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Assessing the social return on investment of an algae-salt mariculture polygeneration system in coastal communities

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Abstract. Coastal communities are highly vulnerable to climate change yet play a critical role in mitigating global warming. However, many experience poverty due to limited income and inadequate access to clean water and energy. Although various assessment frameworks exist, studies on the social return on investment (SROI) for polygeneration systems in coastal communities remain scarce. Therefore, this study proposed a novel algae-salt mariculture polygeneration system to address these challenges, incorporating the SROI approach to evaluate its social value, with a coastal community in Pamekasan Regency, Madura Island, serving as a case study. The system integrates solar salt production and seaweed farming with solar energy–derived potable water production and pyrolysis technology within the saltworks area. The SROI methodology involves identifying key stakeholders, mapping outcomes, evidencing and valuing those outcomes, and establishing impact by accounting for deadweight, attribution, displacement, and drop-off, from which the SROI ratio is ultimately derived. This system produces solar salt, seaweed, clean water, and energy, benefiting local farmers. Excess electrical energy is supplied to the coastal community once the system's energy needs are met, while the pyrolysis process produces bio-oil, biogas, and biochar as fuels. Furthermore, the system reduces CO_2 emissions by 1,000 kg per year through seaweed absorption and renewable energy utilization. Financial proxy values were assigned to these outcomes, resulting in an SROI ratio of 10.28:1, indicating that every $1 invested in this system generates $10.28 of social value. Ultimately, this proposed system will shed light on how stakeholders can enhance the well-being of coastal communities, improve the saltworks model, and contribute to climate change mitigation while also enabling the implementation of an energy-self-sufficient village.

1. Introduction

The world is currently dealing with climate change, which is mostly caused by human activities like deforestation and the burning of fossil fuels [1]. Ecosystems and communities have been disturbed as a result of these activities, with coastal regions being especially at risk. These areas have been severely impacted by rising sea levels, more frequent extreme weather events, and the deterioration of marine ecosystems, which has eroded coastal lands, flooded homes, and damaged infrastructure [2]. Furthermore, the destruction is made worse by the increasing severity of cyclones and flooding, which has a negative impact on the livelihoods and standard of living of coastal communities. Coastal regions have a lot of promise for global mitigation initiatives, despite these obstacles. Mangroves and other coastal ecosystems act as significant carbon sinks, lowering the levels of carbon dioxide in the atmosphere [3]. These mitigation efforts can also be aided by the integration of polygeneration systems, which produce multiple outputs like energy, water, and agricultural products, and the adoption of renewable energy. In order to improve local resilience and further larger climate change mitigation objectives, this study focuses on creating and deploying a polygeneration system powered by renewable energy within saltworks in coastal communities.

A polygeneration system is a process that efficiently generates multiple outputs from a single integrated unit, using either standalone or multiple inputs, making it suitable for remote areas [4]. There is recent published literature on developing polygeneration systems suitable for remote areas. Manesh et al. [5] proposed an innovative solar biomass polygeneration system that can meet the water and power demands to support tomato farming, alongside an innovative waste treatment process. The overall energy efficiency was greater than 31%, the total environmental impact rate was approximately 6 points per hour, and the system's ecological sustainability index was estimated at 9.45. A multiple-output renewable energy system, designed to support rural and remote communities, has also been reported [6]. This system can be implemented in either on-grid or off-grid configurations. In the context of the study, the cattle-farming village benefits the most from the proposed system. The community can convert biomass waste from the cattle farm into electricity to meet its energy demands, reducing CO_2 emissions by up to 67% compared to conventional fossil fuel energy supplies. Furthermore, a polygeneration system based on renewable heat sources to support rural communities has also been reported [7]. Interestingly, the proposed system generates not only power and heating but also cooling and desalinated water. The cooling configuration can produce ice for fish preservation, while the desalinated water can supply potable water. Moreover, a study on enhancing saltworks performance, powered by renewable energy to meet the energy needs of coastal communities, has also been conducted [8]. The study demonstrated that the performance and quality of crude solar salt production can be enhanced by employing several technologies that accelerate the salinity of brine water in a shorter time, with renewable energy playing a crucial role in the system. As a result, improving the quality of the salt can reduce processing costs and enhance the durability of equipment in the processing segment [9].

Although literature suggests that renewable energy-based polygeneration systems are feasible for remote areas, particularly coastal regions, and can enhance community wealth, numerous challenges remain. Coastal communities often depend on a single natural resource, such as crude solar salt production in saltworks [10], which is increasingly threatened by climate change. This dependency may exacerbate their vulnerability to poverty and socioeconomic instability. Therefore, increasing output and diversifying products through the implementation of a polygeneration system is recommended [11]. Poverty and their reliance on rudimentary solar salt farming, which is becoming more and more threatened by climate change, are major issues for coastal communities in the case study area. Furthermore, adaptation and vulnerability reduction are hampered by limited access to technology. These communities continue to be caught in a vicious cycle of instability and poverty in the absence of sufficient assistance. Therefore, better technological assistance is necessary to boost resilience, lower poverty, and raise income [12]. The technical and financial feasibility of renewable energy-based solutions in remote locations has been the subject of some studies. For example, Suryawan et al. [13] and Rahman et al. [14] highlight the benefits of renewable energy systems in tourism and local economies. In response to the growing demand for diversified products and technological support, this study proposes integrating seaweed, biofuels, and potable water production within saltworks. Moreover, this concept boosts crude solar salt production by utilizing brine rejection from the desalination system. Furthermore, a comprehensive impact evaluation should be conducted using a Social Return on Investment (SROI) analysis for coastal communities. SROI is a powerful economic tool that offers a structured approach to evaluate the complete range of value, encompassing social, environmental, and economic advantages, including those derived from social and agricultural initiatives [15]. It involves active participation with key stakeholders to evaluate and measure the value generated by the project. Using financial proxies, SROI assigns a monetary value to the outcomes experienced by stakeholders, producing a ratio. For example, a ratio of 2:1 indicates that for every $1 invested, $2 worth of social value is created.

SROI was chosen because of its comprehensive ability to capture a wider range of social, environmental, and economic outcomes that are frequently missed by traditional methods, even though cost-benefit analysis (CBA) and life cycle assessment (LCA) are frequently used to evaluate the economic and environmental impacts of projects. SROI, on the other hand, is best suited for projects that yield substantial social and environmental benefits since it takes into account non-market values and prioritizes stakeholder engagement [16]. The value of renewable energy technologies in coastal communities can be measured using SROI methods, which combine economic valuation and narratives of change to highlight their impact. This study is the first to use SROI in evaluating a polygeneration system within saltworks. By doing this, it improves knowledge of SROI in relation to environmentally friendly, renewable technologies and provides useful advice for practitioners and legislators wishing to evaluate the results of technology-driven projects, particularly in rural or coastal areas.

2. Material and method

2.1 System Description

The proposed Algaesalt Mariculture Polygeneration System demonstrates the integration of a solar energy-based polygeneration system with a pyrolysis process. This system integrates the production of crude solar salt, seaweed, potable water, and biofuels, such as bio-oil, biogas, and biochar, through pyrolysis within saltworks. The system is designed for coastal communities globally, where saltworks serve as the primary infrastructure. A case study will be conducted in Pamekasan Regency, Madura Island, Indonesia, at the following GPS coordinates: 7° 10' 1.6356" S, 113° 34' 1.2756" E.

The main component of this system, the saltworks, is made to generate crude solar salt. The feedwater reservoir pond, evaporation pond, and crystallization pond are typically the main parts of saltworks. With an estimated production rate of 300 tons of crude solar salt per hectare, the suggested system is installed on a 5-hectare saltworks in this case study. The main purpose of the feedwater reservoir pond, which is typically the largest, is to store feedwater. However, the reservoir pond in this suggested system also serves as a seaweed (Gracilaria sp.) cultivation pond. Seaweed is grown in the feedwater reservoir, which is about 2 hectares in size and makes up 40% of the saltworks' overall area. Harvesting takes place after 45 days of cultivation, and the seaweed produces about 2 tons per hectare. Before being moved to the solar dryer, the harvested seaweed is dried for a day at the pond's edge in a tray dryer.

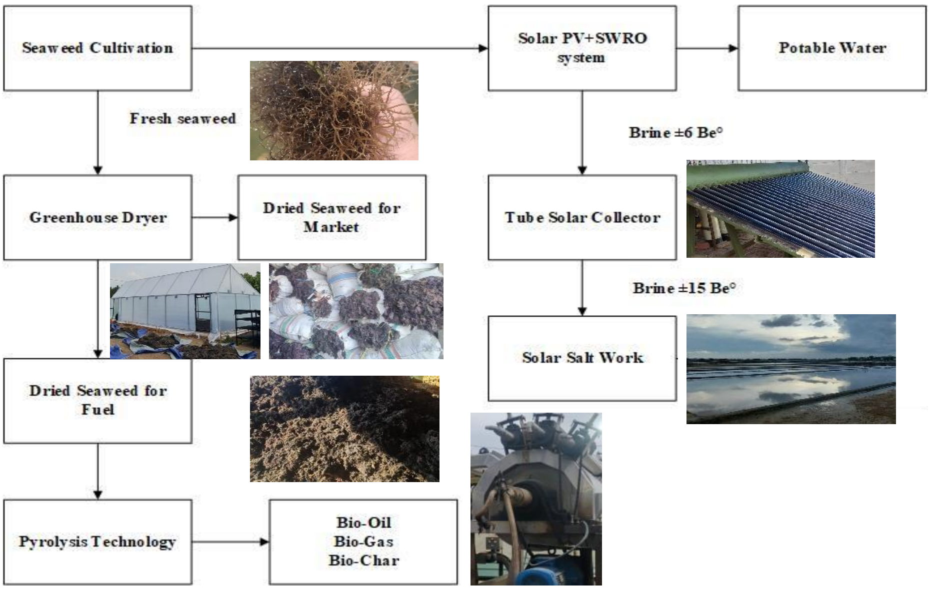

Figure 1 Schematic illustration of proposed algaesalt mariculture polygeneration system

In this study, the solar dryer, adapted from Amir et al. [17], is enlarged to cover an area of 18 m^2 and is estimated to dry 300 kg of wet seaweed per day. The dried seaweed is then used as a precursor for biofuel production via the pyrolysis system. Preliminary studies using a one-step chemical pyrolysis production system revealed that dried seaweed of Gracilaria sp., when used as the precursor, yields approximately 39.6% biogas, 15.9% bio-oil, and 44.5% biochar. There are many benefits to integrating seaweed into the saltworks, including giving salt farmers more revenue because they can produce both seaweed and crude salt. Furthermore, growing seaweed improves the quality of the reservoir pond's feedwater, which is subsequently utilized as feedwater for desalination to create drinkable water. By lowering pre-treatment expenses and extending the filtration system's lifespan, the better water quality also helps the desalination system. A 1000 GPD reverse osmosis system with 60% brine rejection and solar PV panel power is used to produce potable water. Transferring the rejection brine, which has a salinity of up to 60 Baume, to the tube solar collector system causes the water to evaporate, raising the brine's salinity to 150 Baume. In the end, this brine is sent to the crystallization pond to help produce crude solar salt.

2.2 Methodology

2.2.1 Technical Aspect

As shown in Table 1, the suggested algae-salt mariculture polygeneration system combines aquaculture, seaweed farming, salt production, potable water production, and renewable energy to improve the resilience and sustainability of coastal communities. The five-hectare system yields 1,500 tons of salt annually in addition to 32 tons of seaweed grown on two hectares. Solar PV panels, which produce 3,072 kWh yearly, power the system. In addition to helping to generate roughly 7,120 kg of biochar, 2,120 liters of bio-oil, and 5,904 kg of biogas, this energy supports the desalination process, which produces 1,000 GPD of clean water. This multi-output system has been demonstrated to reduce CO_2 emissions by 6,948 kg on an annual basis while concurrently providing critical resources such as clean water and food. These benefits are not only environmental but also economic and social, offering cost advantages and enhancing community resilience. The total investment required for the implementation of this system amounts to 44,117 USD, which encompasses the capital necessary for the integration of these sustainable technologies.

Table 1 An overview of the predicted production output of the proposed system

No	Parameter	Unit	Value
1.	Seaweed Production (2 Ha)	Ton/year	32
2	Salt Production (5 Ha)	Ton/year	1500
3.	Solar PV electricity Production	kWh/year	3,072
4.	Potable Water Production	GPD	1,000
5	Fuel production		
	Biochar	Kg	~ 7,120
	Bio-oil	Liter	~ 2,120
	Biogas	Kg	~ 5,904
6	CO_2 Reduction	Kg/year	6,948
7.	Total Investment	USD	44,117

2.2.2 Identifying key stakeholders

Stakeholder analysis was the first step in gathering data for this study in order to identify individuals or groups that were either directly or indirectly impacted by or involved with food rescue organizations' operations. Desk-based research was used to identify stakeholders, and a survey was primarily used to gather feedback from these stakeholders in order to support the financial proxies and assumptions used in the SROI analysis. The purpose of the survey was to gather qualitative and quantitative information about how food rescue efforts affected the local populace, including perceived benefits, challenges, and changes in socioeconomic circumstances. A stakeholder map outlining the relevant stakeholder groupings was produced as a result of this process. To fully understand the system's impact, it is crucial to identify all parties impacted, both directly and indirectly, in the context of SROI analysis. As a result, the following categories apply to the stakeholders in this case study. The project is located in East Java, Indonesia's Lembung Village, Galis District, Pamekasan Regency.

a. Local Farmers:

   The project directly benefits local farmers, especially those engaged in salt production via solar salt farming methods. These farmers are integral to the operating chain, and their livelihoods are intricately connected to the project's success and efficiency. By producing and selling salt, farmers generate revenue and support the regional economy. Additionally, their involvement encourages farming methods that could benefit from sustainable farming practices, like using pyrolysis-generated biochar. The initiative's creation of economic opportunities has an immediate impact on local farmers, who may also be able to access resources like energy or water.

b. Coastal Community:

The coastal population constitutes the indirect beneficiaries of the project, acquiring access to clean drinking water and excess electricity. These resources are essential for enhancing quality of life, particularly in areas where access to potable water and dependable energy sources is constrained. Better water quality benefits the neighborhood's health, and having access to cheap or extra electricity boosts its economic opportunities. By encouraging environmental sustainability, the project helps the coastal community become more resilient to the effects of climate change, such as rising sea levels and water scarcity. Additionally, the project may reduce energy poverty in coastal areas by making renewable energy more accessible, which would benefit businesses and households.

2.2.3 Mapping outcomes

In this stage, the key outcomes of the system are identified and mapped to understand the relationships between inputs, outputs, and long-term impacts.

a. Inputs:
The costs of solar panels, pyrolysis units, desalination plants, and seaweed farming infrastructure are all included in the system's total investment. During the evaluation period, this variable is typically assessed in connection with capital expenditures and operating costs.

b. Outputs:

1. Crude Solar Salt: Amount of salt produced annually.
Through the sale of salt, the dependable production of salt through solar salt farming offers real economic benefits to nearby communities. Through the production and distribution of salt, this business generates jobs for the local population.

2. Seaweed: Kilograms of seaweed produced.
Because seaweed is used in a variety of industries, such as food, cosmetics, and pharmaceuticals, its cultivation has a significant economic impact. Through carbon dioxide absorption and habitat rehabilitation, this project helps restore marine ecosystems while also increasing seaweed production and creating new economic opportunities for fishermen and seaweed growers.

3. Clean Water: Liters of potable water generated.
Public health and general quality of life are directly impacted by the availability of clean water. Providing access to drinkable water improves hygiene standards and reduces the risk of waterborne infections. Additionally, having access to clean water boosts economic productivity by allowing communities to focus on work and productive activities without worrying about water scarcity.

4. Biomass Products: Bio-oil, biogas, and biochar produced via pyrolysis.
The biomass products produced via pyrolysis provide sustainable substitutes for fossil fuel-derived energy. The generated bio-oil and biogas can fulfill local energy requirements, whereas the biochar can enhance soil quality and promote

sustainable agriculture. These goods collectively reduce carbon emissions and aid in climate change mitigation efforts.

5. Excess Energy: kWh of surplus energy distributed to the community.
   By lowering energy costs for households and nearby businesses, distributing excess energy to the community has long-term positive economic effects. Additionally, distributing excess energy promotes the development of a more independent and sustainable energy infrastructure and lessens reliance on imported energy sources. By enabling better access to essential energy resources for daily tasks, this improves quality of life.

c. Outcomes:
   1. Social Outcomes: Better access to clean water, more revenue from diversified farming, improved food security, and better livelihoods for regional farmers.
   2. Economic Outcomes: Higher revenue from more products and more local jobs.
   3. Environmental Outcomes: Seaweed farming improves water quality and lowers CO_2 emissions through the use of renewable energy.

d. Impacts:
   The system has shown a number of long-term benefits, such as decreased poverty, increased community climate change resilience, and better health of coastal ecosystems.

2.2.4 Evidencing and valuing outcomes
An integral part of the SROI methodology is the process of proving and evaluating results. It guarantees that the changes that have taken place can be clearly quantified and that the measured outcomes appropriately reflect those changes. Therefore, by giving the results a monetary value, this stage helps us to understand and communicate the true impact of the intervention in a meaningful and useful way. Table 2 presents the financial proxies and computed values for demonstrating and assessing outcomes.

Table 2 Financial proxies and calculated values for primary outcomes

Outcome Category	Outcome	Projected Value	Financial Proxy
Social outcomes	Access to clean water	\$22,075.2/year	Cost of bottled water (USD 0.016 per liter) ,
	Health benefits	Estimated savings of \$5,000/year	Savings in healthcare costs (waterborne diseases)
Economic outcomes	Income from seaweed farming	\$16,000 / 2 hectares / year	The market price of seaweed (USD 0.5 per kg)
	Salt Farming	\$150,000 / 5 hectares	Market Price of 0.1 USD/kg
	Biofuels	\$3,000/year	-
	Energy savings	\$368.64/year	Cost of traditional energy (USD 0.12 per kWh)
Environmental outcomes	CO_2 emissions reduction	\$512/year	Carbon credit market price (USD 75 per ton of CO_2)

2.2.5 Establishing impact
The final stage prior to computing the SROI is to ascertain the extent of the consequence that would have transpired in the absence of the project, considering other influencing circumstances. The elements referred to as "impact filters" include drop-off, attribution, displacement, and

deadweight. The goal is to identify the portion of the result that can be directly attributed to the initiative. Deadweight evaluates the extent to which a result would have occurred on its own, while displacement shows whether the result would have outweighed a different advantage in a different situation. Drop-off measures the decline in impact over time, whereas attribution describes the role of additional contributors. These filters necessitate knowledgeable percentage estimations, generally derived from pertinent literature. Each percentage is applied to the value of the outcome to account for external factors, and the modified values are combined to ascertain the total net effect. These filters function as a verification mechanism, guaranteeing that the SROI ratio precisely reflects the true value of the social investment.

2.2.6 Calculating the SROI

The calculation of the SROI represents the culminating stage in the SROI analysis process. The process entails the estimation of the collective social value yielded by a project or intervention as compared to the capital outlay. The SROI ratio is a metric that calculates the monetary value of the social, environmental, and economic impact achieved in relation to the resources invested in a given project [18], as written in Equation 1.

$$SROI\ Ratio = \frac{\substack{Present\ Value \\ (Total\ Financial\ Value\ of\ Outcome)}}{Value\ of\ Inputs} \tag{1}$$

3. Results

3.1 Calculating the Impact

In conducting the assessment, the researcher adhered to the precautionary principle by multiplying the outcome quantities with their respective financial proxy values and subtracting the deadweight percentage for each outcome. The determination of the overall impact was achieved by the summation of all the individual results (see Table 3).

Table 3 Impact value calculated for primary outcomes

Outcome	Value	Deadweight (%)	Attribution (%)	Drop-off	Impact
Access to Clean Water	22,075	15%	10%	5%	16,043
Health Benefits	5,000	20%	20%	10%	2,880
Income from Seaweed Farming	16,000	5%	25%	15%	9,690
Salt Farming	150,000	10%	5%	10%	115,425
Biofuels	3,000	10%	10%	5%	2,066
Energy Savings	369	5%	30%	20%	221
CO_2 Emissions Reduction	512	10%	40%	30%	263
Total Impact (USD)					146,587

3.2 Calculating the SROI

As shown in Table 4, the project evaluation's financial impact was assessed using the SROI method, yielding a total Net Present Value (NPV) of USD 453,726.17. The total initial investment was USD 44,117. The present value of annual cash flows was calculated over a five-year period using a 14% discount rate; it dropped from USD 128,078.97 in the first year to USD 74,645.83 in the fifth year. The Weighted Average Cost of Capital (WACC), which accounts for both the cost of debt and the cost of equity, was used to determine the 14% discount rate. The Capital Asset Pricing Model (CAPM), which takes into account the company's beta, the risk-free rate, and the market risk premium, was used to calculate the cost of equity. The market risk premium was 6.87%, while the risk-free rate, which was calculated using the yield on five-year government bonds (10 February 2025), was 6.69%. The business had a beta of 1.13, which represents its comparative market risk. The discount rate was changed to 14% to reflect the company's capital structure, even though the WACC was calculated at 14.45%, assuming no debt costs. The social value generated per unit of investment, or the SROI ratio, was found to be 10.28. This shows that USD 10.28 in social value was produced for every dollar invested. The outcomes demonstrate how effective the recommended approach is at generating social value. This study produced a higher SROI value, roughly three points greater than other SROI programs [19]. The elevated value is ascribed to the pivotal function of the polygeneration system, which markedly improves results. Consequently, by employing single or dual inputs to produce numerous outputs, the system enhances its advantages, significantly elevating the overall value represented in the SROI calculation. These results highlight the capability of polygeneration systems to enhance both technical and economic performance while also providing increased social benefits in coastal community initiatives.

Table 4 Impact Projection

Projection	Year					
	Initial	**one**	**two**	**three**	**four**	**five**
Initial Investment	-44,117					
		146,587.15	146,587.15	146,587.15	146,587.15	146,587.15
Total	-44,117	146,587.15	146,587.15	146,587.15	146,587.15	146,587.15
Discount Rate (%)	14%					
Present value (USD)	-44,117	128,078.9	111,907.65	97,778.12	85,432.60	74,645.83
NPV (USD)	453,726.17					

$$\boldsymbol{SROI\ ratio} = \frac{\mathbf{453,726.17}}{\mathbf{44,117}} = \mathbf{10.28}$$

4. Discussion

The purpose of this study was to evaluate the Social Return on Investment (SROI) of a polygeneration system that combines the production of salt, seaweed, renewable energy, and potable water in coastal communities. Each dollar invested in this integrated system yields more than ten times its value in social, environmental, and economic benefits, according to the findings, which showed a significant SROI ratio of 10.28. The polygeneration system's intricate features, which meet the vital needs for water and electricity while also producing additional revenue from the production of biomass and seaweed, are the cause of the high ratio. According to the study's findings, the proposed system can help coastal communities with a number of issues, particularly those related to revenue diversification, poverty reduction, and climate resilience. The primary beneficiaries, local farmers, benefit from increased revenue from the production of seaweed and salt. Additionally, the surplus energy produced can be distributed to the larger coastal community, ensuring access to drinkable water and promoting energy independence. These findings align with other research indicating the capacity of renewable energy sources to bolster community resilience [9] [5].

Moreover, the incorporation of seaweed cultivation into the saltworks system enhances water quality by lowering the pre-treatment expenses for desalination, so benefiting the local water production process. This synergistic association between seaweed cultivation and water treatment has been observed in previous studies concentrating on coastal aquaculture and resource recovery systems [7]. This integrated system provides a comprehensive solution to the difficulties confronting coastal towns, addressing both water scarcity and economic vulnerability through the utilization of environmental and economic advantages.

The system's capacity to diminish CO_2 emissions by roughly 7,000 kg per year is substantial in terms of environmental impact. The incorporation of renewable energy in such systems is extensively documented. The supplementary usefulness of seaweed as a carbon sink provides an extra dimension of environmental advantage that has not been thoroughly investigated in prior research. The decrease in CO_2 emissions via seaweed absorption and renewable energy use corresponds with the global focus on sustainable strategies for addressing climate change.

However, other factors may affect the enduring viability and scalability of the suggested system. The study's results are promising; nonetheless, the system's economic feasibility is significantly dependent on local context, encompassing resource availability, infrastructure, and community involvement. The substantial initial investment needed, along with the necessity for ongoing monitoring and adjustment, may present obstacles to scaling in resource-constrained regions. Subsequent study ought to concentrate on enhancing financial models to integrate region-specific characteristics and evaluate the system's sustainability across diverse coastal environments.

This paper emphasizes the social and environmental benefits but fails to thoroughly examine the possible societal challenges associated with adopting such a system. Community engagement, education, and training will be essential for guaranteeing the system's success. The engagement of local stakeholders in the implementation phase will be crucial in assessing the system's performance and its capacity to produce enduring social value.

5. Policy implication and future study

The favorable outcomes from the SROI analysis of the algae salt mariculture polygeneration system underscore the substantial benefits of incorporating renewable energy and sustainable practices in coastal communities, especially in saltworks. Policymakers ought to promote the use of these technologies to bolster salt production while improving food, water, and energy security in coastal areas. This method not only creates economic opportunities but also aids in climate change mitigation. Investments in this sustainable model bolster the establishment of energy self-sufficient villages, an effort advocated by Pertamina, Indonesia's state-owned oil enterprise. Nonetheless, additional research is imperative to enhance the conclusions of this study. Subsequent research should concentrate on the enduring effects of these systems on local economies and ecosystems, especially with enhancements in efficiency and scalability across various coastal areas. Furthermore, examining community involvement and financial sustainability will be essential for evaluating long-term feasibility and widespread adoption. The quality of system outputs, including solar salt, seaweed, and biofuels, necessitates more scrutiny. Seaweed possesses significant promise as a pyrolysis precursor for high-value products, and future study should focus on species selection, pyrolysis technology, and operational parameters.

The successful replication of this strategy in other countries will hinge on addressing various issues, especially related to scalability, funding, and community preparedness. Scalability presents a considerable difficulty, as the system's infrastructure may necessitate extensive modification to accommodate the varied climatic and economic conditions of different coastal regions. In areas with inadequate infrastructure or resources, financing may provide a significant obstacle to extensive implementation, as the initial capital necessary for renewable energy infrastructure and sophisticated production facilities can be considerable. Furthermore, the community's preparedness to embrace new technology, particularly in isolated coastal areas, requires extensive capacity-building initiatives, encompassing training, education, and local involvement to guarantee the sustainable operation and maintenance of the system.

6. Conclusion

This study highlights the significant social, economic, and environmental benefits of incorporating a polygeneration system into coastal communities, specifically via the algae-salt mariculture system. The analysis of the SROI approach revealed that these systems can produce a significant social return, with each dollar invested yielding nearly tenfold its value in social benefits. The amalgamation of renewable energy, seaweed cultivation, salt manufacturing, and potable water generation constitutes a comprehensive strategy that tackles essential issues such as poverty, water and energy security, and climate change mitigation. These findings highlight the potential for scalable solutions that might improve community resilience, promote sustainable development, and create economic possibilities. Future research should focus on enhancing these systems, investigating their long-term effects, and evaluating their scalability to other places, especially those that are susceptible and located in coastal zones.

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Declaration of Competing Interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement
The data that support the findings of this study are available from the corresponding author, [NA], upon reasonable request.

CRediT authorship contribution statement
Fiki Milatul Wahyu: Writing—original draft, investigation, methodology, data collection, and data analysis. Nizar Amir: Conceptualization, supervision, and writing—review & editing. Abdul Kadir: investigation, data collection, and data analysis. Yulius S. Bulo: supervision and writing—review & editing. Ermawan Fitra: supervision and writing—review & editing. Mohamed Kheireddine Aroua: supervision and writing—review & editing.

References

[1] Amir N, Hussin F, Aroua M K and Gozan M 2025 Exploring seaweed as a sustainable solution for carbon dioxide adsorption: trends, opportunities, and future research prospects Renew Sustain Energy Rev **213** 115458
[2] Roy P, Pal S C, Chakrabortty R, Chowdhuri I, Saha A and Shit M 2023 Effects of climate change and sea-level rise on coastal habitat: vulnerability assessment, adaptation strategies and policy recommendations J Environ Manage **330** 117187
[3] Zhang T, Liu H, Lu Y, Wang Q, Loh Y C and Li Z 2024 Impact of climate change on coastal ecosystem and outdoor activities: a comparative analysis among four largest coastline covering countries Environ Res **250** 118405
[4] Jana K and De S 2015 Polygeneration using agricultural waste: thermodynamic and economic feasibility study Renew Energy **74** 648–660
[5] Khoshgoftar Manesh M H, Davadgaran S and Mousavi Rabeti S A 2024 Novel solar-biomass polygeneration system based on integration of ICE-ORC-MDC-HDH-RO and tomato greenhouse to produce power, freshwater, and biological wastewater treatment Energy Convers Manag **308** 118349
[6] Umam F, Wahyu F M, Efendi M Y, Amir N, Gozan M and Asmara Y P 2024 Techno-economic and environmental analysis of an on-grid and off-grid renewable energy hybrid system in an energy-rich rural area: a case in Indonesia J Robotic Control **5** 1365–1378
[7] Praveen Kumar G, Ayou D S, Narendran C, Saravanan R, Maiya M P and Coronas A 2023 Renewable heat powered polygeneration system based on an advanced absorption cycle for rural communities Energy **262** 125300
[8] Efendy M, Wahyu F M, Amir N and Gozan M 2024 Feasibility analysis of a novel high-production saltworks powered by renewable energy: an Indonesian case study Strategic Plan Energy Environ 847–880
[9] Amir N, Efendy M, Hidayat R and Gozan M 2021 Analysis and comparison of different dewatering methods on salt quality E3S Web Conf **328** 05007
[10] Amir N, Efendy M, Rini D A S and Gozan M 2023 Effect of washing operating parameters on the quality of dried salt in salt washing plant J Biosyst Eng **48** 1–12
[11] Bartolucci L et al 2023 Biomass polygeneration system for the thermal conversion of softwood waste into hydrogen and drop-in biofuels Energies **16** 1286
[12] Pilag Kakeu C B, Miamo Wendji C, Kouhomou C Z and Mapa Kamdoum G C 2024 Can technological innovations contribute to more overcome the issue of poverty reduction in Africa? Technol Soc **76** 102463
[13] Suryawan I W K, Rahman A, Suhardono S, Sutrisno A D, Nguyen V V and Lee C-H 2025 Evaluating tourist preferences influences on renewable energy initiatives in coastal tourism settings Reg Stud Mar Sci **85** 104148
[14] Suryawan I W K, Rahman A, Suhardono S and Lee C-H 2025 Visitor willingness to pay for decarbonizing tourism: supporting a net-zero transition in Nusa Penida, Indonesia Energy Sustain Dev **85** 101628
[15] Martin W, Pham A, Wagner L and Werner A 2022 Social value of a Canadian urban food bank garden J Agric Food Syst Community Dev 1–26
[16] Lee S-T and Jung S-M 2025 Social return on investment as a tool for environmental impact and strategic assessments: evidence from South Korea Environ Impact Assess Rev **112** 107765

[17] Amir N, Mustajib M I, Gozan M and Chan C 2024 Development of a novel tray solar dryer for aquaculture product: experimental study on drying kinetics and product quality in Eucheuma cottonii seaweed Solar Energy **273** 112503
[18] Moral Torres E et al 2020 Social value of a set of proposals for the ideal approach of multiple sclerosis within the Spanish national health system: a social return on investment study BMC Health Serv Res **20** 84
[19] McGrath R and Stevens K 2019 Forecasting the social return on investment associated with children's participation in circus-arts training on their mental health and well-being Int J Sociol Leisure **2** 163–193