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SUSTAINABLE ENERGY FOR RADAR SYSTEMS IN INDONESIA'S OUTERMOST ISLANDS: A COOPERATIVE GAME THEORY ANALYSIS

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ABSTRACT

Indonesia's vast territorial waters, essential for natural wealth and strategic trade routes, face significant security challenges, including smuggling, illegal fishing, marine pollution, and maritime terrorism. To address these threats, Indonesia has implemented the Integrated Maritime Surveillance System (IMSS), primarily powered by diesel generators and, in some cases, supplemented by solar cells. This study explores the potential of transitioning IMSS to sustainable energy sources, specifically solar cells, to enhance environmental sustainability and operational independence. Utilizing cooperative game theory, we analyze the compromise values of using solar cells, diesel generators, and PLN (state electricity) to determine the optimal energy mix that balances cost-efficiency and renewable energy utilization. Through cooperative game theory, we evaluate the total costs and net present values (NPV) of each energy source under different usage scenarios (100%, 75%, 50%, and 25%). The NPV method is applied to assess the profitability and cost-effectiveness of each energy source over a 10-year period, discounting future cash flows to present value to account for the time value of money. This analysis shows that while solar cells require high initial investment, they offer significant long-term operational cost savings and environmental benefits. Conversely, diesel generators, despite lower initial costs, incur high operational and maintenance expenses. PLN electricity, though reliable in certain areas, faces limitations in remote regions. By determining the payoff matrix and eliminating dominant strategies, we identify the optimal compromise strategy that maximizes the use of renewable energy while minimizing costs. This approach not only supports Indonesia's green economy initiatives but also ensures reliable and efficient maritime surveillance. The findings advocate for a strategic shift towards greater reliance on solar energy for IMSS, promoting environmental sustainability and enhancing the system's overall effectiveness in securing Indonesia's maritime domain. This study contributes to the broader discourse on sustainable energy transitions in critical infrastructure and highlights the applicability of cooperative game theory in resource management.

Keywords: Cooperative Game Theory, NPV, IMSS, Green Energy

1. INTRODUCTION

Indonesia's seas have historically served as a wellspring of natural wealth and vital strategic trade routes for the nation. The country's vast territorial waters, while holding immense economic promise, also present formidable security challenges. The presence of an expansive maritime domain, studded with thousands of islands and intersected by bustling trade routes, renders Indonesia susceptible to a wide array of threats. These encompass activities like smuggling, which can range from the illicit trade of goods to narcotics trafficking, putting the nation's economic stability at risk. Moreover, the lure of Indonesia's rich fishing grounds has attracted illegal fishing operations that not only deplete marine resources but also undermine the livelihoods of local fishermen. Environmental issues, such as marine pollution and habitat degradation, pose further concerns, endangering the ecological integrity of these precious waters. Beyond these challenges, Indonesia faces the persistent menace of maritime terrorism, as its strategic sea lanes may be targeted by extremist groups seeking to disrupt global trade and stability. Lastly, the country must grapple with the issue of people smuggling, as its vast coastlines and numerous islands can be exploited by human traffickers, necessitating efforts to safeguard human rights and maintain the nation's security. Balancing the economic potential of its seas with the imperative of security remains a significant and ongoing challenge for Indonesia.

Indonesia's largely poorly monitored territorial waters, compared to the close surveillance at airports and land travel lanes, provide an opening for foreign vessels to easily pass through Indonesian waters, as long as they comply with applicable regulations. This condition increases the level of vulnerability to various threats, which threaten not only economic interests but also territorial sovereignty, as well as national security and defense. In recent years, Indonesia has sought to improve water security by implementing a coastal surveillance radar-based security system, known as the Integrated Maritime Surveillance System (IMSS), especially in the northern border, especially in the Strait of Malacca (Ariantoko, 2023) and the Indonesian archipelago can be seen in figure 1.

IMSS plays an important role in monitoring the movement of ships entering and leaving Indonesian territorial waters, in addition to monitoring ships crossing the Indonesian coastal area the radar is also to monitor if there is an accident at sea or the piracy of commercial ships in the Indonesian sea area. So further efforts are needed to strengthen and maximize the use of this system, especially in areas that are the outer boundaries of the Indonesian archipelago. (Dotulung, 2020)

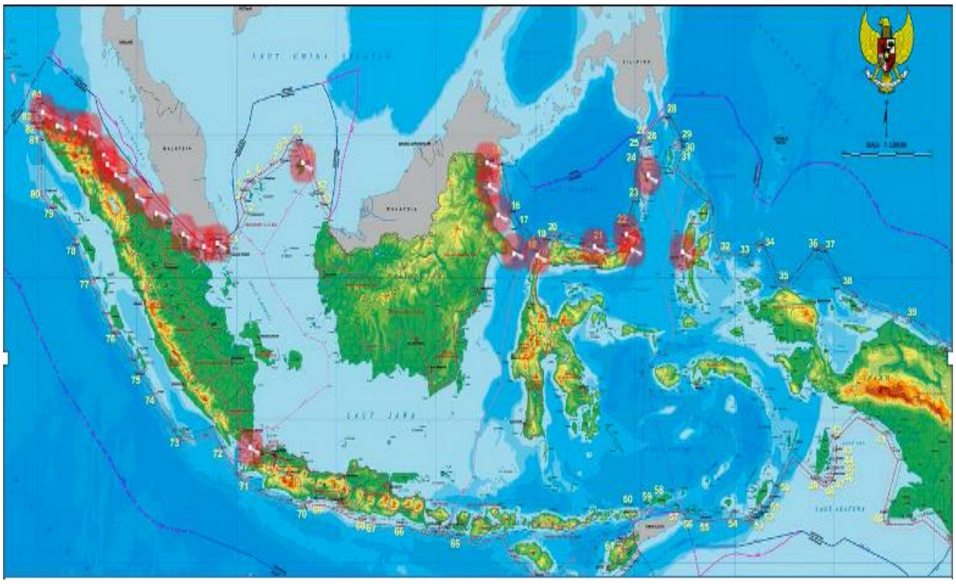

Fig.1 IMSS Location

Currently, IMSS Radar uses electricity from PLN in areas covered by the national electricity network (PLN). However, obstacles arise when the area where IMSS is located is outside the reach of PLN's network, so it uses diesel generator resources as the main power source and solar cells as supporting power (Gunawan, 2023).

On the other hand, to support the achievement of the Government's main target in overcoming global climate problems through the implementation of the green economy to date. This effort is shown by the Government through its commitment to encourage the provision of optimal resources to accelerate the sustainable energy transition. In the International Seminar on Leveraging Performance Audit Impact Towards Green Economy, the Coordinating Ministry for Economic Affairs is committed to supporting sustainable renewable energy development to increase the target of reducing Greenhouse Gas emissions to minimize the negative impact of emissions produced. The phenomenon of greenhouse gases occurs due to the increasing amount of carbon in the air which causes heat from sunlight to be trapped which will increase temperatures globally (Fadzil, 2022). The Indonesian Navy leadership also supports the government program by considering the potential use of renewable energy as the main power source for IMSS radars.

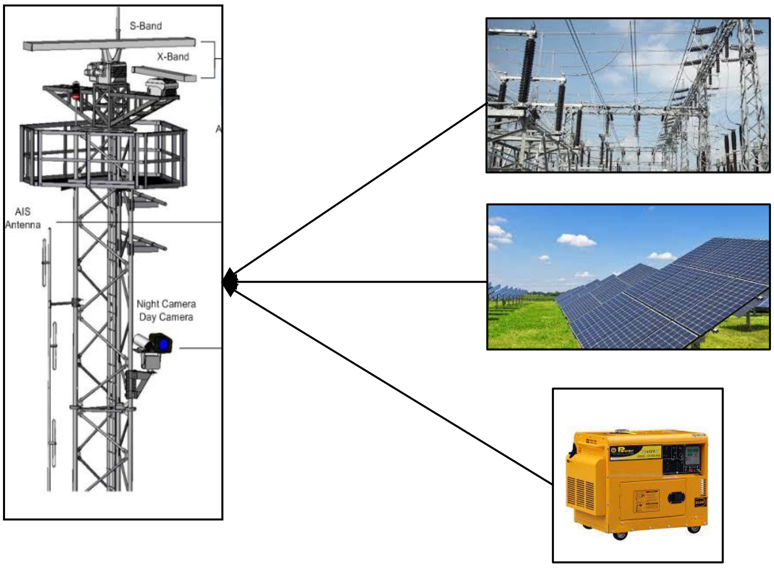

Fig.2 Power supply for IMSS

In addition to contributing positively to environmental sustainability, the use of solar cells also provides advantages in terms of independence, where the system can operate independently without being too dependent on outside resources. The move towards the use of renewable energy such as solar cells for IMSS Radar is a strategic step in the effort to reduce environmental impact and improve the efficiency of maritime surveillance systems. In addition, independence in power supply will improve the reliability of surveillance systems, given the lower dependence on outside resources. With this change, it is expected that IMSS Radar will be able to operate more efficiently, effectively, and environmentally friendly so that it can be more effective in carrying out its duties in maintaining the security of Indonesian waters. Here is the architecture of the power supply on the IMSS radar.

In the Figure 2, it can be seen how the IMSS radar obtains power supply, namely from PLN from solar cells and diesel generators. In areas that have a reliable PLN electricity network, the main source of power comes from PLN, followed by solar cells as a backup power source. In addition, there is also a generator that acts as an emergency power source. However, the use of these resources still depends on fossil energy, namely from coal-fired power plants, the main fuel of which is coal.

The existing literature has put forth a substantial amount of research on sustainable energy that utilizes cooperative game theory. This section will introduce the most pertinent studies and highlight the key distinctions when compared to our proposed model. Research conducted by (Bo-Li, 2022) integrates solar PV energy sources, wind turbines and diesel generators based on multi-energy with deep merging between electricity and gas grids. Four possible game planning models are proposed using game theory analysis methods. development of interval optimization-based coordinated operating strategies for gas-electric integrated energy (IES) systems that consider wind power demand and uncertainty responses (Bai, 2016).

Traditional energy generation using diesel generators is not easily disturbed by external factors and the energy supply is stable. However, high operating costs, slow response rates, and serious air pollution are certain to make diesel generators no longer follow future development trends. Hence, the use rate of diesel generators gradually decreases. On the other hand, distributed energy represented by wind and solar energy has a good level of safety and flexibility, as well as lower environmental pollution, but it is strongly influenced by weather factors, with a high degree of uncertainty, fluctuation, and time variation. (Barelli L, 2015).

In this study, researchers will look for compromise values from the results of each resource using cooperative game theory so that the best composition of the use of resources used by IMSS radar is obtained so that the use of solar cells as renewable energy is expected to be more dominant to support renewable energy but at a cost that is not too expensive. So, it is expected that the results obtained can be environmentally friendly and reduce the amount of carbon that exists as expected by the government (Presiden, 2021). This study aims to find the compromise point of the use of these three resources using cooperative game theory.

2. MATERIAL AND METHOD

2.1 Game Theory

Game theory is a mathematical approach used to formulate and analyze situations in which there is competition and conflict between various players in decision-making involving interactions. In decision-making with game theory, there is more than one decision-maker, often referred to as a player, who has different goals. The decisions taken by each player have an impact on the outcome obtained by all players involved. The peculiarity of game theory is the presence of interaction between players, which differs from conventional decision-making theory which involves only one decision-maker. To achieve their goals, each player has a wide choice of strategies that they can apply. The goal of game theory is to understand and predict how players will behave in situations involving these interactions, hoping to achieve their respective goals (Maschler, 2013). One of the fundamental assumptions in game theory is that all players are rational. Players in game theory can be divided into two types: two-person games, in which the game involves two players, and N-person games, in which more than two players are involved in the game. Players always choose the decision that will give the best result according to their goals, and their decision is not influenced by personal preference.

While a cooperative game is a type of game where all players can coordinate or work together to determine a mutually beneficial strategy, the strategy produced in this game may not always be the best choice optimally for one of the players, because it is based on an agreement reached by both parties that will benefit all parties or will not harm one party after cooperation and coordination (Melati, 2017).

Cooperative Game Theory is a branch of game theory that studies how groups of players (coalitions) can cooperate to achieve mutual benefits. In this theory, a group of cooperating players is called a coalition, which can range from small groups to large ones encompassing all players in the game. The main focus of this theory is on how the benefits obtained from cooperation can be distributed, regulated through a characteristic function that assigns value or benefits to each coalition. There are two types of cooperative games: transferable utility games, where benefits can be distributed in measurable forms such as money, and non-transferable utility games, where benefits cannot be easily measured, like contributions in a sports team.

Key concepts in cooperative game theory include the Core, which is a set of allocations ensuring that no coalition would gain more by breaking away; Shapley Value, a method for distributing benefits fairly based on each player's contribution; Nucleolus, a solution that minimizes player dissatisfaction with their allocation; and the Bargaining Set, a set of allocations where no player has a legitimate reason to reject the allocation. Cooperative game theory is applied in various fields such as economics, management, and political science, for business cooperation, international negotiations, and resource allocation, helping create better solutions through cooperation rather than individual actions.

2.2 IMSS Radar

The establishment of the Regional Maritime Security Information Center (IMSS) by the Indonesian Navy involves several stages and cooperation with the US Government. In 2005, the development of the IMSS radar began and continued to expand until 2014. The construction of IMSS I commenced in 2005, followed by Phase II. In April 2006, the U.S. Embassy in Jakarta expressed the U.S. Government's interest in assisting with the implementation of the IMSS development, demonstrating a commitment to enhancing maritime security in the region. By 2012, the Indonesian Navy had held a meeting with the U.S. Embassy to further discuss maritime security, emphasizing the ongoing cooperation between the two nations. The IMSS is equipped with a 2D surface radar with an X band that can observe the sea surface up to 40 miles or 70 km, an Automatic Identification System (AIS) to monitor the movement of commercial ships, and radio and satellite communications to send data to the control center located at the TNI AL Headquarters. This robust setup underscores the strategic importance of IMSS in maintaining maritime security.

The IMSS operates continuously, 24 hours a day, 7 days a week, with no downtime for observations. This necessitates a reliable and uninterrupted power supply to support its operations. The power for IMSS is sourced from PLN (Perusahaan Listrik Negara), diesel generators, and solar panels, each with its distinct advantages and limitations. In the outermost areas, the reach of PLN resources is often limited. Many IMSS radar locations are on the outermost borders of Indonesian islands where PLN's electricity network is either non-existent or unreliable due to frequent outages, making it an unreliable primary power source.

2.3 Diesel Generator

Diesel generators are the main power source for IMSS. An IMSS system requires 20Kw of power according to the specifications provided by the (Operator, 2023) those in charge of operating and maintaining the equipment. So, it requires a power source from a generator with a minimum power of 25Kw. Because for safety the maximum generator power is 80% of the required power. In this study, the diesel generator applies as a player and is notated with Dg. Dg in this study has values, namely operational costs, investment costs and maintenance costs.

$$\text{Total Cost Dg} = Bi+Bo+Bhar \qquad (1)$$

Bi: Investment or purchase costs
Bo: operational costs i.e., fuel usage
Bh: maintenance costs

The investment cost of a diesel generator with a capacity of 25 kW is between 80 to 100 million or the middle value of 90 million. The value is the value of the initial investment cost. Next is operational costs, namely the use of diesel fuel needed by diesel generators in one month. According to (Hayatullah, 2021) in finding diesel fuel consumption is as a berry.

$$S=K\times P\times T \qquad (2)$$

S: Required amount of diesel

K: 0,2 (Fuel consumption constant required per kilowatt per hour)

T: generator usage time

By using the formula above, the fuel consumption needed in one day is 120 litres, while the consumption for one month is 3,600 litres. If the fuel used is for industrial marine at a price of 20,100 / litre. So the operational cost for a 25Kw generator for one month is Rp 72,360,000, and the operational cost for one year is Rp 868,320,000. As for maintenance costs according to (Yudiono, 2018) maintenance costs for generators per year is Rp. 94,539,600. So to find equation 1) can be done because all the variables needed are known.

Total Cost Dg: Bi+Bo+Bh
: 95.000.000 + 880.380.000 +94.539.600
: Rp1.057.320.000

Bi : Rp 95.000.000
Bo : Rp 880.380.000
Bh : Rp 94.539.600

From the calculation above, the total cost of the diesel generator is Rp1,057,320,000. The cost is the cost of using a 100% diesel generator or all IMSS power supplied by the diesel generator.

2.4 Solar Cell

Currently, solar cells are used to back up diesel generators. Currently, there is no division between when to use the flow generator and when to use the flow from the solar cell. So, the use of these two energy sources is not optimal. The following is the value of the costs required to support an IMSS system.

$$\text{Total cost Pv} = Pvi+Pvo+Pvh \qquad (3)$$

Pvi: Investment in Solar Cell Development
Pvo: Operating costs
Pvh: Maintenance costs

According to the (ESDM, n.d.) the cost of installing solar cells is 20 million per Kw. At IMSS the power required is 20Kwh. If solar panels will be used as the main power source, then in a day 24 hours. So that the power needed is 20x24, so the power needed is 480Kw.

So, the Pvi is:
Pvi = 480x20jt
= Rp 9.600.000.000

Solar panels do not require operational costs. Because energy utilizes sunlight to generate electricity. So Pvo is 0. As for Pvh, the maintenance cost required is battery replacement. Battery replacement is carried out every 10 years. So that the equation can be solved as follows.

Total Cost Pv = Pvi+Pvo+Pvhar

= 9.600.000+0+0

= Rp9.600.000.000

From the calculation above, the cost is obtained for the installation of solar panels to support IMSS operations. In this calculation, IMSS uses 100% of the power from solar panels.

2.5 PLN electricity flow

Electric current from PLN (Perusahaan Listrik Negara) plays an important role in ensuring the continuous operation of IMSS (Maritime Security Information System) radars located in Indonesia's outer islands. The state-owned power company is providing the necessary power supply to keep the radar system in place for its essential functions in monitoring and securing maritime activity in the region. The condition in the field is that electricity supply from PLN is not used as the main power source because the conditions that exist on the outer island are many obstacles, both from stability, conditions that often die and there are some areas where there is no electricity supply from PLN. However, in this study, researchers assume PLN can reach all areas on the outer islands of Indonesia. For the cost required by electricity, PLN supplies 100% for IMSS in one year is 253,000,000 and installation costs are 20,000,000. on electricity, PLN does not require maintenance, because maintenance is borne by PLN.

2.6 NPV

The NPV (Net Present Value) approach emphasizes that a Euro received in the future carries more uncertainty and is thus less valuable compared to a certain Euro received today. As a result, the projected cash flows in the future are discounted each year. The discount rate used takes into account the opportunity cost of the capital being used, and this cost increases as the perceived risk associated with the innovation opportunity rises. In essence, projects with greater levels of risk are expected to yield higher returns. This means that the NPV approach adjusts for risk, which sets it apart from other metrics like ROI or IRR, as noted by (Gailly, 2011)

In its fundamental application, the discount rate is determined by evaluating the actual cost of the capital invested in the innovation. This involves calculating the weighted average cost of both equity and debt utilized to fund the project. In instances where small projects make it challenging to identify the specific proportions of equity and debt financing, the cost of capital, often referred to as WACC (Weighted Average Cost of Capital), is typically assumed to be equivalent to the company's overall cost of capital. This calculation is based on data from annual reports that consider the company's total equity and liabilities, as noted (Chiesa, 2009).

$$\sum_{t=0}^{n} \frac{NCFt}{(1+r)^t} \qquad (4)$$

Where NPV = net present value.

NCFt = net cash flow generated by innovation project

t = in year

r = discount rate

Commonly used discount rates for corporate projects typically range from 10 per cent to 15 per cent.

However, investors in high-tech start-ups may use rates as high as 25 per cent to 30 per cent, reflecting the intrinsically risky nature of such ventures. The second core principle of the NPV approach involves considering all future net cash flows associated with the innovation opportunity. In contrast, other metrics like the payback period or initial investments focus solely on the initial cash flow. The NPV approach necessitates, on the one hand, the discounting and aggregation of all future net cash flows, where reasonable assumptions can be made. On the other hand, it requires estimating and discounting the ultimate value of any remaining cash flows, often referred to as the "final" value. The value of innovation projects is then the sum of the discounted cash flows, inclusive of the final value. This final value can be estimated as either zero (in cases of innovations facing complete obsolescence), negative (for innovations involving rehabilitation or recycling costs, as seen in the energy sector, for instance), or as an approximation of future cash flows based on factors such as resale value, balance-sheet metrics, or a perpetual value concept.

3. RESULTS AND DISCUSSION

3.1 NPV Energy Sources Cost

The following is carried out the calculation of the net present value of energy sources over 10 years. NPV calculation will be carried out with 100% usage, 75% usage, 50% usage and 25% usage. Here is a table of calculations of NPV 100% use for 7 years.

Table.1 NPV 100% Use of Energy Sources

Source	Invest	Ops1	Ops2	Ops3	Ops4	Ops5	Ops6	Ops7	NPV Value
PLN	20	253	253	253	253	253	253	253	1.351
Generator	95	975	975	975	975	975	975	975	5.244
Solar Cell	9.600	0	0	0	0	0	0	0	9.060

In the table above is the cost required for each energy source to supply IMSS 100%. PLN has the smallest investment costs and operational costs tend to remain not the most expensive and not the cheapest. Diesel generators have slightly greater investment costs than PLN but have the highest operational and maintenance costs. The latter are Solar panels which have the largest investment costs but have the most operational costs small, it cost nothing because energy takes sunlight to generate electricity. After calculating the NPV of 100% of energy use, then calculate the NPV of 75% of the energy use of each Source. The calculation results can be seen in the table below.

Table.2 NPV 75% Use of Energy Sources

Source	Invest	Ops1	Ops2	Ops3	Ops4	Ops5	Ops6	Ops7	NPV Value
PLN	20	190	190	190	190	190	190	190	1.019
Generator	95	650	650	650	650	650	650	650	3.512
Solar Cell	7.200	0	0	0	0	0	0	0	6.790

In the NPV calculation of 75% of energy use from each source, there has been no significant change from the results that previously PLN had the smallest investment value, but there was a change in operational costs which were previously 253 million to 190 million. In diesel generators, there is a difference in operational costs from 975 million to 650 million. While in solar cells there is a change from the previous 9.6 M to 7.2 M, while operational and maintenance costs on solar cells do not yet exist.

Table.3 NPV 50% Use of Energy Sources

Source	Invest	Ops1	Ops2	Ops3	Ops4	Ops5	Ops6	Ops7	NPV Value
PLN	20	125	125	125	125	125	125	125	677
Generator	95	575	575	575	575	575	575	575	3.117
Solar Cell	4.800	0	0	0	0	0	0	0	4.530

In the table above, the results of the NPV calculation of the cost of using 50% energy sources for IMSS, PLN generators and solar panels. Every source of cost decreases.

Table.4 NPV 25% Use of Energy Sources

Source	Invest	Ops1	Ops2	Ops3	Ops4	Ops5	Ops6	Ops7	NPV Value
PLN	20	79	79	79	79	79	79	79	435
Generator	95	220	220	220	220	220	220	220	1.248
Solar Cell	2.400	0	0	0	0	0	0	0	2.260

In the table above is the calculation of the NPV of each source supplying 25% of the power required by the IMSS radar. from the results of the NPV calculation, it can be seen the cost of each source.

3.2 Game Theory

The next step is to address the issue of sharing energy sources using cooperative game theory. With this approach, we can achieve optimal results in the utilization of renewable energy while reducing high costs. Cooperative game theory enables stakeholders in the energy system to collaborate and efficiently share energy resources. Therefore, this will help achieve a better balance between environmental sustainability and economic efficiency in the use of renewable energy sources. By applying cooperative game theory principles, we can allocate energy resources more equitably and minimize waste, leading to a more sustainable and cost-effective energy system. This not only benefits the environment by promoting the use of clean, renewable energy sources but also offers economic advantages by streamlining the energy production and distribution process, ultimately making renewable energy a more accessible and viable option for the future. It is a promising approach that has the potential to revolutionize the energy sector and contribute to a greener and more sustainable world.

3.3 Payoff Matrix Determination

In this game theory, three main players have a central role in the management of energy resources, namely PLN, diesel generators, and solar panels. Each of these players has a unique strategy relating to the energy resources they control. PLN, as the largest provider of electrical energy in Indonesia, must consider cost efficiency and reliability of energy supply. On the other hand, diesel generators consider operational flexibility and fuel availability. Meanwhile, solar panel owners can focus more on environmental aspects and the utilization of renewable energy.

When all these players are involved in this game, the results of each previous move are recorded in a matrix that includes various possible situations or scenarios. This can include how much energy is produced, costs incurred, or the environmental impact of each strategic choice. With the bimatrix composed, the players can perform analysis to determine the best strategy that will give them the most favourable results.

In a broader context, this approach helps create a better balance between economic, environmental, and energy availability. It also reflects the importance of using renewable energy in reducing negative environmental impacts and ensuring the availability of reliable energy in the future. By integrating game theory into energy-related decision-making, we can achieve more sustainable and optimal solutions for managing energy resources in Indonesia. This is the bimatric table of cooperative game theory.

Table.5 Payoff Matrix

PLN \ Diesel generator Solar Panel	25% Usage	50% Usage	75% Usage	100% Usage
25% Usage	2.260,1.248, 677	2.260, 3.117, 435	2.260, 3.512, 0	2.260, 3.512, 0
50% Usage	4.530, 1.248, 435	4.530, 3.117, 0	4.530, 3.117, 0	4.530, 3.117, 0
75% Usage	6.790, 1.248, 0	6.790, 1.248, 0	6.790, 1.248, 0	6.790, 1.248, 0
100% Usage	9.060, 0, 0	9.060, 0, 0	9.060, 0, 0	9.060, 0, 0

In the bimatric above, there are three players, namely player 1 is a panel prayer, player 2 is a diesel generator, and player 3 is PLN. In the payoff value, there are three values, namely payoff from player 1, payoff from player 2, and payoff from player 3. The purpose of this cooperative game is to divide energy sources so that energy sources can be shared that can maximize the use of renewable energy, namely solar panels, but minimize the costs incurred, by dividing the use of owned sources.

3.4 Compromise Strategy Selection

A compromise strategy is a strategy that does not harm all players, guided by common goals. Unlike noncooperative games that pit each other's best strategy. The strategy that produces the biggest profit for player 1 and gets the smallest loss is the best strategy. The strategy that has the biggest loss impact on the opponent is the best strategy, depending on the purpose of the strategy user.

To facilitate the selection of strategies will use the elimination approach as manifested by (Hillier, 2001). In this elimination approach, it will eliminate from the dominant payoff value. In the matrix above, the dominant payoff value is the one with the largest value from player 1. So that player 1 strategy 100% usage can be eliminated. Eliminating the most dominant payoff, it will make it easier for decision-makers to determine strategy choices that do not benefit one of the players. The results of the first elimination can be seen in the following table 6.

Table.6 Dominant Payoff Elimination Results Player 1

PLN \ Diesel generator Solar Panel	25% Usage	50% Usage	75% Usage	100% Usage
25% Usage	2.260,1.248, 677	2.260, 3.117, 435	2.260, 3.512, 0	2.260, 3.512, 0
50% Usage	4.530, 1.248, 435	4.530, 3.117, 0	4.530, 3.117, 0	4.530, 3.117, 0
75% Usage	6.790, 1.248, 0	6.790, 1.248, 0	6.790, 1.248, 0	6.790, 1.248, 0

After making the first elimination that eliminates one strategy from player 1, then look again at the payoff table whether there is still a dominant value in the matrix table above. In the table, there is the smallest dominant value found in player 3, which is a zero value in all strategies of 75% and 100% usage. So that these two strategies can be eliminated. The results of the elimination matrix can be seen in the following table 7.

Table.7 Dominant Payoff Elimination Results Player 3

PLN \ Diesel generator Solar Panel	25% Usage	50% Usage
25% Usage	2.260,1.248, 677	2.260, 3.117, 435
50% Usage	4.530, 1.248, 435	4.530, 3.117, 0
75% Usage	6.790, 1.248, 0	6.790, 1.248, 0

After carrying out elimination in the player 3 strategy, the player 2 strategy has two strategies, namely 25% usage and 50% usage. After carrying out the final elimination, look again at whether there is a dominant pay off value. In table 7, there is still the smallest dominant value in player 3 in strategy 3. Next, carry out elimination in the strategy. So that leaves the following strategy that does not have a dominant value.

Table 8 Dominant Payoff Elimination Results Player 3

PLN \ Diesel generator Solar Panel	25% Usage	50% Usage
25% Usage	2.260,1.248, 677	2.260, 3.117, 435
50% Usage	4.530, 1.248, 435	4.530, 3.117, 0

Table 8 presents a scenario where each player—solar panel, diesel generator, and PLN—has two remaining strategies, specifically 25% and 50% usage. This results in a total of four possible payoffs:

a. Solar Panel 25% Usage, Diesel Generator 25% Usage
b. Solar Panel 25% Usage, Diesel Generator 50% Usage
c. Solar Panel 50% Usage, Diesel Generator 25% Usage
d. Solar Panel 50% Usage, Diesel Generator 50% Usage

These four payoffs represent the combined outcomes of the different strategy pairings between the players. By reducing the number of strategies to two for each player, the complexity of the decision-making process is significantly minimized. This streamlined approach allows researchers to more easily analyze the interactions and trade-offs between different energy sources.

Furthermore, focusing on these specific payoffs facilitates the identification of the optimal compromise strategy. Researchers can now examine which combination of solar panel and diesel generator usage best balances the goals of cost efficiency and green energy utilization, ensuring that no single player dominates the outcome and that the overall strategy supports sustainable and economical energy management for the IMSS system.

4. CONCLUSION

The compromise strategy selection process successfully identifies strategies that are beneficial to all players and do not disadvantage any single party, adhering to common goals. Using Hillier's (2001) elimination approach, dominant strategies are systematically removed, making it easier to determine equitable decisions. The initial elimination of player 1's 100% usage strategy, followed by the removal of player 3's 75% and 100% usage strategies due to zero value payoffs, narrows down the choices. After these eliminations, the analysis focuses on the remaining strategies to ensure they are not dominated by any other. The final selection leaves two strategies for each player, simplifying the determination of a compromise payoff value. The identified strategies effectively balance cost and green energy utilization, with the four remaining payoffs highlighting scenarios of 25% and 50% green energy usage. These scenarios align with the objectives of cost efficiency and environmental sustainability.

This method demonstrates the effectiveness of cooperative game theory in harmonizing diverse interests and optimizing resource use in complex systems. By ensuring no single player's interests dominate, the approach fosters collaboration and supports the sustainable transition to renewable energy sources for Indonesia's Integrated Maritime Surveillance System (IMSS). The findings highlight the potential of cooperative strategies to improve both economic and environmental outcomes in the management of critical infrastructure. However, this research has certain limitations. One primary weakness is the reliance on static data and assumptions, which may not accurately reflect real-world variability and dynamics. The model does not account for potential fluctuations in energy prices, technological advancements, or changes in policy that could affect the feasibility and cost-effectiveness of the proposed strategies. Additionally, the cooperative game theory approach assumes rational behavior and perfect cooperation among all players, which may not always be achievable in practice due to conflicting interests or external pressures. These limitations suggest that while the findings provide a solid foundation, further research incorporating dynamic and real-time data, as well as consideration of practical implementation challenges, is necessary to validate and refine the proposed strategies.

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