

OPTIMIZING FISH PRODUCTION: THE INFLUENCE OF DIGITAL TECHNOLOGIES ON SUSTAINABILITY AND WELL-BEING OF INDONESIAN ARTISANAL FISHERMEN

Optimasi Produksi Ikan: Pengaruh Teknologi Digital terhadap Keberlanjutan dan Kesejahteraan Nelayan Tradisional Indonesia

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Abstract

This study examines the impact of early Industry 4.0 digital technologies on the sustainability and entrepreneurial well-being of Indonesian small-scale fishermen. Despite abundant marine resources, their sustainable livelihoods are challenged by the commercial fishing industry's unbalanced performance. Employing quantitative methods and surveys in western Indonesia, the research reveals a significant link between artisanal fishermen as entrepreneurs and the sea as a natural resource provider, crucially mediated by digital transformation. To achieve both short-term and long-term sustainability, harnessing the potential of digital technology for responsible sea exploitation is essential. Findings indicate that digital transformation significantly enhances the relationship between fishermen and the maritime ecology. By embracing digital solutions, artisanal fishermen can optimize resource utilization, improve operational efficiency, and enhance their overall well-being, ensuring the long-term viability of small-scale fisheries.

Keywords: Small-scale Fisheries, The Ocean, Entrepreneurial Well-being, Sustainability, Fish Production

Abstrak

Studi ini mengkaji dampak teknologi digital awal Industri 4.0 terhadap keberlanjutan dan kesejahteraan kewirausahaan nelayan skala kecil di Indonesia. Meskipun memiliki sumber daya laut yang melimpah, mata pencaharian berkelanjutan mereka terancam oleh kinerja yang tidak seimbang dari industri perikanan komersial. Dengan menggunakan metode kuantitatif dan survei di wilayah barat Indonesia, penelitian ini mengungkapkan hubungan yang signifikan antara nelayan tradisional sebagai wirausaha dan laut sebagai penyedia sumber daya alam, yang secara kritis dimediasi oleh transformasi digital. Untuk mencapai keberlanjutan jangka pendek dan jangka panjang, memanfaatkan potensi teknologi digital untuk eksploitasi laut yang bertanggung jawab sangatlah penting. Temuan menunjukkan bahwa transformasi digital secara signifikan meningkatkan hubungan antara nelayan dan ekologi maritim. Dengan mengadopsi solusi digital, nelayan tradisional dapat mengoptimalkan pemanfaatan sumber daya, meningkatkan efisiensi operasional, dan meningkatkan kesejahteraan mereka secara keseluruhan, memastikan kelangsungan jangka panjang perikanan skala kecil.

Kata Kunci: Perikanan Skala Kecil, Lautan, Kesejahteraan Wirausaha, Keberlanjutan, Produksi Ikan

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Introduction

Indonesia is an archipelagic island state which has huge marine resources and will provide sustainable economic opportunities, social and environmental sustainability if it is managed in a balance between production needs and nature conservation. The gross domestic product of fisheries until 2023 reached 5.6 billion USD with national fish consumption of 56.48 kg per capita which is greater than world consumption of 20 kg per capita (Tuter, 2024). The number of Indonesian fishermen is 3 million people, and the majority of whom are small-scale fishermen or the artisanal fishermen, who live in poverty (Natalia, 2024).

Small-scale fishermen, who are both business owners and operators of their vessels, often face solitary, stressful, and hazardous conditions at sea as part of their entrepreneurial endeavors. While previous research has highlighted the potential for entrepreneurial well-being to bring joy, purpose, and satisfaction (Wiklund et al., 2019; Hahn et al., 2012), it is insufficient to solely focus on well-being. To ensure sustainable and stable performance throughout the entrepreneurial journey, a more comprehensive approach is necessary.

Despite rising fish prices, fish catch quantities have been declining (Octavianto, 2023). While this might be attributed to basic supply and demand economics, other factors such as climate change, overfishing, and illegal, unregulated, and unreported (IUU) fishing, which disrupt sustainable fishing practices, could also be contributing to depleted fish populations. This decline in catch has discouraged individuals from pursuing careers as artisanal fishermen, even though Indonesia possesses vast maritime resources exceeding 7 million square kilometers (BPS, 2016). This phenomenon underscores the inability of the sea to sustain the livelihoods of artisanal fishermen in one of the world's largest maritime nations.

Small-scale fishermen, characterized by their ownership of vessels ranging from 5 to 30 meters in length and 1 to 30 gross tons in weight, often operate independently or with small crews of up to 10-20 people. These fishermen constitute the majority of fishing fleets globally, including Indonesia, where over 90% of fishermen are classified as small-scale or artisanal (Hoenner et al., 2022; Berkes, 2001). Their ownership of boats positions them as entrepreneurial artisans who invest their resources in fishing as their primary livelihood.

It is widely believed that digital transformation can provide a sustainable competitive advantage, particularly for small-scale and artisanal entrepreneurs, such as fishermen in Indonesia, who heavily rely on natural resources (Hoenner et al., 2022; Krotov, 2017; Pradipto et al., 2018). Digital technology transforms how people manage natural resources by accelerating data-based decision making (Tilley et al., 2024). Their study in Timor Leste shows that through a system to collect, analyze and display small-scale fisheries data, the government can improve their fisheries sector as they can provide real-time data-driven policy. The system facilitated collaboration between intragovernmental institutions, as well as between government and communities, and brought new investment into the fisheries sector. For our study, the digital transformation focuses on the use of applications for digital tracking technology for small scale fishermen. Through this technology, fishermen will get accurate information regarding fish gathering area or locations, weather forecast, the wind direction and sea wave height, and safety. In this way, fishermen can use it to increase their catches and reduce the cost of fishing (Rizkinaswara, 2019).

We hypothesize that an imbalance in economic, social, or environmental sustainability may exist (Butar et al., 2020). It is crucial to investigate how entrepreneurial well-being may impact the sustainability of artisanal fishing and the potential mediating role of digital transformation in this relationship. This study aims to examine the influence of entrepreneurial well-being and the

mediating effect of digital transformation on the relationship between entrepreneurial well-being and sustainable fishing practices.

Literature Review

Sustainable Competitive Advantage

Several studies define sustainability as a holistic approach that encompasses economics, social, and environmental performance, often referred to as the triple bottom line (TBL) (Butler et al., 2011; Rivera & Kurnia, 2015; Hourneaux et al., 2018). While large firms may have the resources to readily adopt sustainable practices, many small firms in developing countries are enthusiastic about integrating environmental concerns into their operations without sacrificing financial performance (Roxas et al., 2017; Miska et al., 2018).

The resource-based view (RBV) posits that firms can achieve superior performance by leveraging their valuable, rare, inimitable, and organizationally embedded resources and capabilities (Barney & Hesterly, 2019). Recent studies have extended the RBV to incorporate social and environmental considerations, leading to the emergence of the social resource-based view (SRBV) and natural resource-based view (NRBV) (Barney et al., 2011; Hart, 1995; Tate & Bals, 2018). By integrating these perspectives, firms can achieve a sustainable triple bottom line performance.

To achieve sustainable performance, small businesses must embrace innovation (Roxas et al., 2017; Matejun, 2018). This includes adopting new technologies to support sustainable practices (Tommasetti et al., 2018). Technology can help reduce uncertainty and enhance sustainability performance (Longoni & Cagliano, 2018). Therefore, it is essential to examine the impact of small-scale fishermen's innovative entrepreneurial orientation on their sustainability efforts.

Entrepreneurial Well-Being and Sustainable Small-Scale Fishery

Entrepreneurship involves pursuing opportunities through innovation, risk-taking, proactivity, and self-reliance (Lumpkin & Dess, 1996). While financial gain is a key motivator, recent research on entrepreneurial well-being suggests that entrepreneurs are driven not only by economic rewards but also by the affective and cognitive experiences associated with the entrepreneurial journey (Abreu et al., 2019).

Entrepreneurial well-being research is a multi-faceted field that examines both entrepreneurial orientation and the subjective and psychological well-being of entrepreneurs (Wiklund et al., 2019). Psychological well-being encompasses dimensions such as autonomy, self-development, self-acceptance, purpose in life, environmental mastery, and positive relationships, while subjective well-being includes factors like material well-being, health, broadening the scope of entrepreneurship research to include well-being, we aim to foster more sustainable entrepreneurial journeys.

Sustainable entrepreneurship is an ideal state for entrepreneurial journeys. Previous research suggests that sustainability requires a triple bottom line approach, balancing economic, environmental, and social performance (Aguiñaga et al., 2018; Jahanshahi, 2017; Knight et al., 2018; Korsgaard et al., 2016). To align with this concept, sustainable entrepreneurship research should adhere to the United Nations Sustainable Development Goals (SDGs) as a framework for addressing global challenges.

Sustainability practices can present significant challenges for entrepreneurs, as they may conflict with individual goals and priorities (Elkington, 1998). Entrepreneurial journeys often

prioritize personal performance and individual goals (Jahanshahi, 2017). As a result, achieving sustainable entrepreneurship can be difficult, as many entrepreneurs prioritize economic performance over environmental and social considerations (Jahanshahi, 2017; Korsgaard et al., 2016). Based on the discussion, hypothesis one is proposed:

H1 : Entrepreneurial well-being of small-scale fishermen negatively influences sustainable small-scale fishery.

Entrepreneurial Well-Being, Digital Transformation, and Sustainable Small-Scale Fishery

The advent industry 4.0 has ushered in a new era of advanced digitalization, characterized by interconnected machines and automated processes (Beier, 2018). This technological revolution promises to significantly enhance business efficiency, performance, and sustainability (Mart & Aguayo-Gonz, 2019). While digital technologies offer substantial benefits, their successful implementation requires more than just technological advancement.

Previous research has emphasized the importance of considering socio-technical factors beyond technology in the context of digital transformation and Industry 4.0. Krotov (2017) identifies three key dimensions of the socio-technical environment: technological, physical, and socio-economic. The technological environment encompasses hardware, software, networking platforms, standards, and data. The physical environment includes human and non-human objects, as well as physical surroundings. Lastly, the socio-economic environment comprises consumers, legislative bodies, and industry associations.

Successful implementation of digital tracking technology for small-scale fishermen requires a holistic approach that considers not only technological factors but also physical and socio-economic dimensions (Hoenner et al., 2022). The digital tracking technology is Android based applications which can be used by small-scale fishermen. These tools help fishermen implement what is called the Smart Fisherman Information System (Sistem Informasi Nelayan Pintar or SINP), since through this system fishermen will plan their business (Muawanah et al., 2018; Susilawati et al., 2020). As their preparation, fishermen can access up-to-date information about fishing areas and weather conditions through an application on their mobile phone. Furthermore, after they have finished catching the fish, the fishermen can access the latest information about fish prices in various fish auction places, so they have alternatives for selling types of fish and auction places with better prices. On the other hand, the applications can prevent overfishing in a certain area. The digital tracking technology must be user-friendly and provide direct benefits to fishermen, aligning with their values and practices. Furthermore, the socio-economic environment, including consumers and government bodies, must support the adoption of digital technology and prioritize sustainability. By integrating these three dimensions, digital transformation can contribute to the sustainable development of small-scale fisheries. Based on the discussion, hypothesis two and hypothesis three are proposed:

H2 : Entrepreneurial well-being of small-scale fishermen positively influences digital transformation.

H3 : Digital transformation positively influences sustainable small-scale fishery.

The proposed model in this research is presented in Figure 1.

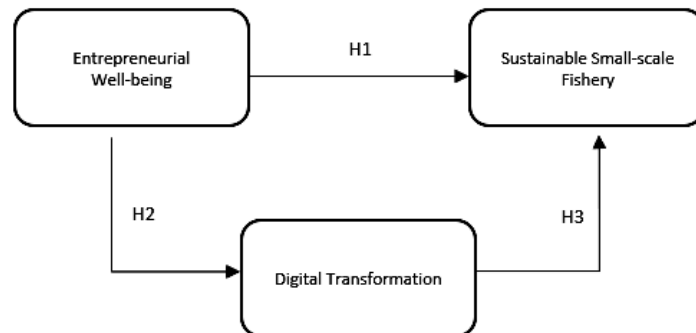


Figure 1. Proposed Conceptual Model
 Source: Data Processed by Researchers, 2025

Methods

Indonesia's vast fishing grounds are divided into 11 designated management areas. According to the Ministry of Maritime and Fisheries (2018), the country boasts a significant fishing fleet with over 372,000 vessels, and a substantial portion (more than 70%) of these are small-scale with less than 10 gross tons, operated by an estimated 800,000 fishermen. While Indonesian law defines small-scale fishing vessels based on their tonnage, a broader definition considers factors like individual ownership of boats and gear, reliance on family or friends for assistance, and part-time fishing activities as key characteristics of small-scale fishermen (Berkes, 2001).

This study focused on a vast area encompassing the Java Sea and the South China Sea, covering a total of 7,712,571 square kilometers within designated fisheries management areas. These regions were selected due to their high concentration of small-scale fishing vessels, with an estimated 97,998 boats operating across 12 provinces spanning the major Indonesian islands of Java, Borneo, and Sumatra. A descriptive-explanatory research approach was employed, utilizing a one-time cross-sectional data collection method and a quantitative analysis framework. Statistical analysis was conducted using Partial Least Squares – Structural Equation Modeling (PLS-SEM) with the aid of Smart-PLS 3.0 software (Ringle et al., 2015).

Results and Discussion

This study analyzed data collected from 245 valid questionnaires. The respondent profile revealed a predominance of small-scale fishing vessels, with 81% of the boats falling within the 1-5 gross tonnage category. A significant proportion (85%) of the fishermen possessed extensive experience, having been engaged in fishing activities for more than five years. Regarding fishing gear, handline, pole, and line methods were the most commonly employed (43%), followed by gill net and fishing net (33%), and trap pod (24%). The age distribution exhibited a bimodal pattern, with 68% of the fishermen aged 35 years or older and 32% belonging to the younger cohort (18-35 years). Finally, fishing frequency varied, with 56% of fishermen spending 10-20 days per month at sea, 22% spending 20-30 days, and the remaining 22% engaging in fishing activities for less than 10 days per month.

Table 1. Confirmatory factor analysis

Construct	Cronbach's Alpha	AVE
SUS	0.88	0.537
DT	0.67	0.501
WELL	0.879	0.579

Source: Data Processed by Researchers, 2025

Confirmatory Factor Analysis (CFA) was employed to evaluate the measurement model. Construct validity was assessed by examining individual item loadings, ensuring they adequately reflected the underlying variables. Additionally, the Average Variance Extracted (AVE) for each construct exceeded the recommended threshold of 0.5, and Cronbach's alpha values surpassed 0.7, as suggested by Hair (2017). Table 1 presents the results, confirming that all constructs in this research met the established criteria for construct validity.

Subsequent to establishing construct validity and reliability, the study proceeded to analyze the structural model by examining the path relationships between the constructs. The influence of each construct was assessed through statistical significance testing using t-values and p-values. A confidence level of 90% was adopted, with t-values exceeding 1.65 and p-values less than 0.05 indicating statistically significant relationships. The results of the path analysis are presented in Table 2.

Table 2. Path Analysis

Hypothesis	Path Coefficient	T-Value	P-Value
WELL → SUS	-0.053	0.726	0.468
WELL → DT	0.512	10.888	0.000
DT → SUS	0.777	16.002	0.000

Source: Data Processed by Researchers, 2025

The path analysis revealed that entrepreneurial well-being did not exert a statistically significant influence on overall sustainable small-scale fishery (SUS), as indicated by non-significant t-values and p-values. In contrast, statistically significant positive relationships were observed between entrepreneurial well-being (WELL) and the dimensions of digital transformation (DT), which in turn affects the sustainability of small-scale fisheries. Although the direct relationship between entrepreneurial well-being and overall sustainability was not statistically significant, a negative path coefficient was observed. This suggests that a higher level of entrepreneurial well-being among small-scale fishermen may be associated with a lower perceived level of overall sustainability.

Multi-group analysis conducted within the Smart-PLS framework revealed a significant interaction effect between fisherman age and the relationship between entrepreneurial well-being and overall sustainability (SUS). Older fishermen exhibited a negative perception of SUS, while younger fishermen demonstrated a positive perception. This finding aligns with previous research by Jahanshahi (2017) on small businesses, which observed a negative perception of sustainability among older entrepreneurs. This discrepancy may be attributed to differing priorities. Younger fishermen may prioritize long-term sustainability to ensure the continued viability of their livelihood. In contrast, older fishermen may face greater immediate pressures, such as increased family responsibilities and the burden of debt incurred to cover operational costs. While the direct

relationship between entrepreneurial well-being and SUS was not statistically significant in this study, the observed negative interaction effect suggests that a strong focus on entrepreneurial well-being may inadvertently have detrimental consequences for sustainability. This implies that entrepreneurial well-being, while crucial for individual development, may not adequately emphasize the broader principles of the triple bottom line, encompassing economic, social, and environmental sustainability.

The path analysis demonstrated a significant and positive relationship between entrepreneurial well-being and digital transformation (DT), thereby supporting Hypothesis 2. This finding aligns with previous research in digital entrepreneurship, which has consistently shown that entrepreneurs perceive significant benefits from digital transformation (Ciriello et al., 2018; Nambisan et al., 2019; Zaheer et al., 2019). Our study corroborates these findings, indicating that small-scale fishermen also recognize the potential advantages of digital technologies. This is further supported by Hoenner et al. (2022), who investigated the use of satellite tracking technology in small-scale fisheries. Their study revealed that fishermen can leverage data on fishing patterns to optimize fuel consumption by efficiently locating fishing grounds and minimizing fuel wastage. Furthermore, access to visual and empirical data on seasonal fishing patterns enables fishermen to make informed decisions regarding optimal fishing locations. Other key benefits of digitalization include access to real-time information on fish market prices, facilitating direct communication between fishermen, mongers, and consumers. Notably, digitalization enhances sustainability through improved traceability and transparency, enabling stakeholders to track the origin and journey of fish products from capture to consumption, thereby ensuring adherence to sustainable fishing practices.

The path analysis revealed a significant and positive relationship between digital transformation (DT) and overall sustainability (SUS). This finding underscores the pivotal role of digitalization in enhancing the sustainability of small-scale fisheries across economic, social, and environmental dimensions. The utilization of digital platforms, such as smartphones and dedicated fishing applications, can provide valuable data on past, present, and future fishing patterns, enabling fishermen to adopt sustainable practices. For example, these platforms can identify and designate no-fishing periods to protect fish stocks during spawning seasons. Furthermore, real-time data on catch per unit effort (CPUE) can be collected to monitor fishing activity and ensure adherence to annual fishing quotas. This data-driven approach fosters sustainable fishing practices by providing crucial information on fishing grounds, seasonal variations, and resource utilization.

This study concludes that digital transformation may act as a crucial mediator in the relationship between entrepreneurial well-being and small-scale fisherman sustainability. The total indirect effect of entrepreneurial well-being on sustainability through digital transformation was found to be 0.397, while the direct effect was negligible (-0.053). These findings underscore the pivotal role of digital transformation in enhancing the sustainability of small-scale fisheries. By leveraging digital technologies, fishermen can optimize fishing operations by identifying optimal fishing grounds and minimizing fuel consumption. Furthermore, direct-to-consumer channels facilitated by digital platforms can empower fishermen by circumventing the price manipulation of middlemen. Notably, digitalization provides valuable insights into fishing pressure within specific zones, enabling fishermen to adopt more responsible harvesting practices, such as limiting catches and allowing for adequate recovery periods in targeted fishing areas.

Conclusion

This study found that entrepreneurial well-being did not significantly influence the sustainability of artisanal fisheries. However, a significant positive relationship was observed between entrepreneurial well-being and digital transformation. Furthermore, digital transformation was found to exert a significant positive influence on the sustainability of artisanal fisheries. While prior research on entrepreneurial orientation has consistently demonstrated a positive and significant impact on the triple bottom line of sustainability, this study, specifically focusing on artisanal fishermen, revealed a different outcome. These findings suggest that the pursuit of higher levels of wealth by artisanal fishermen may prioritize short-term gains over long-term sustainable practices.

This research highlights an inconsistency in the existing literature regarding the relationship between entrepreneurial well-being and sustainability. However, the study emphasizes the crucial role of digital transformation in mediating this relationship. By integrating digital technologies such as satellite tracking devices, fishing apps, and weather prediction tools, stakeholders can incentivize artisanal fishermen to adopt sustainable fishing practices. This includes compliance with regulations to combat illegal, unreported, and unregulated fishing through mandatory reporting of fishing activities. In conclusion, this research strongly suggests that digital transformation plays a pivotal role in mediating the relationship between entrepreneurial well-being and sustainability within the artisanal fishing sector, thereby contributing to the development of a more sustainable fishing industry.

Further research is recommended to investigate the generalizability of these findings. Future studies should explore the relationship between entrepreneurial well-being, digital transformation, and sustainability in other regions of Indonesia or in comparable maritime nations to determine the consistency of these findings across diverse contexts.

The results of this study found that digital applications may facilitate artisanal fishermen to achieve the business and environmental sustainability. Currently, there are various applications available in the market, that help small fishermen to get more optimal marine catches and increase cost efficiency and safety. The government through regional governments and the community needs to continue to increase awareness of the benefits of this application, so that it will increase the level of use among the artisanal fishermen. However, the application must be developed in such a way that the fishing community, who generally have lower level of education, can utilize the application easily. Apart from that, the government needs to continue to develop the distribution of internet services throughout Indonesia, so that the application can be used by more fishermen throughout Indonesia. Finally, regulations on larger capture fish companies must also be improved by implementing more sustainable fishing regulations, because the larger capture fisheries companies have a greater impact on business and environmental sustainability. We need to learn from Indonesian forestry industry, where the bigger players who do the most damage to the environment, but indigenous people who use forest land sustainably are accused of being the cause of forest destruction.

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