Available online at: http://jurnal.utu.ac.id/jppolicy

Jurnal Public Policy

| ISSN (Print) 2477-5738 | ISSN (Online) 2502-0528 |

Penta Helix Collaboration in Coastal Waste Management for Sustainable Empowerment of Traditional Fishing Families

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ARTICLE INFORMATION

Received: Februari 22, 2025
Revised: October 17, 2025
Available online: January 30, 2026

KEYWORDS

Penta-Helix model; Coastal Waste Management; Community Empowerment; Public Sector Performance

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A B S T R A C T

This study implements the Penta-Helix collaborative model in an empowerment program for traditional fishing households in Medang Deras Subdistrict, Batubara Regency, North Sumatra Province, through innovative interventions in coastal waste management, transforming waste into calcium-based products. The study aims to address suboptimal coastal waste management and the economic marginalization of fishing communities. The model engages five key actors: the Batubara Regency Government, academics from the University of Sumatera Utara, the private sector represented by PT Indonesia Asahan Aluminium, traditional fishing communities, and media personnel affiliated with the Indonesian Journalists Association. Employing an action research methodology, the study began with surveys, observations, interviews, and focus group discussions with the Penta-Helix actors, followed by empowerment interventions through structured training in coastal waste management. The intervention was implemented via knowledge transfer and training across four stages: (1) collection of coastal waste, (2) processing waste into calcium powder, (3) application of innovative products to meet household needs, and (4) continuous mentoring. The findings indicate that the innovation intervention significantly enhanced local knowledge and skills, increased environmental awareness, and fostered entrepreneurial capacities within traditional fishing households. Moreover, the Penta-Helix actor collaboration successfully established innovation-driven community groups acting as ambassadors to expand the program's impact. The study recommends institutionalizing the Penta-Helix model within regional development strategies, complemented by fiscal incentives, to strengthen inclusive and sustainable coastal economies.

INTRODUCTION

Indonesia, as the world's largest archipelagic nation, possesses vast marine biodiversity and abundant coastal resources (Warren & Steenbergen, 2021). Nevertheless, traditional fishing communities especially in peripheral regions such as Medang Deras in Batubara Regency continue to face chronic socio-economic challenges. These include persistent poverty, low education, limited livelihood diversification, and increasing vulnerability to environmental degradation (Aisyah & Sontang, 2022). The accumulation of unmanaged coastal waste particularly organic residues from shellfish and plastic debris adds ecological pressure and limits opportunities for productive resource utilization (Foley et al., 2018). This dual burden of poverty and pollution underscores a structural failure in both local development planning and coastal governance (Aisyah et al., 2025) .

The marginalization of fishing communities is not merely an outcome of ecological or economic limitations, but stems largely from the fragmentation and weakness of public sector governance (Kitunzi, 2021). Government-led empowerment initiatives are often top-down, short-lived, and implemented without robust engagement from communities or non-government stakeholders (Yukalang et al., 2018). This lack of institutional synergy diminishes program sustainability and local ownership (Forss et al., 2021). In Medang Deras, minimal collaboration between government, academia, private companies, media, and community groups has further weakened the effectiveness of empowerment programs aimed at enhancing resilience and environmental stewardship.

In response, the concept of collaborative governance has gained prominence in public policy discourse as a solution for systemic policy failure in complex, multistakeholder environments. Within this framework, the Penta Helix model which promotes structured interaction among five actors: government, business, academia, media, and communities has shown promise in enhancing innovation, public accountability, and sustainable development outcomes (Calzada, 2020). Despite its growing popularity, most applications of the Penta Helix model have occurred in urban or high-capacity institutional settings, such as smart city planning, digital infrastructure, and university-industry partnerships (Asy'ari et al., 2025). Its operationalization in marginalized, rural, and informal contexts such as coastal fishing communities remains poorly documented and under-theorized (Amrial et al., 2017).

Empirically, a research gap also persists. Existing studies tend to treat coastal waste management and community empowerment as largely separate domains, with limited analytical integration between environmental management and livelihood development (Berkes, 2009; Foley et al., 2018). Only a small body of research has meaningfully incorporated circular economy approaches, particularly the transformation of shellfish waste into high–value calcium-based products, into community-based livelihood strategies (Geissdoerfer et al., 2017; Kirchherr et al., 2017). Even fewer studies employ participatory action research (PAR) to systematically document how such collaborative, multi-actor processes unfold in real time within traditional coastal villages in Indonesia, thereby leaving a critical empirical gap in understanding inclusive governance dynamics in localized coastal contexts (Kindon et al., 2007; McNiff & Whitehead, 2011; Chambers, 2017).

By contrast, international best practices offer compelling insights into how collaborative models can be adapted and localized. For example, the European Union's Blue Economy Strategy demonstrates how coastal regions in Spain, Portugal,

https://doi.org/10.35308/jpp.v12i1.11590

and Greece have built multistakeholder platforms that integrate marine conservation with inclusive local economic development. These initiatives are supported by formal governance frameworks and funding mechanisms that incentivize community engagement and innovation. In Japan, coastal waste recycling programs have been successfully embedded within rural fisheries through partnerships between local governments, universities, and cooperatives demonstrating the potential of university-led technology transfer in empowering small-scale fishermen (Moshkal et al., 2024). Similarly, in the Philippines and Thailand, local governments and NGOs have initiated waste-to-energy and plastic upcycling programs with strong community involvement, effectively linking environmental goals with grassroots economic incentives (Kirchherr et al., 2023).

These comparative experiences underscore the urgency for Indonesia to develop localized yet institutionally supported models of coastal empowerment that align with global standards of inclusive, multi-actor development governance. However, Indonesia still lacks a structured, scalable framework to institutionalize such models at the regional level particularly in 3T (*tertinggal*, *terluar*, *terdepan*) areas.

Theoretically, this study is grounded in the Penta-Helix collaboration model, which was originally developed from the Triple Helix framework by Etzkowitz and Leydesdorff (1995) and subsequently expanded into the Quadruple and Penta Helix models by Carayannis and Campbell (2012). The Penta-Helix model conceptualizes innovation and governance as the outcome of systematic collaboration among five key actors: government, academia, industry, civil society, and the media. This model emphasizes co-creation, knowledge exchange, public participation, and policy–market integration as fundamental mechanisms for achieving sustainable development and inclusive innovation.

In this study, the Penta-Helix model is operationalized within the context of coastal waste management and community empowerment, where collaborative interaction among stakeholders is essential for translating environmental challenges into socio-economic opportunities. To strengthen the intervention-based nature of this research, the study is further anchored in Action Research theory as formulated by Lewin (1946) and later elaborated by McNiff and Whitehead (2011), which emphasizes cyclical processes of planning, action, observation, and reflection through participatory engagement with community actors.

Based on this integrated theoretical framework, the analytical indicators used in this study are derived from both the Penta-Helix collaboration dimension and the empowerment outcome dimension. The Penta-Helix indicators include: (1) the regulatory and facilitative role of local government, (2) the knowledge production and capacity-building role of academia, (3) the technology provision and market linkage role of industry, (4) the participation and collective agency of local fishing communities, and (5) the dissemination and advocacy role of the media. Meanwhile, the empowerment indicators consist of: (1) improvements in community knowledge and technical skills, (2) growth of environmental awareness, (3) development of calcium-based product innovation, (4) expansion of household income opportunities, and (5) the sustainability of community-based entrepreneurial groups formed through the program.

This study addresses the aforementioned theoretical and empirical gaps by applying the Penta Helix collaborative governance model in the context of Medang Deras, using coastal waste management as a strategic entry point. It integrates circular economy innovation, particularly the transformation of shellfish waste into calcium-based products, with participatory empowerment methods grounded in action research. All five Penta Helix actors local government, academic institutions (Universitas Sumatera Utara), the private sector (PT Inalum), local media, and traditional fishing communities are actively involved in program co-design, training, implementation, and impact monitoring.

Previous studies have demonstrated that the integration of the Penta-helix model enhances the socio-economic resilience of coastal communities facing environmental threats and illegal fishing and strengthens farmer empowerment (Saputra, 2022). Media involvement in the Pentahelix collaboration has also been crucial for supporting rural development (Nurdin et al., 2023). Moreover, applications of the Pentahelix model in coastal waste management in Indonesia have shown the value of multi-actor collaboration in addressing marine pollution through research-based innovations and in increasing community participation in beach clean-ups. Academic contributions to developing technological solutions for coastal waste management have been explored by Santoso and Cahyani (2022). However, this study introduces a clear novelty: the direct technological intervention in the management of organic coastal waste sourced from traditional fishing activities. The uniqueness lies in transferring knowledge and skills to traditional fishing families, enabling them to process organic coastal waste into value-added calcium-based innovative products. This technological empowerment approach not only addresses environmental issues but also creates new sustainable economic opportunities. Thus, the research significantly advances the application of the Pentahelix model by demonstrating an integrated empowerment strategy combining coastal waste management, technological innovation, and socio-economic development in traditional fishing communities.

The novelty of this research lies in the adoption of the pentahelix model within a coastal community empowerment program, utilizing the potential of coastal waste as a source of innovation to enhance both environmental and economic sustainability. Specifically, this study aims to: (1) map the socio-economic profiles of fishing households; (2) analyze their needs and readiness to participate in empowerment programs; and (3) design and implement innovative coastal-waste management interventions through training activities based on penta-helix collaboration.

METHOD

This study adopts an action research design within the framework of the Penta-Helix collaboration model. The Action Research method was selected due to its strong relevance in simultaneously investigating and directly intervening in the socio-economic conditions of traditional fishermen's families, who remain within a low-income economic stratum. Action Research has been empirically demonstrated to ensure that community aspirations and needs are systematically accommodated at every stage of the research process (Dustman et al., 2014). Epistemologically, Action Research is rooted in the qualitative-participatory paradigm, which emphasizes reflection, collaboration, and social transformation (Lewin, 1946; Tripp, 2005). However, in its practical implementation, this study also incorporates quantitative data through the use of structured questionnaires and descriptive statistical analyses. Therefore,

https://doi.org/10.35308/jpp.v12i1.11590

this research is classified as mixed-methods–based on Action Research.

This study represents the utilization of outcomes from cross-disciplinary collaborative research, integrating social-community approaches with technological engineering approaches in coastal waste processing. The engineering approach focuses on the design, testing, and optimization of mechanical processing systems for shell-based coastal waste and similar materials, thereby producing technologies that are effective, efficient, and field-ready. Meanwhile, the social approach is directed toward enhancing public awareness and community participation in coastal waste management, while simultaneously facilitating the transfer of research outputs to target groups. This process is realized through the empowerment of traditional fishermen's family groups and participatory training models, ensuring that the developed technologies are easily adopted, practically applicable, and locally sustainable (Garcia et al., 2022).

The study was conducted in four coastal villages in Medang Deras District, Batubara Regency, North Sumatra Province (Figure 1). This location was selected due to its substantial marine resource potential, despite persistent socio-economic challenges and deficiencies in coastal waste governance. The research was carried out over a one-year period, from August 2023 to July 2024, encompassing the entire Action Research cycle from diagnostic assessment through to sustainability planning.

Figure 1. Research location
Source: obtained from google maps

The study's participants included all traditional fishing families living in the designated research area, who primarily rely on marine and coastal resources for their livelihoods. To select participants who were particularly relevant to the study's objectives, a purposive sampling method was utilized. This approach resulted in the selection of 159 respondents, predominantly women from fishing households actively involved in shellfish and clam processing, as well as *tamin* and *mentarang*. Women were emphasized as key respondents due to their significant roles in post-harvest processing and waste management activities, making their insights vital for assessing opportunities related to coastal waste utilization. The purposive sampling method was deemed suitable for this research as it enabled researchers to focus on individuals with specific expertise, knowledge, and involvement concerning the practices being examined.

Data collection involved both primary and secondary sources to ensure a thorough understanding of the research issue. Primary data were gathered through various means: in-depth interviews, focus group discussions, structured questionnaires, and field observations. In-depth interviews were conducted with selected members of fishing households, local leaders, and other pertinent stakeholders to obtain detailed information regarding livelihood strategies, community challenges, and attitudes toward waste utilization. Focus group discussions involving groups of women processors provided an opportunity for collective dialogue that allowed researchers to capture shared experiences, local knowledge, and innovative practices connected to shellfish and clam processing. Structured questionnaires were distributed among all 159 respondents to gather quantitative data about socio-economic conditions, household income levels, production patterns, and waste management practices. Additionally, direct observations during visits to fishing villages and processing sites enabled researchers to document community practices alongside environmental conditions and everyday realities related to coastal resource use.

Secondary data were sourced from official government reports, relevant academic studies, statistical records, and policy documents. These resources offered essential contextual information concerning fisheries development, socio-economic indicators within coastal communities, and overarching policy frameworks affecting resource management as well as waste utilization. The analysis employed a mixed-method approach that integrated both quantitative and qualitative elements. Quantitative data from questionnaires were analyzed using Microsoft Excel with frequency distributions and descriptive statistical techniques summarizing household characteristics alongside production practices and livelihood profiles. Qualitative data from interviews, focus group discussions, and field observations underwent thematic analysis involving systematic coding of transcripts and field notes to identify recurring themes reflecting community perspectives on livelihood challenges along with waste utilization practices.

RESULTS AND DISCUSSION

Socio-Economic Profile of Traditional Fishermen Households

Poverty experienced by traditional fishermen households constitutes a complex, structural, and multidimensional problem. Poverty is not solely the result of low-income levels but is also shaped by environmental factors, limited access to productive resources, low educational attainment, and weak access to social protection and empowerment programs (Chambers, 2017; Béné, 2009). Chambers (2017) argues that poverty in coastal communities is frequently exacerbated by unfavorable environmental conditions, including natural resource degradation and seasonal dependency, which substantially heighten the economic vulnerability of fishermen households. In a similar vein, Béné (2009) emphasizes that traditional fishermen households belong to the category of *vulnerable livelihoods*, as they are characterized by unstable income streams and a lack of diversification in livelihood sources.

Therefore, efforts to empower traditional fishermen households must begin with a comprehensive understanding of their socio-economic profile as a fundamental basis for designing targeted and context-sensitive interventions. An analysis of socio-economic conditions encompassing education levels, income, access to public services, asset ownership, and the environmental conditions of residential areas serves as a critical instrument for formulating effective and sustainable empowerment programs (Todaro & Smith, 2020). Accordingly, this section focuses on assessing the needs of traditional fishermen households in Medang Deras Subdistrict by mapping their socio-economic profiles (see Table 1), which provides an

empirical foundation for the formulation of assistance schemes and empowerment strategies aimed at improving household welfare.

Table 1. Socio-Economic Profile of Traditional Fishermen Families

Questions variable of Traditional Fishermen Family Socio Economics	Frequency	Percentage
Education level: Elementary school	68	43%
Income/day		
20.000 – 40.000,-	13	8%
50.000,-	58	36%
60.000 – 80.000,-	29	18%
100.000,-	17	11%
200.000 – 250.000,-	4	3%
Not sure	38	24%
Insufficient income	138	87%
Expenditure on food /month		
	27	17%
140.000 – 1.050.000	11	7%
1.200.000	60	38%
1.500.000	33	21%
1.800.000-3.000.000	2	1%
4.000.000– 4.500.000	26	16%
Not sure		
Expenditure on fuel per month		
	15	9%
50.000 – 200.000	55	35%
300.000 – 540.000	28	18%
600.000 – 900.000	24	15%
›1.000.000	37	23%
Not sure		
Expenditure on water costs per month		
30.000 – 90.000	68	43%
100.000 – 120.000	20	13%
100.000 – 250.000	24	15%
Not sure	47	29%
Expenses for electricity costs		
	20	13%
25.000 – 50.000	37	23%
55.000 – 90.000	61	38%
100.000 – 300.000	41	26%
Not sure		
Do not have other skills/Jobs	146	92%

Source: obtained from primary data (2023)

Based on a survey of 159 respondents, the majority of households were classified as low-income, with an average daily income of less than IDR 50,000. Such income levels are insufficient to meet basic household needs, including food consumption, children's education, electricity and water bills, and transportation expenses, let alone to enable savings, particularly as many households remain burdened by debt. Furthermore, approximately 43% of fishermen have low educational attainment, and as many as 92% reported having no alternative sources of employment beyond fishing activities and the processing of marine products.

These findings indicate that the socio-economic conditions of traditional fishermen households remain entrenched in poverty. The households face limited livelihood options and thus require alternative income-generating activities as a strategic means of improving their living conditions. Consequently, it is essential to identify the suitability and specific needs of traditional fishermen households (see Table 2) as prospective participants in empowerment programs aimed at transforming coastal waste into innovative value-added products.

Analysis of Needs and Readiness for Empowerment Programs

Based on the findings of the socio-economic survey, it was identified that, beyond economic hardship, respondents had largely never received assistance from government programs. The survey results indicate that 84% of respondents had never benefited from any form of governmental support. Moreover, 77% reported that they had never been included in skills training programs. In addition, 92% of respondents stated that they had never been involved in decision-making processes or consulted regarding their actual needs, indicating a persistent gap in the implementation of bottom-up, community-based policy approaches in empowerment initiatives (Setiawan & Darmawan, 2020).

https://doi.org/10.35308/jpp.v12i1.11590

The accumulation of coastal waste also emerged as a significant issue, with 57% of respondents acknowledging the presence of waste in coastal areas. However, 84% of these respondents reported that they simply disposed of the waste due to a lack of awareness of its potential economic value. Notably, 85% of respondents expressed willingness to participate in training programs focused on processing coastal waste into innovative products. This condition highlights a substantial opportunity to integrate waste management into community empowerment programs. Such empowerment initiatives are expected to provide fishermen with alternative livelihood opportunities, which may ultimately contribute to improving their overall living standards.

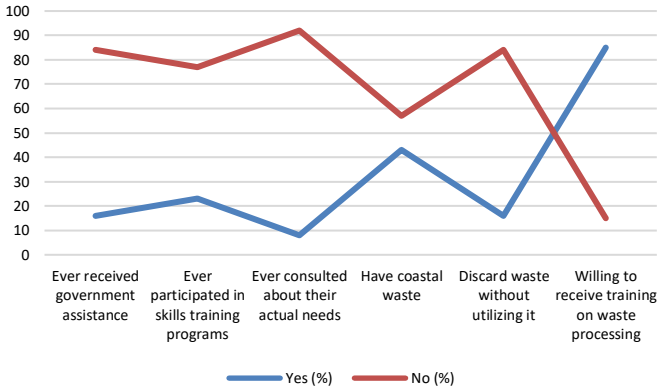

Figure 2. Needs Assessment Analysis of Traditional Fishermen Households

Interventions within empowerment programs for traditional fishermen households require a fundamental shift toward collaborative modes of implementation. The primary objective of such a shift is to enhance the effectiveness of empowerment initiatives, which to date have largely failed to deliver tangible outcomes. This shortcoming is evidenced by the majority of respondents reporting that they have not experienced any meaningful assistance from government programs.

The intervention adopted in this study employs the Helix model proposed by Leydesdorff and Etzkowitz, which emphasizes multi-actor collaboration involving diverse stakeholders. Accordingly, this study examines a helix-based collaborative framework applied to the treatment of coastal waste management by transforming it into innovative products within the context of empowerment programs for traditional fishermen households. The analysis therefore seeks to elucidate both the rationale for adopting a helix-based collaborative approach and the sequential stages through which such collaboration is operationalized.

Application of the Helix Model in Empowering Traditional Fishermen Households

Drawing on prior research, scholars have emphasized the need for performance-oriented interventions in empowerment programs targeting traditional fishermen households through the establishment of strong and sustainable local partnerships (Aisyah et al., 2025). Initial partnership-building efforts focused on connecting three key empowerment actors government, academia, and industry within the framework of the Triple Helix model introduced by Leydesdorff and Etzkowitz (1995). Collaborative empowerment based on the Triple Helix model has been widely recommended to foster sustainable empowerment outcomes through community participation and product innovation (Leydesdorff & Etzkowitz, 1995; Figenschou et al., 2025).

Fundamentally, the assistance required for empowering traditional fishermen households lies in enhancing their capacity to develop alternative livelihood opportunities. This perspective aligns with Chambers' (2017) assertion that capacity building and livelihood diversification constitute the core of empowerment strategies for impoverished communities. In this regard, the research team proposed an innovative technique for transforming coastal waste into value-added products, specifically calcium-based food and beverage products, as an empowerment instrument for traditional fishermen households.

The intervention was implemented through three main stages. In the first stage, the research team conducted knowledge transfer activities related to the collection and management of coastal waste materials, including *tamin* shells, *mentarang* shells, *kepah* shells, and other types of shellfish waste. In the second stage, knowledge transfer was directed primarily toward fishermen's wives, focusing on technical processes such as cleaning, drying, calcination, milling, and boiling of coastal waste materials. In the third stage, participants were trained in the application of calcium-rich solutions derived from processed shell waste to produce a range of calcium-based food and beverage products.

The application of the Triple Helix collaborative model in empowering traditional fishermen households was initially implemented in a single coastal village, namely Medang Village. The role of the village government proved to be critical to the sustainability of the Coastal Waste Management Program. The village administration facilitated community engagement by socializing the program among fishermen and providing venues for surveys and training activities. Furthermore, formal collaboration was institutionalized through the establishment of Memoranda of Understanding, Memoranda of Agreement, and Implementation Arrangements involving the regency, sub-district, and village governments in partnership with Universitas Sumatera Utara.

Industry participation, represented by PT Inalum, provided substantial support within this collaborative framework. Through its involvement, the company gained new insights into how coastal waste management initiatives can contribute to improving the socio-economic conditions of traditional fishermen households. PT Inalum also facilitated market access for emerging entrepreneurial groups among fishermen households by enabling product sales through the Inalum Corner. Building on these outcomes, the company expressed its commitment to further collaboration by integrating the Coastal Waste Management Program into its Corporate Social Responsibility (CSR) initiatives across other coastal areas.

Based on the positive outcomes achieved through the Triple Helix intervention, the USU research team expanded stakeholder involvement to empower traditional fishermen households across four coastal villages in Medang Deras Subdistrict, thereby amplifying the program's impact. As skills, self-confidence, and economic initiative among coastal women's groups increased, their roles evolved into those of core actors within the empowerment process. This transformation is consistent with community-based empowerment theory, which posits that successful empowerment is marked by a shift in community positioning from passive beneficiaries to active agents of development (Chambers, 2017).

Simultaneously, rapid advancements in online information dissemination underscore that media actors no longer function merely as passive channels of publicity but have emerged as strategic stakeholders in social empowerment processes. Media play a crucial role in enhancing public awareness, expanding program outreach, and educating communities about waste management and circular economy principles. From a governance communication perspective, media contribute to strengthening public legitimacy and facilitating social oversight of program sustainability (Sjölander-Lindqvist et al., 2022).

The strengthening of active participation among fishermen households, reinforced by the strategic role of media, constitutes a key indicator of successful collaboration within the framework of collaborative governance (Ansell & Gash, 2008). When communities are directly engaged as primary actors and media actively disseminate best practices, empowerment programs can transcend local boundaries and achieve broader, more sustainable, and institutionalized impacts. Accordingly, the collaboration framework evolved from a Triple Helix to a Penta Helix model by incorporating community and media actors as central pillars of empowerment. This expansion is not merely structural but also substantive, as it reinforces participation, social legitimacy, and program sustainability within the governance of traditional fishermen household empowerment in coastal regions.

Stages of Coastal waste management in the Empowerment of Traditional Fishermen Households

The empowerment of traditional fishermen households requires a structured, collaborative, and needs-based approach that is firmly grounded in the real conditions of coastal communities. Within this context, the Penta Helix model was adopted as the primary implementation framework, as it emphasizes synergistic interaction among five key actors academia, government, industry, community groups, and the media in fostering sustainable social innovation (Ansell & Gash, 2008; Carayannis & Campbell, 2012). This cross-actor collaboration is considered particularly relevant for addressing the intertwined challenges of poverty, limited access to knowledge, and weak coastal waste management faced by traditional fishermen households in Medang Deras Subdistrict.

The implementation of the Penta Helix collaboration in this program was not undertaken instantaneously but rather through a series of systematic, interrelated, and continuous stages. Each stage was deliberately designed to ensure that the interventions were grounded in local potential, participatory in nature, and capable of generating measurable changes in community knowledge, skills, and behavior. The stages are outlined as follows.

Mapping of Coastal Waste Potential

The mapping of coastal waste potential in Medang Deras Subdistrict constituted the initial step of the fishermen household empowerment program and aimed to optimize locally available resources, including waste generated from fishing-related activities and household-based seafood processing. One of the primary methods employed in this stage was direct field observation. In addition, supporting data were obtained from village authorities, who provided insights into community livelihood patterns, marine-based economic activities, and strategic locations where waste accumulation commonly occurs.

This research phase began with observations conducted across four coastal villages in Medang Deras Subdistrict: Medang Village, Pakam Village, Sei Buah Keras Village, and Pangkalan Dodek Village. The observations identified multiple waste accumulation points, particularly shell waste generated by fishermen's wives during seafood processing activities. Specific findings included:

1. Shell waste accumulation in Mesjid Hamlet, Sei Buah Keras Village;
2. *Tamin* shells identified in Benteng Hamlet, Pakam Village;
3. *Kepah* shells dispersed across Mesjid Barat Hamlet, Lalang Village, as well as Teluk Baru Hamlet and Tangkahan Hamlet in Medang Village;
4. *Mentarang* shells found in Kuala Sipare Hamlet and Pematang Eru Hamlet, Medang Village.

These coastal wastes, comprising shells of *kerang*, *tamin*, *kepah*, and *mentarang*, were largely unutilized and left to accumulate in several village locations. In fact, such waste possesses considerable potential if properly managed. Shell-based waste is known to contain up to 95.7% calcium carbonate ($CaCO_3$) (Suhaera et al., 2024). Previous studies have demonstrated that $CaCO_3$ derivatives obtained through calcination exhibit antibacterial activity against *Escherichia coli* (Jannah, Z., & Rohmawati, L., 2018), while shell powder applications have been shown to accelerate wound contraction and angiogenesis (Song et al., 2017). Moreover, $CaCO_3$ compounds can function as neutralizing agents for soil and water acidity, thereby addressing coastal environmental pollution caused by waste accumulation (Elfarisna et al., 2024).

Despite these scientifically documented benefits, local coastal communities were largely unaware of the economic and ecological potential of shell waste. Limited knowledge regarding its utilization constituted a major barrier to effective waste management. Consequently, transforming this waste into value-added products represents a critical challenge in improving fishermen household welfare while simultaneously preserving coastal ecosystems. Addressing this challenge necessitates the transfer of knowledge and appropriate technologies from competent actors, particularly academic institutions, through training and sustained community mentoring.

Focus Group Discussions (FGDs) for the Formation of Community Driving Teams

Following the waste potential mapping, the research team organized Focus Group Discussions (FGDs) involving village heads, hamlet leaders, community figures, and groups of traditional fishermen households. These FGDs aimed to identify the specific challenges faced by coastal women particularly shell peelers related to hand health issues and waste management practices, as well as to determine intervention targets and locations. Additionally, the FGDs served to establish shared understanding and collective commitment among stakeholders toward the empowerment program.

Participation during this stage was highly active, with community members openly articulating constraints, needs, and recommendations regarding program implementation. The researchers functioned primarily as facilitators, systematically documenting participants' inputs and translating them into relevant training designs.

As a result of the FGDs conducted with village governments, 20 program participants were selected from fishermen

https://doi.org/10.35308/jpp.v12i1.11590

households across four villages, Medang, Pakam, Sei Buah Keras, and Pangkalan Dodek. These participants consisted predominantly of coastal women who are wives or family members of traditional fishermen and were formally nominated by the sub-district government to receive education and training on coastal waste governance. The selected participants, as recipients of knowledge transfer, were expected to serve as future program multipliers, disseminating empowerment practices to broader community groups in Medang Deras Subdistrict. In parallel, researchers emphasized the importance of preserving traditional culinary heritage by innovating local foods enriched with organic calcium derived from village-based resources, such as calcium-fortified *rasidah* cake, *karas* cake, *sampan* cake, calcium-enriched *kasai* fish crackers, and similar products.

Socialization, Demonstration, and Training in Coastal Waste Processing

The stages of socialization, demonstration, and technical training in coastal waste processing represent a critical phase in empowering traditional fishermen households, as they function as the primary entry point for transforming community knowledge, attitudes, and skills. Chambers (2017) emphasizes that effective empowerment must begin with awareness raising, enabling communities to recognize and value resources that have long been overlooked. Accordingly, the socialization activities provided to selected fishermen households sought to shift community perceptions of coastal waste—particularly shell waste—from environmentally harmful refuse to economically valuable and functional resources.

The technical training on processing shell waste into calcium powder reflects an applied form of capacity building. Procedures such as boiling, sun-drying, roasting, and grinding into fine powder were intentionally designed to be simple, replicable, and suitable for fishermen households. This approach aligns with the concept of appropriate technology, which emphasizes the adaptation of technological solutions to local social, economic, and cultural contexts (Todaro & Smith, 2020). The utilization of calcium powder in everyday household food and beverage products further demonstrates that the introduced innovations were non-elitist and directly integrated into the domestic needs of fishermen families.

In addition to production training, demonstrations of calcium powder application as a water filtration medium served as a strategic visual and contextual learning tool. According to Rogers (2003), direct demonstrations constitute one of the most effective mechanisms in the diffusion of innovation, as they significantly enhance technology adoption at the community level. This demonstration reinforced participants' understanding that shell waste holds not only economic value but also health and environmental benefits, thereby encouraging behavioral change in coastal waste management practices.

In terms of program outcomes, the socialization, demonstration, and training activities yielded several significant results. First, they increased ecological awareness and knowledge among fishermen households regarding sustainable coastal waste management. Second, they enhanced participants' technical skills in processing shell waste into calcium powder for use in food, beverages, and water filtration. Third, they fostered motivation and self-confidence particularly among coastal women's groups to develop calcium-based products as potential household enterprises. Fourth, they contributed to a reduction in indiscriminate shell waste disposal practices, resulting in tangible improvements in coastal environmental quality.

Figure 3*.Coastal Waste Management Education and Training*
Source: obtained from primary data (2023)

Implementation of Penta-Helix Collaboration as a Strategy to Improve the Performance of Empowerment Programs

The implementation of the Penta-Helix collaborative working system holds significant promise for improving the performance of government empowerment programs, particularly those that have previously exhibited weak outcomes due to fragmented and uncoordinated actions among key stakeholders. The Penta Helix approach is adopted based on the recognition that complex social problems are more effectively addressed through collaborative mechanisms rather than isolated, sector-specific interventions (Ansell & Gash, 2008; Bryson et al., 2019).

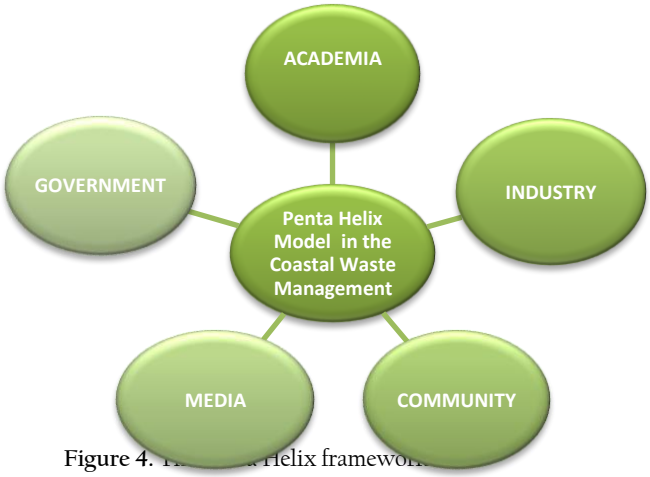

Figure 4. [illegible] Helix framework
Source: Author, 2025

Empowerment Dimensions within the Penta Helix Collaborative Model

During the research phase, the research team initiated a Focus Group Action (FGA). The FGA was positioned not merely as a discussion forum but as an instrument of social engineering designed to align perceptions, interests, and commitments across multiple actors within a single collaborative governance framework. From a collaborative governance perspective, the FGA functioned as an initial arena for face-to-face dialogue, which is a critical precondition for building trust, developing a shared understanding of problems, and formulating collective goals (Ansell & Gash, 2008; Bryson et al., 2019). Conceptually,

the FGA in this study was designed as an initial interaction space among the five Penta Helix actors government, academia, industry, traditional fishermen household communities, and the media.

The FGA activities were coordinated by academic actors, who assumed the role of initiators and primary facilitators while performing a boundary-spanning function to bridge the interests of the state, market actors, local communities, and the public sphere. This role is consistent with knowledge-based governance theory, which positions academia as a key actor in translating scientific knowledge into public policy and social practice (Carayannis & Campbell, 2012; Crosby & Bryson, 2018). The FGA successfully convened all Penta Helix actors and focused on identifying solutions to coastal waste management challenges in North Sumatra.

Government actors were represented by members of Commission B of the North Sumatra Regional House of Representatives, the Head of the Environmental Agency, the Head of the Cooperative and MSME Agency, the Head of Medang Deras Subdistrict, and staff representatives from the Mayor of Medan and the Regent of Batubara. These actors primarily presented existing government waste management programs and policy approaches. Academic participants included experts in social sciences and science and technology from Universitas Sumatera Utara and several private universities in Medan City, who shared research experiences related to innovative waste-based products and their societal benefits. Industry participation was represented by PT Inalum through its Vice President for Corporate Social Responsibility. Community representation comprised coastal women's groups from Medang Village, Medang Deras Subdistrict, who had previously been beneficiaries of Triple Helix-based innovation programs, as well as women's groups from four coastal villages in Medang Deras Subdistrict. Their participation demonstrated the program's effectiveness, as they had developed practical skills in producing calcium powder from shell waste and applying calcium solutions for daily household consumption and small-scale enterprises. Media actors were represented by *koranmedan.com*, an online media outlet that supports community empowerment initiatives through publication and public dissemination.

Each actor was provided with an opportunity to articulate perspectives, inputs, and expectations. The outcomes of the Focus Group Action revealed that government performance in waste governance remains predominantly oriented toward the provision of new landfill facilities due to the overcapacity of existing landfills. The finding that existing landfills have exceeded their capacity indicates a fundamental failure of conventional disposal-based approaches. This reinforces critiques within environmental policy literature that end-of-pipe strategies are no longer adequate to address the complexity of coastal waste challenges (Morawska-Jancelewicz, 2022). In this context, the FGA functioned as a policy learning arena, facilitating a paradigm shift in government perspectives from waste disposal toward zero-waste and circular economy approaches.

Several academic experts present at the FGA proposed that both executive and legislative branches of government should actively collaborate with multiple stakeholders to develop innovative waste governance policies oriented toward zero-waste solutions. Furthermore, the findings indicate that the empowerment dimensions within the Penta Helix collaboration are extensive, encompassing social, economic, technological, ecological, and policy dimensions. Based on initial research findings on coastal community poverty, empowerment can be achieved through enhanced participation and environmental awareness, while circular economy practices create new income opportunities from waste. Academic and industry actors contribute by providing technology transfer and skills training to strengthen community capacity. This collaboration also supports marine pollution mitigation and the reduction of extreme poverty through sustainable practices. In parallel, local governments play a critical role in providing regulatory frameworks and long-term policy support to ensure program sustainability (Morawska-Jancelewicz, 2022; Santoso & Cahyani, 2022; Campbell & Carayannis, 2020).

Figure 5. *Implementation of Penta-helix Focus Group Action (FGA) at the Hall of the North Sumatra Governor's Office*

Source: obtained from primary data (2023)

Penta Helix Collaboration as a Driver of Sustainable Innovation in Coastal Waste Governance

The outcomes of the intervention, which was grounded in coastal waste utilization and product innovation within an empowerment framework, have significantly enhanced both knowledge and skill acquisition among traditional fishermen households. Through participation in the program, households developed the capacity to independently produce organic calcium-based products derived from coastal waste. Their involvement generated tangible benefits, including increased awareness of the importance of collecting coastal waste, the ability to process shell waste into calcium powder, and the application of calcium-enriched water in daily food and beverage consumption. These innovation-oriented interventions produced measurable program outcomes, as participating fishermen households reported routine use of calcium water to support their household health needs.

These achievements further facilitated formal collaboration with the Batu Bara Regency Government, represented by the Head of the Cooperative and Micro, Small, and Medium Enterprises (MSME) Office. The Batu Bara Cooperative and MSME Office has continued to support the training program by assisting emerging MSMEs through the issuance of Business Identification Numbers (Nomor Induk Berusaha/NIB) and by providing improved product packaging to enhance the market appeal of coastal calcium products. Moreover, the Cooperative and MSME Office has expressed a strong commitment to sustaining and expanding the coastal waste management program developed by the research team by replicating it in other coastal villages, including Gambus Laut Village, in coordination with the Batu Bara Fisheries Office, thereby ensuring a more equitable distribution of program benefits.

The sustainability and scalability of the program are strongly reinforced by the Penta Helix collaborative framework (Calzada,

https://doi.org/10.35308/jpp.v12i1.11590

2020). Through this model, empowerment initiatives can access a broader range of resources, engage diverse expertise, and establish robust support systems by mobilizing multi-sectoral stakeholders, thus enhancing long-term program effectiveness (Calzada, 2020). The application of Penta Helix collaboration in empowering traditional fishermen households also strengthens community ownership and self-reliance by actively involving participants in decision-making processes and equipping them with the necessary skills and resources (Astuti et al., 2020). As a result, fishermen households gain greater agency over their economic trajectories, engage more effectively in market-oriented activities, and are better positioned to negotiate fairer prices for their products (Nur & Koliopoulos, 2022).

Performance of Empowerment Programs within the Penta Helix Model

The research team implemented the Penta Helix model as an intervention strategy through coastal waste management for traditional fishermen households, aiming to address structural poverty in coastal regions (Aisyah et al., 2021). Cross-sectoral collaboration within the Penta Helix framework facilitated a comprehensive intervention in the form of tailored training programs designed to meet the specific needs of the fishing community. The training program focused on three key components: (1) the utilization of coastal waste, (2) processing coastal waste into innovative products guided by zero-waste principles, and (3) the application of these innovative products as productive economic skills that can generate alternative sources of income for fishermen households (Aisyah et al., 2022).

This socio-economic empowerment-oriented training program was developed and implemented through a collaborative partnership between Universitas Sumatera Utara as the academic actor, PT Inalum as the industrial actor, and the local government serving as regulator and facilitator. The government, particularly through the Office of Cooperatives and MSMEs, played a critical role in facilitating the transformation of innovation-supported groups into emerging entrepreneurs by providing support in legal compliance, institutional development, and enhanced economic access. Additionally, the sustainability of the program was reinforced through CSR funding from industry partners and amplified via media dissemination (e.g., *koranmedan.com*), which functioned to extend the program's impact into the public sphere.

The effectiveness of the Penta Helix collaborative model in this study was assessed using parameters derived from multiple theoretical frameworks, namely: (1) the contribution of the five key actors, and (2) the benefits of innovation (Carayannis et al., 2019; Kholiavko et al., 2021; Durán-Romero et al., 2020; Taratori et al., 2021; Morawska-Jancelewicz et al., 2022; Uduji & Okolo-Obasi, 2020). These parameters focus on the programmatic processes, ranging from the initiation of innovations, the synergy of collaboration, to the outcomes of knowledge transfer programs, which are measurable through post-training improvements in community skills and the socio-economic impacts of waste-based innovative products, such as increased household income and reduced coastal waste.

1. Analysis of the Contributions of Penta Helix Actors

Within the Penta Helix collaboration, academia functions as a knowledge-based key actor responsible for designing, implementing, and overseeing the sustainability of empowerment programs for traditional fishermen households, particularly those centered on coastal waste management. Academic actors not only transfer knowledge and technology for processing waste into calcium-based products but also build social capacity and agency while bridging the interests of government, industry, community, and media to ensure that the collaboration remains focused on public-oriented and sustainable outcomes.

The government acts as both regulator and facilitator, providing policy legitimacy, creating participatory spaces, and strengthening community institutions through the establishment of local mobilization teams that serve as replication agents for the program. Industry, exemplified by PT INALUM, contributes as a resource provider and sustainability enhancer through CSR-based, shared-value initiatives, simultaneously opening avenues for market access and scaling the economic impact of community innovations.

The traditional fishing community itself undergoes a transformative process, shifting from passive beneficiaries to primary empowerment actors. Community members assume roles as producers, local innovators, social mobilizers, and custodians of program sustainability at the village level. Meanwhile, media serves as a strategic actor in information dissemination, innovation diffusion, public awareness enhancement, and the promotion of social legitimacy and program transparency.

Collectively, the synergy of these five actors demonstrates that the success of coastal waste-based empowerment programs is not determined by sectoral efforts alone but relies on multi-actor collaboration that is participatory, transformative, and sustainable. Each actor fulfills its designated role and function, contributing to the overall effectiveness of the program (see Table 2).

Table 2. Actor Role Analysis

Penta-helix Actors	Role in the Coastal Waste Governance
Regent	1. Giving approval for the implementation of traditional fishing family empowerment training activities. 2. The Regent has the authority to dispose of carrying out fishermen empowerment training activities
Head of the Cooperative Office	1. Providing assistance in the management of Business Identification Numbers (NIB) 2. Propose trainees to obtain a P-IRT licensing course from the Health Office. 3. Providing services in the form of Packaging Houses to make it easier for the trainees to design their product packaging.

Medan Deras Sub-district Village Government)	1. Providing direction to researchers to be able to coordinate with the Village Head and his equipment. 2. Issue a notification letter to the intended village to assist in the implementation of activities 3. Assigning KASI Government to coordinate with the Village in preparing training activities. 4. KASI Government monitors to ensure that the training activities run smoothly
Village Government (Head of Medang Village)	1. Giving permission in the implementation of empowerment activities initiated by USU Researchers. 2. Directing the Hamlet Head to assist the activities of USU researchers. 3. Providing Facilitation in the form of a room for Training activities. 4. Encouraging fishing families to participate in the Training. 5. Mobilizing the Family Welfare Empowerment (PKK) team to participate in training activities
Village Government (Head of Kuala Sipare and Pematang Eru Hamlets)	1. Introducing USU Researchers to fishing families to be used as respondents to conduct surveys 2. Gathering these respondents to be together with researchers in the implementation of the survey. 3. Together with the researcher, we conducted an FGD to the fishermen's families who are the heads of the fishermen's group in ensuring that a complete questionnaire is filled out. 4. Coordinating with the Village Head and his apparatus in preparation for the implementation of the training. 5. Preparing for training events
Head of the Cooperative Office	1. Coordinating with the industry in implementing empowerment programs and utilizing the potential of CSR to support fishermen. 2. Playing a role in providing assistance in the form of licensing and packaging to Innovation Fostered MSMEs that have been formed
USU Academic Team	1. Observation to traditional fishing families in Medang Deras District, Batubara Regency. 2. Initiating Pentahelix Focus Group Action (FGA). 3. Conducting surveys and data collection on coastal waste and village potential through interdisciplinary research. 4. Developing a training program on coastal waste reduction methods and the utilization of coastal waste into calcium innovation products. 5. Carry out knowledge transfer, education and training on innovative methods of turning coastal waste into calcium innovation products to coastal women. 6. Forming a driving team of coastal women based on calcium innovation under the guidance of USU. 7. Providing assistance to the driving team for the application of calcium innovation products to food and beverages and Publication of activities in online media and youtube.
PT. Inalum	1. Gaining knowledge transfer from USU researchers in the coastal waste utilization program into calcium-based innovation products. 2. Approve the activity plan for their CSR program to be carried out in their designated Village
Traditional Fishing Families	1. Willing to be involved in a training program known from the survey results. 2. Traditional fishing families are willing to take part in the training after being notified. 3. Fisher families receive knowledge transfer of coastal waste management and product innovation

https://doi.org/10.35308/jpp.v12i1.11590

	4.	After the training event, the traditional fishermen are willing to collect coastal waste to be processed into calcium-based innovative products (collecting clam shells, cleaning, squeezing and mashing them for frying, boiling, settling and filling into containers to be ready for drinking).
	5.	Traditional fishing families apply calcium water to various food and beverage products to meet the needs of their families.
Media	1.	Supporting the dissemination of information and education about waste management and fishermen's success stories.
	2.	Publication of Pentahelix 's collaboration program in waste management and improving the socio-economic status of coastal fishermen in Medang Village, Batubara Regency.

Source: Author, 2023

Based on the analysis of Penta Helix collaboration in this coastal waste management study, the government emerges as the most influential actor. Regional government authorities, including the regent, heads of cooperative offices, and village officials, provide the permits and regulatory frameworks that constitute the legal foundation for implementing empowerment programs targeting traditional fishermen households. Their role extends beyond administrative approval and guidance; they facilitate coordination with villages and ensure community participation. By issuing local policies and formal notifications, regional governments guarantee that programs operate smoothly and comply with existing regulations. This support provides the legitimacy and stability essential for mobilizing all stakeholders within the collaborative framework.

The government functions as the primary decision-making actor, holding the authority to approve proposals and allocate resources both critical elements for successful program implementation. Decisions made by the government can determine the success or failure of collaborative initiatives. Moreover, the government legitimizes initiatives proposed by other actors, such as academia and industry. According to Bäckstrand (2019), governmental support is crucial for fostering synergy among diverse stakeholders, as it has the capacity to shape public policies that reinforce collaboration. The government's influence is also evident in its facilitative role, coordinating various actors in the collaboration process, particularly across different governmental departments. This aligns with Ansell and Gash's (2008) view that governments must actively create spaces for effective collaboration.

The Most Proactive Penta Helix Actor

The coastal waste management program was initiated by academics from Universitas Sumatera Utara (USU). In this action research study, USU academics play an active role as innovators, not only proposing the governance innovation but also conducting research to support the program. They serve as the primary driving force of the collaboration, initiating the program by submitting proposals, conducting surveys, and implementing research and training activities for coastal communities.

Furthermore, USU academics lead cross-sector coordination through Focus Group Action (FGA), connecting government, industry, community, and media actors. They also facilitate knowledge transfer to fishermen households, particularly in transforming coastal waste into economically valuable calcium-based products. Academics are not limited to research functions; they ensure direct community engagement and empowerment. Through knowledge transfer and training, they enhance local capacity for waste management, demonstrate a commitment to community empowerment, and secure the sustainability of the program. By fostering strong synergy between actors, including government and private sector partners, USU academics exemplify the critical role of intensive collaboration and co-development of ideas, as emphasized by Keast and Mandell (2014). Consequently, USU academics exhibit a high degree of proactivity, significantly contributing to social innovation and the success of collaborative coastal waste governance.

2. Benefits of Innovation

The findings of this study indicate that the management of coastal waste, transformed into calcium-based innovative products, has produced a significant shift in the perceptions and capacities of traditional fishermen households. They no longer regard waste as an environmental burden, but rather as an economic resource with added value. Fishermen families acquire technical knowledge and skills to process shellfish waste into calcium-based products, which are subsequently utilized as calcium-enriched water for household consumption.

The diverse range of innovative products produced serves as a tangible indicator of the program's effectiveness. These innovations create new economic opportunities, particularly for coastal women, who previously lacked access to waste-processing industrial activities. Consequently, the benefits of these innovations are not merely technological but also directly contribute to strengthening the household economy of fishermen families.

From an environmental perspective, the program provides ecological advantages by reducing the volume of coastal waste and improving environmental quality, even though quantitative measurements have yet to be conducted. Conceptually, these findings reinforce the notion that waste-based innovation within the Penta Helix framework simultaneously integrates social, economic, and environmental dimensions, which are central characteristics of sustainable development.

Figure 6. Empowerment Program Achievement
Source: Koran. Medan.com, 2024

As illustrated in Figure 6, after acquiring skills through knowledge transfer from academics on coastal waste management, traditional fishermen households are not only able to convert waste into calcium-based products but also apply them to meet various household needs, including food and beverages. Through these skills, previously unutilized coastal waste is transformed into economically valuable products. Beyond contributing positively to the environment through waste reduction, traditional fishermen families gain the opportunity to create new products, which can serve both domestic consumption and generate new economic prospects. These innovations enable them to develop enterprises, increase income, and enhance the economic resilience of traditional fishermen households.

Analytically, Figure 6 demonstrates the success of the Penta Helix approach in empowering traditional fishermen households. The products displayed on the left side reflect the effective transfer of knowledge and technology from academics to the community, extending beyond training to the production of innovative, ready-to-consume, and potentially marketable products. Meanwhile, the documentation on the right side illustrates the synergy among actors industry (PT INALUM) through CSR, academics as designers and mentors, government as facilitator, community as primary actors, and media as a tool for public legitimacy reinforcement.

Furthermore, the figure depicts the socio-economic transformation of coastal women from passive beneficiaries to producers and local innovators. The impacts are multi-dimensional: economic, through new business opportunities; ecological, via reduced coastal waste; and social, through enhanced self-confidence and public recognition. Therefore, this figure serves as a visual testament that calcium-based coastal waste management can function as a transformative, sustainable, and replicable empowerment instrument for other coastal regions.

CONCLUSION

This study represents an intervention in community empowerment programs employing a Penta-Helix approach, which mobilizes five key actors to collaborate in the implementation of empowerment initiatives for traditional fishermen's families. The program was operationalized through a series of outreach and training activities conducted by the research team from Universitas Sumatera Utara (USU) for coastal communities, particularly fishermen's households, focusing on the governance of coastal waste into innovative, calcium-based products.

The Penta-Helix model applied in this study involves five principal actors: (1) the Batubara Regency Government, which actively facilitates and supports the implementation of empowerment programs; (2) academics from Universitas Sumatera Utara, who are responsible for program design, development of coastal waste management innovations, and the execution of knowledge transfer and technical mentoring; (3) the industrial sector, represented by PT INALUM, which provides financial support through corporate social responsibility initiatives to strengthen the socio-economic empowerment of fishermen's families; (4) traditional fishermen's families, who serve as the primary subjects of empowerment by acquiring knowledge and skills in processing coastal waste for household nutritional and health needs; and (5) the media, which disseminates information to the broader public on the importance of cross-actor collaboration in achieving sustainable socio-economic empowerment outcomes.

Substantively, this study is expected to facilitate the sustainable socio-economic empowerment of traditional fishermen's families. Consequently, further research is warranted to assess the program's performance more comprehensively, particularly regarding business sustainability and long-term economic impacts. Subsequent studies are also anticipated to promote the formation of additional coastal waste management action groups in other villages and to support the continued development of innovation-driven MSMEs (micro, small, and medium enterprises) in these communities.

This research has several limitations that must be considered when interpreting the findings. First, the study's geographic scope was confined to four coastal villages in Kecamatan Medang Deras, meaning the results may not fully represent the social, economic, and ecological conditions of coastal communities in other areas with different characteristics. Second, the economic impacts of the empowerment program were measured descriptively, based primarily on changes in skills, participation, and emerging business opportunities, without long-term quantitative data on income growth, business sustainability, or household economic stability. Third, environmental impacts, such as reductions in waste volume and improvements in coastal environmental quality, were assessed qualitatively through observation and community perceptions, rather than standardized ecological measurements. Fourth, the use of action research and participatory methods introduces potential subjectivity, as outcomes are highly dependent on social dynamics, researcher involvement in the field, and specific local contexts. Therefore, generalizations from this study should be made cautiously.

ACKNOWLEDGMENTS

This study was funded by Universitas Sumatera Utara through Grant No: 55/UN5.2.3.1/PPM/KP-TALENTA/R/2023. The authors would like to express their sincere gratitude to all supporting parties for their invaluable contributions and assistance throughout the course of this research

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