, and regulations, helping small-scale fishers make informed decisions. Similarly, IoT-based monitoring systems are playing a transformative role in aquaculture by providing continuous, real-time data on water quality and fish health. Solar-powered fishing gear reduces reliance on costly fossil fuels, mitigating the environmental impact of fishing activities while improving the economic viability of operations. Despite the potential benefits of these technologies, their adoption has been hindered by several factors, including financial constraints, technical expertise, and infrastructure limitations, particularly pronounced in rural and remote areas (Nyarko et al., 2023).

1.3. Challenges and Barriers to Technology Adoption

While the benefits of low-cost technologies are well-documented, their widespread adoption remains a challenge in many developing countries. Small-scale fishers and aquaculture farmers, who form the backbone of the industry in low-income regions, often face significant financial barriers to acquiring and implementing new technologies. Despite the low upfront cost of many of these technologies, the lack of access to financing, combined with limited technical skills and knowledge, restricts their uptake. According to a study by Sohail et al. (2020), small-scale fishers in rural regions often lack access to the capital and training necessary to effectively use mobile apps or IoT systems, hindering their ability to capitalize on these technologies' benefits.

Infrastructure limitations further complicate the situation. Reliable internet connectivity and electricity are prerequisites for successfully deploying many low-cost technologies, often unavailable in remote areas. Solar-powered technologies can mitigate some of these infrastructure challenges. However, they, too, require initial investment and consistent maintenance, which may be unavailable to communities struggling with poverty and lack of access to resources. Additionally, resistance to change remains a key barrier, as many fishers and aquaculture farmers continue to rely on traditional practices, often due to unfamiliarity with or scepticism toward new technologies. Overcoming these barriers requires coordinated efforts from governments, NGOs, and the private sector to provide financial support, training, and infrastructure improvements (Nyarko et al., 2023).

Specifically, the paper explores the role of mobile apps in improving fisheries management, the benefits of IoT-based monitoring systems in optimizing aquaculture practices, and the advantages of solar-powered fishing gear in reducing operational costs and minimizing environmental impacts. The study will also analyze the socio-economic and environmental challenges hindering these technologies' adoption and provide policy recommendations for overcoming these barriers.

1.4. Significance of the Study

This study contributes to the growing knowledge of how low-cost technologies can transform developing countries' fisheries and aquaculture sectors. The findings will provide valuable insights into the practical application of these

technologies, the barriers to their adoption, and the steps required to ensure their successful implementation. Policymakers, development agencies, and NGOs can use the results to design interventions and programs that promote the adoption of sustainable technologies in fisheries and aquaculture. By addressing the barriers to technology adoption and identifying best practices, this study will help unlock the potential of low-cost technologies to improve food security, livelihoods, and environmental sustainability in small-scale fisheries and aquaculture communities.

This study explores the potential of low-cost technologies in enhancing the sustainability, productivity, and profitability of fisheries and aquaculture in developing countries. This paper aims to assess the effectiveness of mobile apps, IoT-based monitoring systems, and solar-powered fishing gear in addressing the challenges faced by small-scale fisheries and aquaculture operations. Through an in-depth analysis of case studies from Africa, Asia, and Latin America, the study examines how these technologies are applied in real-world settings and evaluate their impact on food security, economic development, and environmental sustainability.

1.5. Structure of the Paper

This paper is structured as follows: Section 2 overviews key low-cost technologies in fisheries and aquaculture, including mobile applications, IoT-based monitoring systems, and solar-powered fishing gear. Section 3 examines the benefits of these technologies, highlighting their role in improving efficiency, reducing costs, and enhancing sustainability. Section 4 discusses the challenges and barriers to technology adoption, including financial constraints, infrastructure limitations, and resistance to change. Section 5 presents case studies from developing countries, demonstrating the real-world impact of these technologies. Section 6 offers recommendations for policy development, capacity building, and infrastructure investments to support technology adoption. Section 7 concludes with a summary of findings and recommendations for future research.

2. Low-Cost Technologies in Fisheries and Aquaculture

Fisheries and aquaculture are vital to the global food system, particularly for small-scale fishers in developing countries (Finegold, 2009). These sectors are under increasing pressure to meet the growing demand for fish while ensuring sustainability and minimizing environmental degradation. Low-cost technologies have emerged as key solutions to these challenges, offering accessible, scalable, and cost-effective alternatives to traditional methods. In this section, we will examine three major low-cost technologies—mobile apps for fisheries management, Internet of Things (IoT)-based fish monitoring systems, and solar-powered fishing gear—and explore their benefits, challenges, and potential for broader application (Finegold, 2009).

2.1. Mobile Apps for Fisheries Management

Mobile applications are becoming a powerful tool in managing small-scale fisheries, especially in remote areas where traditional data collection methods are often unfeasible. One such tool, the **Open Data Kit (ODK)**, has proven to be a cost-effective mobile-based data collection platform. ODK allows fishers to gather data on various aspects of fisheries management, including catch rates, water quality, and fish stock assessments. Importantly, ODK is designed to work offline, allowing fishers to store data on their mobile devices and upload it later when an internet connection is available. This feature is particularly beneficial in regions with limited internet access, allowing fishers to participate in data collection efforts without infrastructure limitations (Subong-Espina & Hernando, 2023).

The benefits of using mobile applications in fisheries management are clear. First, they enable more accurate and efficient data collection. Fishers can input real-time data on catch rates, fishing locations, and environmental conditions directly into their mobile devices, reducing the reliance on manual record-keeping. This data can be used for better decision-making regarding catch limits, stock management, and fishery health (Béné et al., 2016). Additionally, mobile apps can provide fishers access to critical information, such as market prices, weather forecasts, and regulations, which helps them make more informed decisions about their operations as shown in Figure 1.

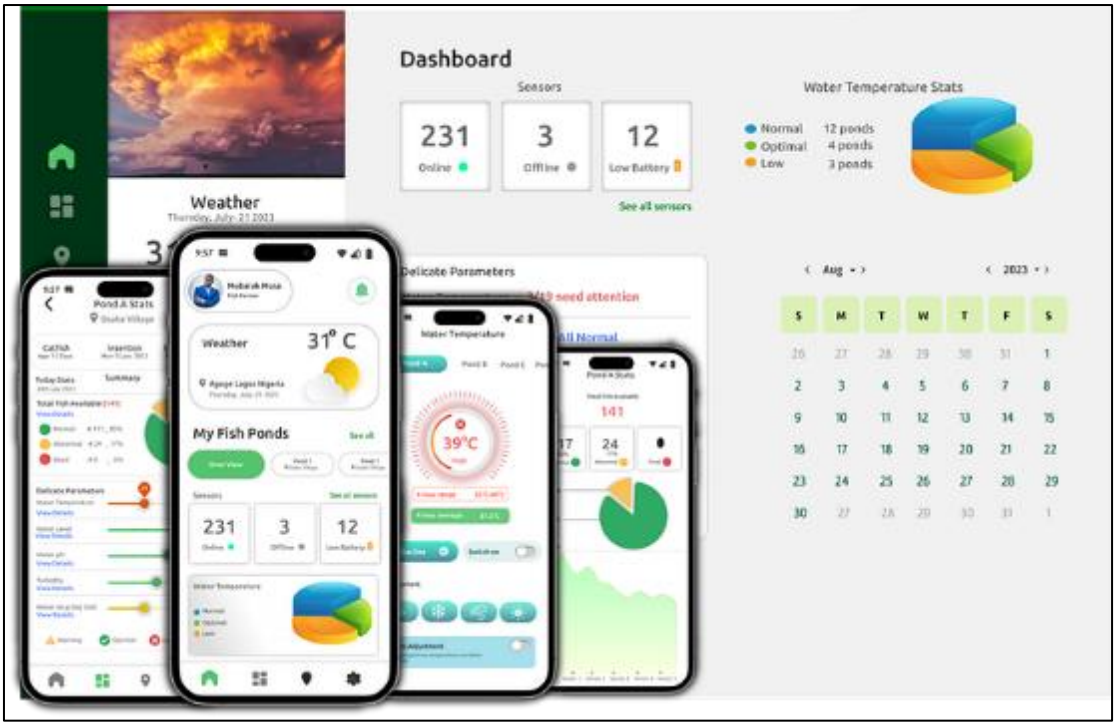

Figure 1 Dashboard of a Fisheries Mobile Application. Source; (Aliyu, 2025)

However, there are several challenges to the widespread adoption of mobile apps in small-scale fisheries. In many remote regions, fishers may have limited access to smartphones or unreliable internet connectivity, which could hinder the use of such technologies. Moreover, the successful implementation of mobile applications depends on the digital literacy of users, and the data collected may be compromised if fishers are not adequately trained to input accurate information (Elegbede et al., 2023f).

2.2. IoT-Based Fish Monitoring Systems

The Internet of Things (IoT) has revolutionized many industries, and its potential to transform aquaculture is significant. IoT-based fish monitoring systems provide real-time data on various environmental parameters, such as water temperature, dissolved oxygen levels, pH, and ammonia concentrations, directly influencing fish health and growth. By deploying smart sensors and automated data loggers in aquaculture systems, farmers can monitor water quality continuously and remotely. These systems can alert farmers to changes in environmental conditions, such as a drop in oxygen levels, enabling timely interventions to protect the fish and maintain optimal growing conditions (Bachtiar et al., 2022).

IoT systems offer substantial benefits for sustainable aquaculture practices. Real-time monitoring reduces the need for manual checks and allows farmers to take corrective actions before issues such as disease outbreaks or fish mortality occur. Furthermore, by optimizing conditions like feeding schedules and water quality, IoT systems can help minimize waste, reduce resource overuse, and prevent unnecessary chemical treatments, promoting more sustainable practices (Yokogawa, 2016). Remotely monitoring fish behaviour and water conditions can also improve operational efficiency and reduce labour costs, especially in more extensive or remote aquaculture operations. Figure 2 shows how IoT is implemented in the monitoring of water quality in a Fish Farm.

Figure 2 IoT Water Quality Prototype. Source; (Sivakumar and Ramya, 2021)

Despite the clear advantages, implementing IoT-based monitoring systems in small-scale aquaculture farms faces several challenges. The initial investment required for purchasing and installing IoT devices may be prohibitive for small-scale farmers, particularly in low-income regions. Additionally, the deployment and maintenance of these systems require technical expertise, which may not be readily available in rural or remote areas. Furthermore, the data generated by IoT systems need to be accurately interpreted and acted upon, which requires a certain level of skill and training among farm operators (Alahmad et al., 2023).

2.3. Solar-Powered Fishing Gear

The adoption of solar-powered technologies in fishing gear represents a sustainable and cost-effective solution to the energy demands of small-scale fisheries, particularly in coastal and rural areas. Solar-powered systems, such as solar-powered lights and navigation equipment, reduce the reliance on fossil fuels, which are both expensive and environmentally harmful. Solar-powered lights have gained popularity in night fishing operations. These lights attract fish, especially small pelagic species like sardines and herring, which are drawn to the light sources and form schools around them. Traditional night fishing often relies on costly kerosene lamps, contributing to pollution. Solar-powered lights offer a cleaner, more energy-efficient alternative (Mills et al., 2014).

The environmental benefits of solar-powered gear are significant. By reducing the dependence on fossil fuels, solar technologies help decrease the carbon footprint of fishing operations and reduce greenhouse gas emissions. Additionally, solar power provides a renewable energy source, making it an ideal solution for fishing communities in areas with limited access to electricity. Solar power can also power other critical fishing equipment, such as refrigeration units for storing catches and water pumps for maintaining proper aquaculture conditions (Saim & Khan, 2021) Figure 3 is a solar panel system used to solve the problem of oyster cultured system.

Figure 3 Solar Panel System. Source; (Vo et al., 2021)

The economic benefits of solar-powered fishing gear are also noteworthy. While the initial setup costs can be a barrier for some fishers, the long-term savings on fuel costs make solar-powered systems an economically viable option. Solar power can significantly reduce operating expenses for small-scale fishers by eliminating the need for kerosene or gasoline. Furthermore, solar-powered systems' durability and low maintenance requirements make them a reliable and cost-effective solution for remote communities.

However, solar-powered fishing gear also faces some challenges. The efficiency of solar panels is weather-dependent, with cloudy or rainy conditions potentially limiting their ability to generate enough energy. Additionally, the initial investment in solar-powered systems may be a significant financial burden for small-scale fishers, particularly those with limited access to capital. Despite these challenges, the long-term benefits of solar-powered fishing gear, both economically and environmentally, make it an increasingly popular choice for many coastal communities (Mills et al., 2014).

In the next section, we explore the benefits and challenges of these technologies in greater detail, focusing on their socio-economic impact and the steps required overcoming the barriers to their widespread adoption.

3. Benefits and Challenges of Low-Cost Technologies

Low-cost technologies have the potential to significantly transform the fisheries and aquaculture sectors by improving operational efficiency, reducing costs, and promoting sustainable resource management. However, while the advantages of these technologies are evident, their adoption and implementation are not without challenges (Alahmad et al., 2023). This chapter will explore the benefits and challenges of adopting low-cost technologies in fisheries and aquaculture, focusing on their impact on efficiency, costs, the environment, and livelihoods.

3.1. Benefits of Low-Cost Technologies

3.1.1. Increased Efficiency in Fisheries Management

One of the key benefits of low-cost technologies, particularly mobile apps and IoT-based monitoring systems, is the significant increase in efficiency they offer for fisheries management. By enabling real-time data collection and analysis, these technologies help fisheries managers and fishers to make more informed decisions about stock assessments, fishing efforts, and sustainability practices. Mobile applications such as the Open Data Kit (ODK) allow fishers to collect and transmit data on catch rates, water quality, and environmental conditions without requiring expensive infrastructure or labour-intensive processes. This increased efficiency leads to better-informed decisions that optimize fishing practices and ensure the long-term sustainability of fish populations (Béné et al., 2016). Furthermore, using IoT devices for continuous monitoring allows fisheries managers to track various environmental parameters, improving resource management by allowing rapid responses to changing conditions.

3.1.2. Reduction in Operational Costs for Fishers

Low-cost technologies also contribute to the reduction of operational costs for small-scale fishers. For instance, solar-powered fishing gear eliminates the need for fossil fuels, significantly lowering the costs associated with fuel consumption, particularly in remote areas where fuel costs can be prohibitively high. Adopting solar lighting for night fishing and solar-powered refrigeration units for fish storage allows fishers to reduce dependency on expensive and environmentally harmful alternatives such as kerosene (Mills et al., 2014). In addition to direct cost savings, technologies that optimize water quality and feeding practices, such as IoT-based monitoring systems, can improve fish growth rates and reduce waste, further lowering operational costs for aquaculture farmers (Bachtiar et al., 2022).

3.1.3. Environmental Benefits through Sustainable Resource Management

Low-cost technologies have a significant positive impact on the environment by promoting more sustainable fishing and aquaculture practices. IoT-based monitoring systems, for example, allow fish farmers to continuously monitor water quality and adjust conditions such as oxygen levels and temperature in real time. By maintaining optimal conditions for fish growth, these systems reduce the risk of overfeeding and waste accumulation, which can contribute to water pollution and ecosystem degradation (Kies et al., 2020). Additionally, solar-powered fishing gear contributes to environmental sustainability by reducing carbon emissions from burning fossil fuels (Saim & Khan, 2021). These technologies support more environmentally friendly practices, helping to conserve marine and freshwater ecosystems and ensuring that fisheries remain productive in the long term.

3.1.4. Enhanced Livelihoods for Small-Scale Fishers and Communities

Resilient small-scale fisheries have undergone significant adaptation and modernization, and in numerous cases, exhibit both sophistication and high efficiency – albeit not invariably progressing towards enhanced ecological sustainability (Cohen et al., 2019). Notwithstanding the fact that some small-scale fisheries possess extensive historical backgrounds and cultural affiliations, they should not be erroneously characterized as obsolete or antiquated, nor can they be reductively dismissed as mere historical remnants of a past era (Cohen et al., 2019). Small-scale fishers in economically disadvantaged nations have emerged as early adopters of advanced technologies such as mobile communication devices, electronic monetary systems, and global positioning technologies and have adeptly responded to the exigencies of emerging markets (Cohen et al., 2019). The adoption of low-cost technologies has the potential to enhance the livelihoods of small-scale fishers and their communities significantly. By increasing operational efficiency, reducing costs, and improving sustainability, these technologies enable fishers to increase their income and secure more stable livelihoods. For example, mobile apps that provide real-time data on market prices and fishing conditions allow fishers to make more informed decisions about when and where to fish, maximizing their catch and income (Pomeroy et al., 2018). Moreover, solar-powered systems enable fishers to expand their activities, such as night fishing, without the financial burden of expensive fuel. As a result, these technologies create new opportunities for income generation and contribute to more excellent economic stability in fishing communities.

3.2. Challenges of Low-Cost Technologies

3.2.1. Socio-Economic Barriers to Adoption

While the benefits of low-cost technologies are significant, several socio-economic barriers hinder their widespread adoption, particularly in developing countries. One of the main barriers is the lack of financial resources available to small-scale fishers and aquaculture farmers, which makes it difficult for them to invest in new technologies. While low-cost technologies are designed to be affordable, the initial setup costs for equipment such as solar panels or IoT sensors can still be a significant financial burden for many fishers (Sohail et al., 2020). Furthermore, small-scale fishers often lack access to credit or financing options that could help them cover the costs of technology adoption. In addition to financial constraints, a lack of technical skills and digital literacy among fishers poses another barrier to adopting mobile apps, IoT systems, and other technological solutions. Without the necessary skills or training, fishers may be unable to operate these technologies effectively, reducing their potential benefits.

3.2.2. Infrastructure Challenges in Remote or Rural Areas

The successful implementation of low-cost technologies in fisheries also depends on adequate infrastructure, often lacking in remote or rural areas. For example, deploying mobile applications and IoT systems requires reliable internet connectivity, which may not be available in many rural or coastal areas where small-scale fisheries are most prevalent. Similarly, solar-powered fishing gear requires access to sunlight, and in regions with inconsistent weather patterns, such as areas with frequent cloud cover or rainfall, solar energy systems may not provide reliable power ((Saim & Khan, 2021). In some cases, even if the technology is available, the lack of physical infrastructure—such as roads, storage

facilities, or electricity grids—can limit its effectiveness. Thus, infrastructure challenges must be addressed to ensure that low-cost technologies can be successfully deployed and maintained in these areas.

3.2.3. Resistance to Change and the Need for Education and Training

Another significant challenge to the adoption of low-cost technologies is resistance to change. Many fishers and aquaculture farmers are accustomed to traditional methods and may hesitate to adopt new technologies, particularly if they perceive them as complex, unnecessary, or challenging to implement. Overcoming this resistance requires education and awareness campaigns that demonstrate the benefits of these technologies in improving efficiency, sustainability, and profitability. Training programs are essential to help fishers and aquaculture farmers learn how to use these technologies effectively and integrate them into their operations. Without adequate training and support, even the most affordable and accessible technologies can fail to achieve their full potential (Sohail et al., 2020). Additionally, local communities may need to be involved in decision-making to ensure that technologies align with their needs and preferences. Next section explores case studies of low-cost technologies in action. It discusses their real-world impact on fisheries management, environmental sustainability, and the socio-economic development of small-scale fishing communities.

4. Case Studies of Low-Cost Technologies in Fisheries and Aquaculture

In order to understand the practical application and impact of low-cost technologies in fisheries and aquaculture, it is essential to examine case studies from various regions. These case studies provide insight into how mobile apps, IoT-based monitoring systems, and solar-powered fishing gear have been implemented in real-world settings and the challenges and benefits associated with their use. By analyzing these examples, we can identify best practices and lessons learned that may help facilitate the broader adoption of low-cost technologies in other regions.

4.1. Case Study 1: Mobile Apps in Small-Scale Fisheries

One of the most successful mobile technology applications in fisheries management is using mobile apps for data collection and market access in small-scale fisheries. A notable example is the Fisheries Management and Sustainability Program in the coastal regions of West Africa, where mobile apps have been deployed to collect data on fish stocks, catch rates, and fishing efforts. These apps have helped local fishers track their catches and share real-time data with fisheries management authorities, facilitating better decision-making and more efficient resource management.

A notable mobile application that has garnered significant acclaim is the Open Data Kit (ODK), which constitutes an open-source software framework enabling organizations to develop and administer application-specific information services while facilitating data collection in environments characterized by resource limitations (Subong-Espina et al., 2023). The implementation of a pilot initiative utilizing the Open Data Kit (ODK) methodology was undertaken to systematically monitor fish landings along the Tapajos River. This monitoring endeavor encompassed the employment of data collectors tasked with the responsibility of recording fish landing data through an application installed on smartphones (Silvano and Hallwass, 2020).

The case study demonstrated the significant potential of mobile apps for improving fisheries management and empowering local fishers. However, it also highlighted some challenges associated with technology adoption, including the initial cost of mobile devices, the need for training using these tools, and ensuring consistent internet access in remote areas. Despite these barriers, the benefits of improved data collection, better resource management, and increased market access far outweighed the challenges, making mobile apps a valuable tool for small-scale fisheries in developing countries.

4.2. Case Study 2: IoT-Based Monitoring in Aquaculture Farms in Southeast Asia

IoT-based monitoring systems in aquaculture have gained traction in Southeast Asia, where aquaculture is a significant source of food production and livelihoods. One notable case is a small-scale shrimp farm in Vietnam, where IoT sensors were deployed to monitor water quality parameters, such as dissolved oxygen, pH, ammonia, and temperature. These sensors provided real-time data on the water quality in the shrimp ponds, enabling farm operators to take immediate action when conditions deviated from optimal ranges (Bachtiar et al., 2022).

IoT-based monitoring allows for precise control over water quality, essential for preventing disease outbreaks and optimizing feeding practices. Farmers could improve shrimp growth rates and reduce mortality by ensuring that the environmental conditions remained ideal. Moreover, the real-time data enabled farmers to minimize the use of chemicals and feed, reducing operational costs and the farm's environmental impact (Bachtiar et al., 2022).

This case study illustrates how IoT-based systems can help aquaculture farmers manage their operations more efficiently and sustainably. However, challenges related to the initial costs of IoT devices and the need for technical expertise to install and maintain the systems were also evident. Despite these barriers, the positive impact on productivity and sustainability made the investment worthwhile for the farm, demonstrating the potential of IoT-based monitoring systems for small-scale aquaculture operations in Southeast Asia (Bachtiar et al., 2022).

4.3. Case Study 3: Solar-Powered Fishing Gear in Coastal Communities in India

The adoption of solar-powered fishing gear in coastal communities in India has provided significant benefits for small-scale fishers who rely on night fishing to capture species like sardines and mackerel. In many parts of India, traditional kerosene lamps were used to attract fish, but these lamps were costly, inefficient, and harmful to the environment. In response, a project in the coastal state of Kerala introduced solar-powered lights to replace kerosene lamps used by fishers at night.

The solar-powered lights are more energy-efficient and environmentally friendly, eliminating the need for kerosene, a fossil fuel. Fishers have reported significant cost savings from the switch to solar-powered lights, as they no longer need to purchase kerosene regularly. In addition to reducing operational costs, using solar power has improved safety for fishers, as they no longer need to handle hazardous fuels in their boats. The adoption of solar-powered fishing gear has also contributed to reducing the carbon footprint of fishing operations, aligning with global efforts to combat climate change (Mills et al., 2014).

Despite the success of this initiative, challenges remain. The initial cost of installing solar panels and lights can be a barrier for many fishers, particularly those in low-income regions. Furthermore, the effectiveness of solar-powered systems depends on weather conditions, as cloudy or rainy days can limit the amount of energy generated by the solar panels. Nevertheless, the long-term economic and environmental benefits of solar-powered fishing gear have made it a highly successful solution in coastal communities in India (Mills et al., 2014).

These case studies illustrate the wide-ranging potential of low-cost technologies in fisheries and aquaculture. From mobile apps that enhance data collection and resource management to IoT-based monitoring systems that improve water quality and reduce costs and solar-powered fishing gear that provides a sustainable alternative to fossil fuels, these technologies have proven their ability to improve the efficiency, sustainability, and profitability of small-scale fisheries and aquaculture.

While challenges such as initial costs, technical expertise, and infrastructure limitations exist, the benefits of these technologies far outweigh the obstacles. The case studies highlight the importance of policy support, access to financing, and capacity building to enable the broader adoption of these technologies, particularly in resource-poor settings. The next section discusses the policy implications and recommendations for further research to ensure the continued growth and success of low-cost technologies in fisheries and aquaculture (Mills et al., 2014).

5. Impact of Low-Cost Technologies on Developing Countries

Adopting low-cost technologies in fisheries and aquaculture can benefit developing countries, particularly in rural and coastal communities that rely heavily on fisheries for food security, income, and livelihoods. These technologies offer solutions to the many challenges faced by small-scale fishers and aquaculture farmers, such as resource depletion, environmental degradation, financial constraints, and limited access to market information (Elegbede et al., 2023d). This section explores the potential impact of low-cost technologies on developing countries, focusing on four key areas: food security, economic development, environmental sustainability, and social empowerment.

5.1. Enhancing Food Security

In developing countries, where access to diverse and affordable protein sources is often limited, fisheries are crucial in ensuring food security. According to the FAO (2020), more than 3 billion people worldwide depend on fish as their primary source of animal protein, and this figure is exceptionally high in regions such as sub-Saharan Africa and Southeast Asia. Small-scale fisheries and aquaculture systems are vital in providing a steady supply of fish to local populations. However, these sectors face numerous challenges, including overfishing, declining fish stocks, and inefficient production systems.

Low-cost technologies, such as mobile apps for fisheries management and IoT-based fish monitoring systems, can directly contribute to improving food security by enhancing the efficiency and sustainability of these systems. For example, mobile apps can provide real-time market prices, fishing conditions, and weather forecasts, helping fishers

decide where and when to fish. These technologies can ensure a more reliable and consistent fish supply by optimizing fishing efforts and reducing waste, improving food availability in local markets (Alahmad et al., 2023). Furthermore, IoT-based monitoring systems that track water quality and fish health in aquaculture can reduce fish mortality and optimize feeding practices, leading to higher fish production. This increase in fish output can directly improve the availability of affordable protein for local communities, addressing malnutrition and dietary deficiency issues, particularly in rural areas where other protein sources may be scarce.

5.2. Promoting Economic Development

Adopting low-cost technologies can also have a transformative impact on the economic development of fishing communities in developing countries. Fisheries and aquaculture are key economic drivers in many coastal and inland areas, providing employment for millions and contributing to their families' livelihoods. According to the FAO (2018), over 56 million people are directly employed in fisheries and aquaculture, with many others benefiting indirectly along the value chain, from processing to distribution.

Low-cost technologies can improve the efficiency and productivity of fisheries, leading to higher fish yields and reduced operational costs. For instance, solar-powered fishing gear significantly reduces the need for costly fossil fuels, allowing fishers to save money on fuel and reinvest it into their businesses. Similarly, the use of mobile apps and IoT-based monitoring systems with AI (Artificial Intelligence) can help fishers optimize their catch, reduce waste, and improve resource management, resulting in higher profits and increased economic stability for small-scale fishers (Ahmad et al., 2024).

In addition, by enabling fishers to access real-time market prices and fishing conditions, mobile apps can reduce the information asymmetry that often limits market access for small-scale fishers. This access to market data helps fishers sell their products at fairer prices and improves their bargaining power, increasing income and economic resilience. As fishers earn more, their purchasing power increases, which can ripple effect on the local economy, stimulating demand for goods and services in surrounding areas.

5.3. Supporting Environmental Sustainability

Environmental sustainability is critical in fisheries and aquaculture, particularly in developing countries where overfishing and habitat destruction are prevalent (Al Jufaili et al., 2020). Unsustainable fishing practices, such as overfishing and harmful fishing gear, deplete fish stocks and threaten the health of marine and freshwater ecosystems. Similarly, intensive aquaculture operations can result in water pollution and habitat degradation.

Low-cost technologies offer a way to mitigate these environmental challenges by promoting more sustainable practices. For example, IoT-based monitoring systems can continuously track water quality and fish health, allowing farmers to adjust their practices in real time to maintain optimal conditions. By preventing disease outbreaks, reducing waste, and optimizing feeding schedules, these systems contribute to the long-term sustainability of aquaculture farms (Bachtiar et al., 2022). Furthermore, these systems reduce the need for harmful chemicals and antibiotics, which can have negative environmental consequences if used excessively.

Solar-powered fishing gear also contributes to environmental sustainability by reducing dependence on fossil fuels. Using solar power instead of kerosene or diesel for lighting and boat operations minimizes carbon emissions, reducing the environmental footprint of fishing activities (Mills et al., 2014). Solar-powered systems are particularly beneficial in remote coastal communities where access to electricity is limited or non-existent, providing a renewable energy source that is both affordable and sustainable.

By promoting sustainable practices, low-cost technologies help preserve natural resources, which is crucial for the long-term health of fisheries and the environment. In turn, these sustainability improvements contribute to fisheries' continued viability, supporting local economies and ensuring food security for future generations.

5.4. Empowering Local Communities and Enhancing Social Inclusion

The introduction of low-cost technologies in fisheries and aquaculture has the potential to empower local communities and promote greater social inclusion. In many developing countries, fisheries are an important source of income for marginalized marginalized groups, including women and youth. However, these groups often face barriers to accessing resources, training, and opportunities in fisheries (Elegbede et al 2023a). Low-cost technologies can help bridge these gaps by providing equitable access to tools that enhance productivity, income, and knowledge.

For instance, mobile apps that provide access to market information, weather forecasts, and fishing conditions can empower women and youth, often excluded from decision-making processes in the fisheries sector, to take a more active role in the industry. By providing access to information and training, these technologies can improve the financial stability of these marginalized groups and increase their participation in the value chain.

Furthermore, the widespread adoption of solar-powered systems in coastal communities can reduce the financial burden on families who rely on fishing as their primary source of income. By eliminating the need for costly fuels, solar power frees up resources that can be used for other essential needs, such as education, healthcare, or improving living conditions. This financial flexibility enhances the overall well-being of fishing families and contributes to poverty reduction in rural areas.

Adopting low-cost technologies in fisheries and aquaculture can significantly improve food security, economic development, environmental sustainability, and social inclusion in developing countries. By enhancing the productivity and sustainability of small-scale fisheries, these technologies can address key challenges such as resource depletion, financial constraints, and limited access to market information. Furthermore, empowering marginalized groups, including women and youth, fosters more inclusive and equitable development in fishing communities.

However, for these technologies to achieve their full potential, it is essential to overcome the challenges of financial barriers, technical expertise, and infrastructure limitations. Through targeted policy interventions, investments in infrastructure, and capacity-building programs, developing countries can create an enabling environment for the widespread adoption of low-cost technologies. By doing so, they can ensure that their fisheries sectors remain sustainable, resilient, and capable of meeting the growing demand for fish in the coming decades.

6. Recommendations for Advancing Low-Cost Technologies in Fisheries and Aquaculture

Implementing low-cost technologies in fisheries and aquaculture is promising for enhancing small-scale fisheries' sustainability, productivity, and economic viability, particularly in developing countries. However, widespread adoption is hindered by several barriers, including financial constraints, technical limitations, and infrastructure challenges. To ensure that these technologies reach their full potential, it is critical to implement targeted strategies and policies. This section presents recommendations to address the key challenges, promote the adoption of low-cost technologies, and ensure long-term sustainability.

6.1. Financial Support and Incentives for Technology Adoption

One of the primary barriers to adopting low-cost technologies is the initial financial investment required, which can be prohibitive for small-scale fishers and aquaculture farmers in developing countries. While these technologies are designed to be affordable, many fishers and farmers lack the financial resources to purchase and implement them. Therefore, governments, international organizations, and development agencies must provide targeted financial support to encourage technology adoption (Elegbede et al., 2023c).

Governments and NGOs should establish funding mechanisms such as subsidies, grants, or low-interest loans to help small-scale fishers and aquaculture farmers purchase and adopt low-cost technologies. Financial incentives such as tax rebates or performance-based subsidies could also be offered to those implementing sustainable technologies, such as solar-powered fishing gear or IoT-based monitoring systems. These financial mechanisms would reduce the initial investment burden and make it easier for fishers to access the technologies that will improve their productivity and sustainability (Amjath-Babu, et al, 2022).

6.2. Strengthening Infrastructure for Technology Deployment

The successful deployment of low-cost technologies often depends on the availability of reliable infrastructure. In many rural and coastal areas of developing countries, access to electricity, internet connectivity, and transportation remains limited, posing significant challenges to adopting technologies like mobile apps and IoT-based monitoring systems. To overcome these challenges, it is necessary to prioritize infrastructure development in areas where small-scale fisheries and aquaculture are critical to the local economy (Elegbede et al., 2023c).

Governments should prioritize investment in infrastructure development, particularly in rural and coastal areas. This consideration includes expanding electricity grids, improving internet access, and investing in transportation networks to facilitate the delivery of technologies to remote communities. By improving basic infrastructure, governments can create an environment conducive to adopting and effectively using low-cost technologies. Furthermore, investments in

infrastructure should be coupled with policies that encourage public-private partnerships to improve technology delivery and maintenance services in underserved areas.

6.3. Capacity Building and Training Programs

For small-scale fishers and aquaculture farmers to effectively adopt and benefit from low-cost technologies, they must have the necessary skills and knowledge (Mills et al., 2019). A lack of technical expertise, digital literacy, and familiarity with new technologies often hinders adoption. Comprehensive training and education programs are essential to ensure that fishers can utilize these technologies to their full potential.

Governments, NGOs, and development agencies should collaborate with local universities, vocational training centres, and private-sector companies to provide training programs focused on mobile apps, IoT-based monitoring systems, and solar-powered technologies. These training programs should be tailored to the specific needs and contexts of small-scale fishers and aquaculture farmers, ensuring that the technologies are accessible and relevant to local communities. Training programs should also focus on the technical aspects of using the technologies and sustainable fisheries management practices, resource conservation, and business skills.

6.4. Promoting Awareness and Education

In addition to providing technical training, raising awareness about the benefits of low-cost technologies among small-scale fishers and aquaculture farmers is essential. Many fishers may hesitate to adopt new technologies due to a lack of understanding of their potential benefits or fear of change. To overcome these barriers, it is essential to engage fishers and local communities through awareness campaigns that demonstrate the value of these technologies in improving productivity, sustainability, and profitability (Elegbede et al., 2023e).

Governments and NGOs should launch awareness campaigns that educate fishers about the advantages of low-cost technologies and their potential to improve operational efficiency, reduce costs, and enhance sustainability. These campaigns can include workshops, community outreach programs, and informational materials such as pamphlets, radio broadcasts, and online content. Highlighting success stories and case studies from other regions can inspire fishers to embrace these technologies and understand their practical applications.

6.5. Strengthening Policy and Institutional Support

Successfully adopting and scaling low-cost technologies in fisheries and aquaculture depends on firm policy and institutional support. Governments play a central role in creating an enabling environment for innovation and ensuring that policies are in place to support adopting sustainable technologies. To maximize the impact of low-cost technologies, it is crucial to align policies with the goals of sustainable fisheries management, environmental protection, and poverty reduction (Rowan, 2023).

Governments should develop and implement policies that support the integration of low-cost technologies into national fisheries and aquaculture development plans. These policies should include incentives for fishers to adopt sustainable practices, such as tax credits for using solar-powered equipment or subsidies for installing IoT-based monitoring systems. Additionally, governments should strengthen the enforcement of fisheries regulations to ensure that these technologies are used to promote sustainability and prevent overexploitation of marine and freshwater resources.

International organizations, development agencies, and private-sector actors should also collaborate to support scaling low-cost technologies. This situation could include providing technical assistance, facilitating knowledge-sharing, and fostering public-private partnerships to ensure that technologies reach the communities that need them most.

6.6. Fostering Research and Development

Research and development (R&D) are crucial for the continued advancing low-cost technologies in fisheries and aquaculture. Ongoing R&D can create more efficient, affordable, and user-friendly technologies that meet the specific needs of small-scale fishers and aquaculture farmers. Furthermore, R&D can help identify innovative financing models, such as pay-as-you-go schemes, that could make these technologies more accessible to resource-poor communities. (Elegbede et al., 2023g)

Governments, NGOs, and private companies should invest in R&D to develop new low-cost technologies tailored to the needs of small-scale fishers and aquaculture farmers. Additionally, research should focus on improving the affordability, durability, and performance of existing technologies, such as solar-powered systems, mobile apps, and IoT sensors

(Elegbede et al., 2022). Collaborative research efforts that involve local communities and fishers can also ensure that new technologies are practical, culturally relevant, and suited to local conditions.

6.7. Encouraging Collaborative Partnerships

Successfully scaling low-cost technologies in fisheries and aquaculture requires collaboration between various stakeholders, including governments, NGOs, private companies, and local communities. These partnerships can help overcome financial, technical, and logistical barriers to technology adoption and ensure fishers can access the necessary resources and support (Elegbede et al., 2023 a,b).

Governments should encourage public-private partnerships to develop, implement, and scale low-cost technologies. These partnerships can leverage the strengths of both sectors—governments' policy and regulatory support and the private sector's technical expertise and innovation. Additionally, collaboration with international development organizations organizations can help provide the funding and technical assistance needed to bring low-cost technologies to small-scale fisheries and aquaculture farms.

Adopting low-cost technologies in fisheries and aquaculture can transform how small-scale fishers and aquaculture farmers operate. Thus making their practices more sustainable, efficient, and profitable. However, addressing the financial, technical, and infrastructure barriers currently limiting their adoption is crucial to ensure these technologies reach their full potential. By implementing targeted policies, investing in infrastructure and capacity building, and fostering collaborative partnerships, governments and organizations can create an enabling environment supporting the widespread adoption of low-cost technologies. This will ultimately contribute to the sustainability of fisheries, the economic empowerment of small-scale fishers, and the enhancement of food security in developing countries (Rowan, 2023).

7. Conclusion

Low-cost technologies have the potential to revolutionize the fisheries and aquaculture sectors, particularly in developing countries where small-scale fishers and aquaculture farmers face numerous challenges. These technologies, including mobile apps for fisheries management, IoT-based monitoring systems, and solar-powered fishing gear, offer significant opportunities to improve operational efficiency, enhance sustainability, and reduce costs. By providing accessible and affordable solutions, these technologies can help small-scale fishers better manage their resources, improve productivity, and contribute to food security.

The benefits of low-cost technologies in fisheries and aquaculture are far-reaching. They can increase the efficiency of data collection and management, reduce operational costs, and promote sustainable practices that minimize environmental degradation. Moreover, these technologies empower local communities by providing them with the tools to enhance their livelihoods, improve market access, and reduce their dependence on costly and environmentally harmful energy sources. In addition, they contribute to environmental sustainability by reducing waste, improving water quality management, and promoting the use of renewable energy sources.

However, despite the apparent potential of these technologies, their adoption in developing countries faces significant barriers. These include financial constraints, infrastructure limitations, lack of technical expertise, and resistance to change. Targeted policy interventions, infrastructure development, capacity-building initiatives, and financial incentives are essential to overcome these challenges. Governments, international organizations, NGOs, and the private sector must collaborate to create an enabling environment that facilitates the widespread adoption of these technologies.

The successful implementation of low-cost technologies in fisheries and aquaculture can provide sustainable solutions to some of the most pressing challenges developing countries face, such as food insecurity, poverty, and environmental degradation. As these technologies evolve, their adoption can contribute to more resilient, efficient, and environmentally sustainable fisheries and aquaculture sectors, ultimately improving the quality of life for millions of people who depend on these sectors for their livelihoods.

In conclusion, low-cost technologies are not just tools for improving fisheries and aquaculture; they are transformative solutions that help small-scale fishers and farmers adapt to changing environmental conditions, reduce poverty, and contribute to global food security. With the right policies, financial support, and infrastructure, the potential for these technologies to drive positive change in developing countries is vast.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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