Small-scale LNG Carriers Revolutionize Power Plant Supply in Eastern Indonesia

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As a consequence of the global greenhouse gas problem, various adjustments are required, particularly in the energy sector. The government program envisages the development and conversion of power plant fuels to LNG to ensure energy distribution throughout the region, especially in Indonesia's remote islands. One of the biggest challenges in distributing energy to remote locations is the logistical difficulties in reaching these areas. Utilization-scale LNG carriers as a mode of transportation offers a potential solution to this problem. This study aims to optimize the distribution of LNG using small-scale LNG carrier transportation mode to meet the needs of power plants. The application of the Capacitated Vehicle Routing Problem method to a single vessel with different speed variations is used to optimize the distribution of LNG aiming to maximize its cargo capacity. The results of this study show that using a vessel with identical specifications as in Eastern Indonesia, operating at a specific speed, optimizes cargo capacity for a single round trip. These results will serve as a basis for future studies and facilitate the further development of existing methods.

KEYWORDS

~ LNG
~ Small-scale LNG
~ Supply chain
~ Renewable energy
~ Sustainable development

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1. INTRODUCTION

The world is facing a major challenge in dealing with greenhouse gas (GHG) emissions. These greenhouse gas emissions have a significant impact on climate change. GHG emissions are mainly caused by human activities (Solomon, 2007). One of the impacts of human activities is the use of fuels. The use of fuels, especially fossil fuels, is the largest source of GHG emissions, especially in the transportation sector and electricity generation. The transport sector, especially shipping, is responsible for 3 % of greenhouse gas emissions by 2022 (Sinay, 2023). With the International Maritime Organization (IMO) policy 2018, the IMO adopted an Initial Strategy for emission reduction called the GHG Strategy. The strategy aims to achieve a carbon reduction intensity of 40% by 2030 and 50% by 2050. Various efforts are therefore being made to ensure that international shipping achieves this target, and one of the efforts with the greatest impact is the replacement of fossil fuels with environmentally friendly alternative fuels.

The electricity generation sector also plays an important role in the problem of greenhouse gas emissions, as fossil fuels are predominantly used for electricity generation. As power generation plays an important role in GHG emissions, the promotion of renewable energy from biomass, hydropower, wind and solar has become a cornerstone of climate policy (Schaffer & Bernauer, 2014). As natural gas is abundant as a fuel with lower emissions compared to fossil fuels, natural gas is an alternative fuel. Infrastructure development and conversion of gas-fired power plants are part of the effort to generate clean energy to achieve the net-zero emissions target. The government's 2015 35,000 MW Power Plant Development program in Indonesia supports this commitment. It aims to increase energy capacity across Indonesia. With the switch from fuel oil to liquefied natural gas (LNG) in power plants, the demand for domestic LNG will increase. Therefore, supply chain analysis and planning are crucial for the distribution of LNG in each region of Indonesia, which consists of so many scattered islands. Under these geographical conditions, the transportation of LNG from the LNG source to the power plant becomes a challenge due to the limited gas pipeline network in Indonesia. This challenge can be overcome by the Small-Scale LNG Carrier (SSLNGC).

SSLNGC is designed to transport small quantities of LNG from import terminals to areas without access to natural gas. Normally these carriers have a maximum loading capacity of 30,000 cbm. With a small carrier capacity, SSLNGC can reach areas that are far from pipelines and have low LNG demand (Pratiwi et al., 2021). This type of SSLNGC has an increased demand due to its flexibility in LNG distribution and the increasing LNG demand that continues to grow every year with the rapidly growing infrastructure for the construction of LNG plants in all regions of Indonesia. SSLNGC is low in emissions as it has a dual-fuel engine that can run on both gas and diesel. Apart from reducing the use of diesel fuel, the addition of gas fuel also aims to reduce emissions from combustion (Murtado, 2018). LNG carrier routing optimization can be effectively performed by developing ship scheduling and routing models considering changing market trends, boil-off gas (BOG) uncertainty, and the latest LNG carrier designs (Cho et al., 2014). The distribution system using SSLNGC works in the same way as conventional LNG carriers. The difference lies in the size of the cargo capacity and the specifications for the small dimensions of the carriers to reach areas that are not accessible with conventional carriers. BOG is a gas that is produced during the vaporization of LNG from storage tanks or LNG carriers and can be used as fuel. It also affects its quantity and quality as well as the overall efficiency of the LNG supply chain (Dobrota et al., 2013).

There are many challenges in the LNG supply chain, especially in the distribution phase, to achieve the LNG demand target. To achieve the target, a careful calculation strategy is required; one of the logistics concepts that can be applied is Just-In-Time Arrival (JITA) (IMO, 2020). JITA is a maritime logistics concept initiated by the IMO (International Maritime Organization) to reduce GHG emissions and increase port efficiency. In the implementation of the LNG supply chain case, this principle is used as a means of coordinating the operational components of the ship with the demand for LNG to meet the relevant criteria in terms of time; an example is meeting LNG demand at multiple points with a target time and optimal cargo distribution. One component that supports this strategy is the fact that digitalization can help reduce fuel consumption and CO_2 emissions, bringing environmental and economic benefits to ship owners and other stakeholders in the maritime system (Pavlinović et al., 2023). Therefore, optimal strategies are considered when planning LNG shipping routes to reduce transportation costs and improve shipping efficiency (Stanivuk et al., 2013).

In this study, the mode of transportation used for LNG distribution is SSLNGC, which is required for LNG transportation (Keppel Offshore & Marine Technology Centre, 2014). For SSLNGC, the distribution model for LNG transportation is needed as the first strategy to design the desired scheme. There are several methods for designing LNG distribution with SSLNGC. For example, Banyupramesta et al. (2022) used a mixed integer linear programming (MILP) model in their study, while Adli et al. (2022) applied the Set Partitioning Problem method. Moreover, the main objective of this study is to optimize the cargo distribution to meet the LNG demand at multiple LNG demand locations using multiple SSLNGCs as transportation mode. One of the methods for the routing problem that can be used is the Vehicle Routing Problem (VRP), which focuses on determining the best route for a group of vehicles that need to travel to multiple points with different constraints. In the case of LNG distribution using VRP, the type of VRP commonly used for LNG distribution cases is the Capacitated Vehicle Routing Problem (CVRP). CVRP is a type of VRP with additional problem variables, namely vehicle capacity, distributed to all demand points. The distribution model strategy uses CVRP as a routing problem method, which usually focuses on optimizing the derivatives of the distance and time variables. With the evolution of time, the developed optimization will provide a gap for adapting to future problems. One of the factors that can provide a gap is an LNG distribution model with the main priority of optimizing the distribution of cargo to multiple points so that the remaining cargo has a minimum compared to previous models. As is known, CVRP, with the main focus on the main constraint of transportation loads, can be used as a means to obtain routes with destinations that meet the criteria. The use of CVRP as a route problem method for the distribution of LNG using SSLNGC has been widely used in previous studies, so this CVRP route problem method is used as the main method for the development of distribution models by finding the right composition so that the existing targets can have a balance in the percentage of effectiveness between the two targets with those to be developed, namely finding models with minimum remaining load.

The application of CVRP in solving route problems illustrates the versatility of this method when it comes to meeting the needs of a variety of commodities. The following studies demonstrate the effectiveness of CVRP in overcoming the challenges associated with the transportation of different types of goods. In the study by Cazabal-Valencia et al (2020), the CVRP method was used to minimize the total cost of distribution and inventory. This was achieved by optimizing vehicle routes in a distribution network with capacity constraints and evenly distributed customer demand. This research is concerned with the optimization of distribution for land logistics networks. In their study, Qiang et al. (2020) present a solution to the CVRP problem for distribution routes in cold chain logistics. They employ a greedy search method to minimize the transportation distance and cost of refrigerated vehicles from depots to customers. In another contribution to this research area, Nurprihatin et al. (2021) present a study on the optimization of rice distribution routes in Indonesian regions with rice surpluses for regions with rice deficits. The authors use the CVRP method to achieve this goal. The focus of this study is on the optimization of distribution via land, sea and air logistics networks.

The research of Panessai et al. (2011) deals with the development of methods for optimizing shipping routes used by Indonesian national shipping companies. CVRP is applied when each ship serving a port route must comply with ship capacity restrictions and must not exceed the amount of cargo that can be transported. In this study, the ship used is a cargo ship. As noted in previous studies, the CVRP method has been used to examine logistical distribution routes for various modes of transportation, including land, air, and sea, as well as in cases where these modes are integrated. The extant research on the application of the CVRP method allows us to narrow down its potential applications. In the present study, we focus on the energy sector, with particular emphasis on the gas sector. Here, the LNG supply chain system encompasses a range of facilities and specifications, including those related to accommodation and transportation modes, notably LNG carriers.

In exploring the potential for collaboration with the Indonesian government, we identified a promising opportunity in the form of the 35,000 MW power plant development program (PLN RUPTL Reports 2021-2030). In the context of this program, we came across a study by Budiyanto et al. (2019) looking at the optimization of LNG distribution by small-scale LNG ships called SSLNG in the Sumatra region. The study chose an area coverage consisting of an island. However, the use of SSLNGC ships is more optimal when it comes to reaching terminal areas that cannot be served by conventional LNG ship sizes which are usually located in areas consisting of many islands. In this study, we narrow the scope of our study to an area consisting of several islands. The next step was to search for studies with a multi-island coverage area. This search yielded a study by Prananda et al. (2022), which showed similarities with previous studies. These similarities were identified by objectively comparing the studies. A gap in this objective can be derived from this study, namely the choice of distribution scenarios with the lowest time variable derivative. In the previous study, the objective of maximizing shiploads was not considered in the distribution of LNG. In this way, our research design distributes LNG with a new objective: to minimize the remaining cargo on the ship by meeting all needs. These are compared using objective choice scenarios with route sequences that focus on the time variables, i.e. the distance traveled.

Previous studies by Budiyanto et al. (2023) resulted in an optimization scenario for the distribution of LNG to Mobile Power Plants using SSLNGC and the results of the economic analysis based on financial feasibility for the case study in the Sulawesi region using the CVRP model as a route problem method with the Greedy algorithm to determine the best route. The study covered route optimization, economic assessment, and design of SSLNGC. The results show that investments in small-scale LNG distribution are profitable, with decent margin rates and estimated payback periods. The study highlights the importance of strategic planning and policy support for sustainable development of LNG distribution networks, especially in remote areas. In a study conducted by Banyupramesta et al. (2022), it was found that LNG distribution in Bali-Southeast Nusa Tenggara using the Fleet Size and Mix Vehicle Routing Problem (FSMVRP) in combination with MILP provides a solution to optimize distribution routes for energy fulfillment. By analyzing different strategies, it is concluded that some strategies are most cost effective due to their operational cost efficiency. In this study, various constraints such as fleet specifications and terminal capacities are considered to determine the optimal distribution route. By applying FSMVRP and

MILP, the study aims to minimize fuel, maintenance and labor costs while ensuring efficient energy distribution. The distribution schemes presented in this study, such as those from the Makassar Terminal, visually represent the optimized routes for LNG distribution in the region.

Overall, this study contributes to the literature on energy distribution optimization and highlights the importance of strategic decision making in distribution management. A study conducted by Abdillah et al. (2021) on the distribution of LNG to power plants in Bali and Nusa Tenggara, Indonesia, has optimized the distribution of LNG in the region. This study successfully calculated LNG distribution, estimated operating costs and conducted risk assessments. The aim of the study was to improve the understanding of the distribution process and the associated risks by analyzing the estimated round trips, operating costs and frequency of leakages. The study found one scenario to be effective by comparing different scenarios.

The results of this study highlight the importance of optimizing LNG distribution in the region and provide a basis for future studies to improve the efficiency and reliability of the LNG supply chain. This study contributes to the development of a sustainable and effective LNG distribution system for power generation in Bali and Nusa Tenggara. A study conducted by Cho et al. (2014) presents a new biannual LNG carrier routing and scheduling model that considers market trend changes and technological advances in LNG carrier design. The model includes a stochastic extension to account for BOG uncertainty in transportation dynamics and uses a fleet of heterogeneous carriers to serve multiple customers. Computational studies demonstrate the model's effectiveness in optimizing ship routes and schedules, with a sensitivity analysis suggesting potential profit gains from replacing Type I carriers with Type II carriers. The studies emphasize the need to investigate uncertainties in LNG supply chain disruptions. Moreover, Stanivuk et al. (2013) aim to analyze the impact of transportation costs on the delivery of LNG via Moss carriers. Specifically, they examine how factors such as fuel costs, carrier design, number of carriers needed, and cargo volume affect the overall cost of LNG transportation. The results of the study underline the significant role of fuel prices in determining the transportation costs for LNG shipments. The study underlines that the use of LNG as a fuel for propulsion engines can lead to significant cost savings in transportation. In addition, the analysis of fluctuating ship prices and navigation costs in adverse weather conditions provides valuable insights for the optimization of LNG transports.

In previous studies, other methods were used to optimize distribution by considering input data such as demand calculation, distance from each destination, and variations in the carrier size and LNG distribution methods (Muzhoffar et al., 2022). This is necessary because the results of the economic analysis are highly dependent on the validation of the prices and costs of investments in the means of transportation and receiving terminals. In the study conducted by Budiyanto et al. (2023), it was found that the gap discussed in this study is the need for a study that addresses the technical aspects of SSLNGC and its economic analysis. This includes gaps in the design of SSLNGCs, such as the optimal utilization of shallow draft SSLNGCs and the use of LNG as fuel for these carriers. In addition, there is a study gap in the comparative economic analysis of LNG distribution to power plants considering factors such as investment costs, operating costs and profit margins. This study highlights the need for a comprehensive understanding of the technical and economic aspects of small-scale LNG distribution in order to effectively assess its feasibility and viability.

In the study conducted by Banyupramesta et al. (2022), the gap lies in the limited investigation of alternative optimization techniques beyond FSMVRP and MILP for LNG distribution in Bali Southeast Nusa Tenggara. While this study effectively compares different strategies and routes, there is potential to explore the application of advanced optimization algorithms or hybrid models to improve the efficiency and cost-effectiveness of LNG distribution in the region. In addition, these studies could also benefit from a more comprehensive analysis of the consideration of environmental impacts and sustainability factors in the optimization process. Examining these aspects can provide a more holistic approach to the optimization of LNG distribution in Bali Southeast Nusa Tenggara. In a study conducted by Abdullah et al. (2021), a study gap was identified in the development of LNG supply chains in many countries, especially in Indonesia, where there has been increased investment in infrastructure facilities.

However, the overall development of the LNG supply chain has yet to be completed. This gap highlights the need for further studies and development to optimize the LNG distribution process and improve the efficiency and effectiveness of the LNG supply chain in the region. A study conducted by Cho et al. (2014) identified a study gap that is addressed in this paper: the limited attention paid to uncertainty in the transportation dynamics of SSLNGC, particularly the impact of BOG in the LNG supply chain. Previous studies focused on external environmental factors and sailing time uncertainties caused by unfavorable weather conditions and did not consider the uncertainties within the LNG carriers. A previous study by Stanivuk et al. (2013) identified a gap in our study: the limited discussion of the specific strategies and technologies that can be implemented to effectively reduce transportation costs and increase efficiency in LNG delivery via Moss carriers. This gap underscores the need to further explore and analyze practical solutions and innovations in LNG transportation to address cost-related challenges. Eastern Indonesia was selected for the study because LNG offtake points are scattered on small and remote islands, which poses a logistical challenge for access to pipelines and conventional LNG vessels. This necessitates the development of a special distribution strategy. The goal of our research is to develop a routing and scheduling model for SSLNGC that integrates the optimization of LNG distribution with BOG produced in the field of SSLNGC transportation dynamics. The aim is to formulate an LNG transportation strategy as a result of this integration.

2. MATERIALS AND METHODS

2.1. Methods

2.1.1. Research Procedures

In order to develop an efficient and effective LNG distribution model to meet the energy demand in Eastern Indonesia, a research process was conducted that involved a series of systematic steps. These included the identification of LNG sources, analysis of demand and optimization of distribution routes and capacities. The process involved several phases, starting with a literature review and ending with key results that align with the objectives. Figure 1 shows the main phases of the study that were carried out to achieve the stated objective.

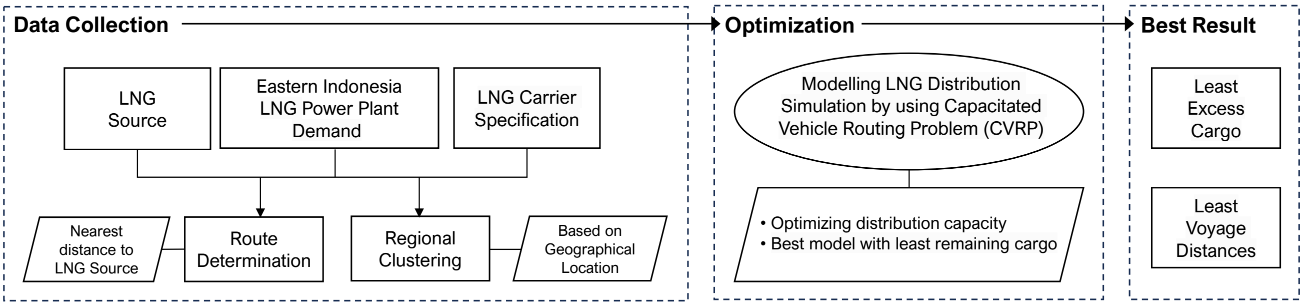

Figure 1. Procedure of this study

The objective of the technical assessment of this study is to analyze the distribution routes and select the most appropriate carrier types to improve the efficiency of the LNG distribution process. The selection of optimal routes is a crucial aspect of logistics management as it determines the most efficient way of delivering goods. This involves a comprehensive assessment of various factors such as distance, fleet planning strategy and navigational challenges to determine the most suitable routes for timely and economical delivery. The selection of suitable transportation companies is based on identifying those that offer optimal cargo capacity, fuel efficiency and suitability for the prevailing maritime conditions in Eastern Indonesia.

The aim is to ensure the reliability of the distribution network by optimizing routes and selecting the most suitable carriers. As shown in the flowchart, the methodology of this study aims to achieve distribution planning that maximizes the efficiency of fleet utilization to optimize the target fleet.

2.1.2. LNG Distribution Model

The modeling of the LNG distribution is based on the location of the LNG plant closest to the power plant area. For this study, an LNG source is selected from the previous step. Then, the distance between the power plant and the LNG refinery source for the regional cluster is determined based on the above determination of the LNG refinery source. In this study, the Milk-Run distribution pattern is used because the studies conducted show that using the Milk-Run distribution pattern has the lowest supply cost (Rakhmawan, 2016). To develop an efficient LNG distribution model using the CVRP approach, a systematic and data-driven methodology is used in this study. The process starts with gathering data from a number of relevant sources, including IGU reports (2023) for carrier data, PLN RUPTL (Indonesian government-owned corporation) reports (2021) for LNG demand, and SKK MIGAS data on LNG sources. The subsequent phase includes an analysis of carrier utilization to determine the optimal option that maximizes distribution efficiency. The summary of the main phases of this study is shown in Figure 2 below.

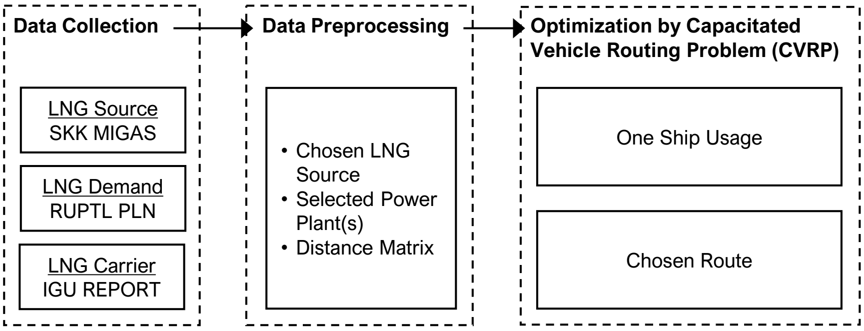

Figure 2. Distribution Modelling in This Study

Using this distribution pattern in LNG distribution, the distribution starts from the LNG refinery source to the LNG receiving point using SSLNGC transportation according to the capacity to be determined, and then the LNG is transported to the LNG receiving terminal. Furthermore, an optimization of the LNG distribution in the power plant is carried out. The collected data is used as input data for the creation of distribution scenario models. In creating this distribution scenario model, CVRP is used as a route problem method with variable distance between the delivery points, power plant requirements, carrier capacity and sailing speed. The CVRP was applied to each variation in the number of carriers with different transportation capacities according to the provisions outlined in this study. It was determined that it is not permissible to use more than one carrier to utilize the same carrier capacity. With this method, many variants of distribution route scenarios with multiple carriers with different capacities are created. The next step from the obtained variants is to select the best scenario in each utilization of the number of carriers with the lowest remaining total load criteria after distribution. To optimize the distribution of LNG, five main components were identified in this study, which are as follows

1. LNG source;
2. LNG receiving terminal as the destination point for LNG distribution;
3. Demand for LNG supplies from each receiving terminal;
4. Number of carriers and LNG loading capacity of carriers;
5. Distance between each distribution point based on a distance matrix.

In this study on the application of the CVRP to LNG transportation, several key components are used for the model calculations. These components include the distances between different locations, the demand at each receiving terminal, the specific locations where this demand must be met, and the specifications of the transportation companies, that include speed, fuel consumption, and capacity. If a carrier is contracted to transport LNG on a specific route, the decision variable is set to 1, otherwise it is set to 0. The model includes multiple locations and different types of carriers to ensure that all demands are met efficiently.

The model determines the optimal routes and assignments for LNG carriers to maximize freight capacity utilization. It combines the effects of decision variables, distances between locations and the distribution of ship cargo for each demand. The decision variable ensures that only assigned routes are considered, including factors such as voyage distance, operating costs and fuel consumption. The model also shows that the total demand from the receiving terminals assigned to each LNG carrier is at most equal to the carrier's cargo capacity. This ensures that each carrier transports a cargo within its maximum load capacity on its assigned route. This is a critical factor in maintaining operational efficiency and safety, as it ensures that each carrier can adequately meet demand without overloading.

Furthermore, the model contains a restriction that each receiver terminal is served exclusively by a single carrier with a certain capacity. This restriction ensures that each terminal receives its required LNG delivery from a single assigned carrier, preventing multiple deliveries or missed deliveries. The terms of this model are such that each route for a given carrier commences at the LNG source, serves the receiving terminal, and then returns to the LNG source. This constraint ensures that each route starts and ends at the same LNG source, forming a complete and closed loop. The term ensures the continuity of the LNG distribution route (Budiyanto, 2023), which is also used to describe this model. It implies that every carrier who has finished his service at a receiving terminal either serves another terminal or returns to the LNG source. This constraint ensures that each carrier maintains a continuous flow of service without remaining idle at any terminal. The model is constrained so that the decision variable can only take the values 0 or 1. This means that each carrier is either assigned to a route (1) or not (0). This binary restriction accurately reflects real-world decision-making processes and ensures that each route is either fully utilized or not utilized at all.

2.1.3 Modelling

The approach to optimize LNG distribution in this study is based on the CVRP model. This approach aims to optimize the efficiency of the LNG delivery fleet by taking into account variations in sailing speed and dynamic distribution requirements. In the study, the CVRP model is used to investigate the distribution of LNG with a focus on a single type of cargo: LNG with a single ship size and a capacity of 15,600 cbm.

CVRP calculation model includes the distance between location i and location j (S_{ij}), the demand of each receiving terminal (D_i), the demand location point (a_i), SSLNGC with the cargo capacity (Q). The decision variable in this study is symbolized as X_{ij}, where ship transport LNG on route (R) from location i to location j. If the ship transports LNG from location i to location j, then X_{ij} is 1, and otherwise it is 0, with $i, j = 1,2,3, ..., i, j =\in R$, and $i \neq j$. The objective function to be achieved is to maximize the LNG cargo transported using a SSLNGC with 15,600 cbm capacity by minimizing the remaining cargo by using the equation below (Budiyanto et al., 2020):

$$min \sum_{i,j \in R,\ i \neq j} X_{ij}\, S_{ij}$$

The equation below has an objective function that ensures that the number of receiving terminals served by ship must have a loading capacity equal to or less than the capacity of the ship serving the route.

$$\sum_{i \in R} D_i \sum_{\sum j \in R, j \neq i} X_{ij} \leq Q$$

The equation below has an objective function that ensures that each receiving terminal is served exactly once by a ship with its capacity.

$$\sum_{i \in R, j \neq i} X_{ij} = 1, \forall\, i = 0, 1, \ldots, n$$

$$\sum_{j \in R, j \neq i} X_{ij} = 1, \forall\, j = 0, 1, \ldots, n$$

The equation below has an objective function that ensures that a given ship route starts from the LNG source, then serves the receiving terminal and then returns to the LNG source.

$$\sum_{j \in R} X_{0j} = 1, \forall\, Q = \{0, 1, \ldots, n\}$$

$$\sum_{i \in R} X_{i0} = 1, \forall\, Q = \{0, 1, \ldots, n\}$$

The equation below guarantees a consistent LNG distribution route. Each ship serving a receiving terminal leaves the receiving terminal to continue the LNG distribution or return to the LNG source (h).

$$\sum_{i \in R, i \neq h} X_{ih} - \sum_{j \in R, j \neq h} X_{hj} = 0, \forall\, h = 1, \forall\, Q = 1, \{1, \ldots, n\}$$

The equation below ensures that the decision variables used are only integers.

$$x_{ij} \in \{0, 1\}, \forall\, i, j = \{0, 1, 2, \ldots, n\}, i, j \in R, i \neq j$$

The CVRP model will be evaluated through several scenarios to determine the optimal configuration to fulfil demand with least remaining cargo and least voyage distance. The logic in our proposed model is shown in Figure 3 below.

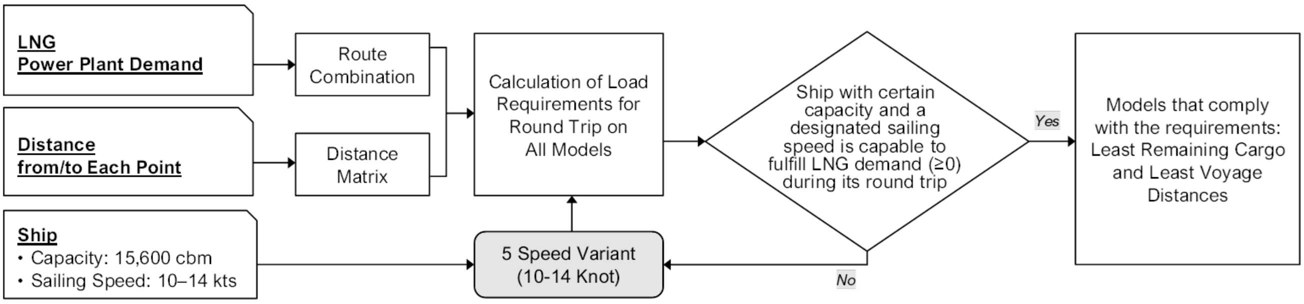

Figure 3. Logic of Model in This Study

Logic flow diagrams with the final result of obtained models according to the desired criteria to be applied to each cluster using three variations of the number of carriers on each model. The limits for determining the type variation and the use of the carrier for each model were determined in advance. Operational carriers for manufacturing this distribution model use five-speed variations for each carrier type. In the objective function, CVRP is used to obtain the total value of the load difference; each model is greater than or equal to 0. As for the use of CVRP in the production of the LNG distribution model, this study applies to models with more than one carrier. Carriers with a larger load capacity will distribute more demand points than carriers with a smaller size. Then, the selected model with the total difference of loads is selected by the determinations, that is, the choice of the model for each use of the number of carriers with the least remaining cargo.

2.2. Materials

2.2.1 Data Collection

In this study, data will be collected to obtain supplementary data on topics that are consistent with the methods used and that will be further analyzed. The data collected with regard to the optimization of LNG distribution for power plants include electricity demand data, gas demand data for each power plant, terminal coordinates (including latitude and longitude) to obtain the distance between locations, the capacity of the power plant to be supplied, the capacity of the LNG refinery, and data of LNG ships in terms of capacity, type, etc. Since in the LNG distribution scenario, several LNG plants in Indonesia could be utilized to meet the power plant demand in Eastern Indonesia, determining the optimal location for the LNG source plant is a crucial consideration. According to the data of KESDM (2022), several LNG sources scattered in Indonesia can be utilized for this study to supply power plants with gas as an energy source (see Table 1). In the implementation of LNG plant in Indonesia, there are Bontang LNG plant in Kalimantan Island which is managed by PT Badak, Tangguh LNG plant in Papua which is managed by BP (British Petroleum), and Donggi Senoro LNG plant in Sulawesi which is managed by PT DSLNG (DONGGI SENORO LNG).

Region	2018	2019	2020	2021	2022 (smt-1)*
Arun (PT Arun)	-	-	-	-	-
Bontang (PT Badak)	8,534,312	6,356,580	4,817,844	4,708,698	2,228,952
Tangguh (BP)	8,193,430	7,874,920	8,208,863	7,821,534	3,571,149
Donggi Senoro (PT DSLNG)	2,332,939	2,204,155	2,408,602	2,182,010	1,182,642
Total LNG Production	19,060,681	16,435,655	15,435,309	14,712,243	6,982,743

*smt-1: Gas production for the first semester of 2022

Table 1. LNG Gas Well Production Data in ton (KESDM, 2022)

The above data on LNG gas well production is from KESDM (2022). The annual production value shows that the projection of the first half of 2022 for the entire year indicates a further decline of around 5.07 %. These steady declines point to ongoing challenges in the Indonesia LNG production sector, likely due to operational inefficiencies, changing market dynamics and regulatory impacts. In this study, two clusters are selected and two LNG sources are considered in terms of their distance. The LNG plant to be used is the one closest to the LNG distribution area in the respective clusters, i.e. in the Maluku and Nusa Tenggara region clusters. The eligible LNG plants are Tangguh, Donggi Senoro and Bontang LNG Plant. With this data, a calculation phase is carried out to determine the production of the current LNG plant.

When determining the LNG demand for gas-fired power plants in Indonesia based on PLN's operating area, the data on PLN RUPTL's electricity demand (2021) is collected. The data to be used is the electricity demand data for the year 2023. In this study, the eastern Indonesian territory with the islands of Maluku and Nusa Tenggara is used as the study material. Since a single terminal is to supply a single power plant, the construction of a receiver terminal near the power plant is sought to facilitate the filling of the ship with the receiver. A single terminal will be built if the nearest plant is close to the coast.

This study identifies the sources of LNG and power plants in Eastern Indonesia, encompassing two major sub-regions. An analysis of the average distance between each power plant in a sub-region and the nearest LNG plant is used as the basis for determining the most efficient plant for the supply of LNG. The selected LNG plant serves as the main source in the LNG supply chain with the aim of ensuring a stable and sustainable energy supply to meet the operational requirements of the power plants in the region. By focusing on the geographical distribution of the LNG plant and the power plant, the aim is to optimize the LNG supply chain, which is essential to meet the growing energy demand in the region.

PLN RUPTL (2021) estimates that gas demand in Eastern Indonesia will increase steadily from 2021 to 2030, peaking around 2028. This increase reflects the region's growing energy demand due to population growth and industrial activity. The fluctuations from year to year indicate major industrial projects or infrastructure developments, with demand stabilizing after 2028. The trend line confirms the overall upward trend and highlights the need for investment in gas infrastructure, implementation of sustainability practices and diversification of energy sources to maintain reliable supply and support further growth. The data in Table 2 is the gas demand of all power plants in Eastern Indonesia, consisting of the Nusa Tenggara and Maluku territories. For each region, several power plants were used for each selected location with the gas demand of each power plant.

No	Region	PLTMG Name	Capacity (BBTU/year)	cbm/day	Coordinate (Lat, Long)
1	Nusa Tenggara	PLTMG Sumbawa 1 & 2	5.25	385.48	-8.447, 117.335
2		PLTMG Bima	5.25	385.48	-8.409, 118.699
3		MPP Flores	2.19	160.8	-8.460, 119.943
4		PLTMG Maumere	4.41	323.8	-8.620, 122.339
5		PLTMG Kupang	1.67	122.62	-10.338, 123.475
6	Maluku	PLTMG Ambon Peaker & Ambon 2	2.65	194.58	-3.549, 128.336
7		PLTMG Seram 1 & 2	1.47	107.93	-3.306, 128.947
8		PLTMG Sofifi	0.55	40.38	0.701, 127.550
9		PLTMG Namlea	1.09	80.03	-3.232, 127.110
10		PLTMG Tobelo 1 & 2	1.79	131.43	1.795, 127.886
11		PLTMG Ternate 2 & MPP Ternate	1.97	144.65	0.767, 127.306

Table 2. Eastern Indonesia Plant Demand Data (PLN RUPTL, 2021)

The identification of the specifications of the ships to be used in the studies will be carried out. As part of this study, LNG ship data will be collected from LNG ship databases such as the IGU Report (2023) and ship registration (Class NK, Bureau Veritas and Det Norske Veritas). A selection process is then carried out based on criteria corresponding to the selection of the type of ship to be used, in particular SSLNGCs with a loading capacity of 30,000 cbm or less. The capacities of the carriers identified vary considerably between 2500 and 30,000 cbm, reflecting the different transportation requirements within the SSLNG industry. Four ships in particular have a maximum capacity of 30,000 cbm, highlighting their crucial role in the transportation of LNG on a large scale.

The years of construction range from 2017 to 2023, indicating a relatively modern fleet, with most ships built in 2021 and 2018. This modernity indicates improved safety, efficiency and compliance with current environmental standards. The data highlights the SSLNG sector's reliance on a mix of medium to large capacity ships to meet the growing demand for LNG distribution and highlights the importance of maintaining a robust ship

Under the LNG distribution model, several ships will be selected that meet the SSLNGC criteria and have a cargo capacity of up to 30,000 cbm. The loading capacity of the vessel influences the amount of LNG transported in a distribution. According to Marine Traffic (2024) and Adli et al. (2022), the ship to be used in this study has a capacity of 15,600 cbm, an overall length of 151 m, a width of 28 m and a draught of 8 m. The ship also has an engine with an output of 8000 kW. According to FleetMon (2024), the maximum speed of the ship is 23.6 knots. These figures provide a comprehensive overview of the physical dimensions and performance of the ship. This ship is used in this study as a reference for the distribution of LNG in the respective regions of Nusa Tenggara and Maluku.

The following is the data on the ships obtained to support the LNG distribution scenario. Using the data collected is used for the analysis and the fuel consumption calculations will be performed based on the selected vessel speeds obtained from 21 ships with a cargo capacity between 1100 and 19,000 cbm along with the average speed for each vessel. As a result, the speed data to be used in this study is within the speed range of 10–14 knots for ships with a capacity of 1100 CBM to 19,000 CBM. Therefore, five speed variants (10, 11, 12, 13 and 14 knots) are selected from the ships within this range. The analysis of the data obtained from Marine Traffic (2024) and FleetMon (2024) examines the relationship between ship capacity and average speed. The capacity of the ships ranges from around 1000 to 20,000 cbm, with an average speed of between 9 and 15 knots. The results show no discernible correlation between ship size and speed. Smaller vessels (about 5000 cbm) exhibit speeds ranging from 10 and 15 knots, while larger ships (about 15,000 cbm) demonstrate speeds predominantly between 10 and 14 knots. This means that factors beyond size, such as technology and operating conditions, have a significant impact on ship speed. The specifications of the selected SSLNGCs assume that each LNG receiving terminal in the study has a minimum depth of 10 meters, which allows access for the selected SSLNGC ships with a draft of 8 meters while ensuring a minimum Under Keel Clearance (UKC) of 2 meters, in accordance with the maritime safety guidelines set by the International Maritime Organization (IMO) in Resolution A. 893 (21) on the Sailing Planning Guidelines, which underlines the importance of maintaining a minimum UKC in critical areas with limited water depth.

2.2.2. Assumptions

In this study, several assumptions are made to refine the distribution strategy. These assumptions are critical to the accurate modelling and analysis of the case study and include the following:

1. LNG sources come from production facilities in Eastern Indonesia.
2. Each LNG receiving terminal specifies a water depth of 10 meters.
3. The carrier supplies from the refinery point to the power plant, assuming that liquefaction and regasification facilities are already available.
4. The carrier enters ports without dwelling or waiting time.
5. Time factors and capacity limitations of the regasification and liquefaction facilities are neglected.
6. The carrier's average sailing or operation speed is not affected by its age and capacity.

2.2.3. Distance Matrices

In order to develop an optimized distribution model for LNG, a distance matrix must first be created. This matrix shows the distances between the locations of LNG sources and power plants as well as between the power plants themselves. Using this distance data makes it possible to plan optimal distribution routes, reduce operating costs and maximize the utilization of the transportation fleet. This approach facilitates the improvement of logistical operations and provides a basis for more effective decision-making in the management of LNG distribution.

To determine the optimal LNG supply source for the Nusa Tenggara and Maluku regions, a calculation was made of the average distance between the location of the power plants in a region and several alternative LNG sources, namely the Bontang LNG plant, the Tangguh LNG plant and the Donggi Senoro LNG plant. The Donggi Senoro LNG plant was selected based on this analysis. This selection is based on the parameter of the shortest average distance between the locations of the power plants in the region and the LNG plant.

The distance matrices shown in Table 3 are used to plan the optimal route for the distribution of LNG.

Cluster 1 (Nusa Tenggara) served from LNG source: Donggi-Senoro (*x0*) in nautical mile							
Location		*x0*	x1	x2	x3	x4	x5
	x0		680	602	529	460	562
PLTMG Sumbawa 1&2	x1	680		105	169	317	414
PLTMG Bima	x2	602	105		81	226	321
MPP Flores	x3	529	169	81	0	151	288
PLTMG Maumere	x4	460	317	226	151	0	208
PLTMG Kupang	x5	562	414	321	288	208	0

Cluster 2 (Maluku) served from an LNG source: Donggi-Senoro (*x0*) in nautical nautical mile								
Location		*x0*	x1	x2	x3	x4	x5	x6
	x0		402	427	322	303	425	310
PLTMG Ambon Peaker and Ambon 2	x1	402	0	40	306	84	417	313
PLTMG Seram 1 and 2	x2	427	40	0	337	124	456	344
PLTMG Sofifi	x3	322	306	337	0	241	141	17
PLTMG Namlea	x4	303	84	124	241	0	378	242
PLTMG Tobelo 1 and 2	x5	425	417	456	141	378	0	138
PLTMG Ternate 2 and MPP Ternate	x6	310	313	344	17	242	138	0

Table 3. Distance matrices from LNG source: Donggi-Senoro in nm (Google, 2024)

Distance information is crucial for determining the most efficient route, reducing travel time and optimizing fleet deployment. The use of this distance matrix enables the development of a more efficient LNG distribution strategy, thereby improving the operational performance of LNG distribution in the Nusa Tenggara and Maluku regions.

3. RESULTS AND DISCUSSIONS

3.1. Results

3.1.1. Route and Region Clusters

The first step in determining routes and regional clusters is to determine the regional cluster of the location between the plants. With the acquisition of power plant data based on the archipelago from PLN RUPTL (2021), the geographical cluster area was divided into two clusters, namely the Nusa Tenggara cluster, which consists of five power plant sites, and the Maluku cluster, which consists of six power plant sites. The steps to determine the route are to create a distance matrix between the power plants and plants in each cluster from one LNG source, Donggi-Senoro.

3.1.2. Distribution Model

Several factors are required to perform CVRP optimization, in particular the determination of the sailing speed and the distances between the points. The solution to the problem of modelling LNG distribution scenarios using the heuristic method is applied to the program to be developed. Several assumptions are used in this study, including:

- Loading and unloading times are constant: three hours (Yusman, 2018).
- Time in port is constant: six hours (Yusman, 2018).
- To overcome the uncertainty of shipping conditions, ten hours (buffer time) are allocated for each voyage from one location to another (Budiyanto et al., 2019).
- Capacity limitation factors of regasification and liquefaction plants are neglected.

The BOG rate for small-scale LNG carriers will be based on the results of the study by Harperscheidt (2011), which is 0.15 % of the ship's capacity per sailing days. The BOG is calculated by multiplying 0.15% of the ship's capacity by the number of sailing days.

This calculation accounts for the daily BOG rate over the duration of the ship's operation and the total LNG capacity of the ship. This assumption ensures that the BOG estimates are in line with IMO guidelines, which supports accurate operational planning and environmental management in line with industry standards. The amount of BOG generated during the duration of the voyage is included as a variable in the calculation, which is added to the total volume of cargo transported in that specific operation.

Figure 4 below illustrates the determination of the model according to the above provisions. Two variables are considered in this distribution model: routing sequences and variation of sailing speed, with an objective function, are models with the least remaining cargo from a round trip distribution. The model selects the most efficient distribution pattern by systematically testing different combinations of routes and sailing speeds, thus improving delivery efficiency.

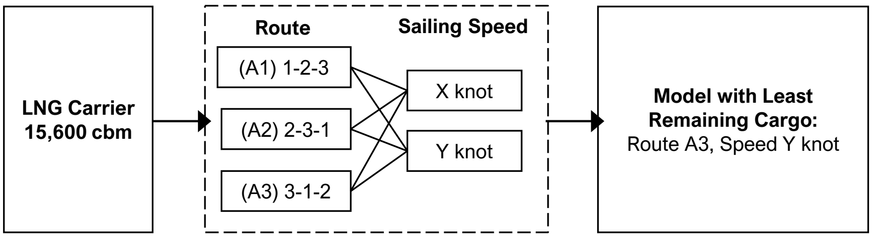

Figure 4. An illustration of model determination

The modelling of LNG distribution scenarios has led to the identification of several key conclusions. The utilization of the iteration results facilitates the examination of the relationship between the total distances travelled and the total remaining cargo of the selected carrier. Specifically, the distribution of an SSLNGC with a capacity of 15,600 cbm was examined at various sailing speeds from 10 to 14 knots.

Figure 5 shows an example route for cluster 2. The figure includes two diagrams: Diagram A, which illustrates the relationship between speed and remaining cargo with sailing time, and Diagram B, which illustrates the relationship between speed and remaining cargo with total sailing distance.

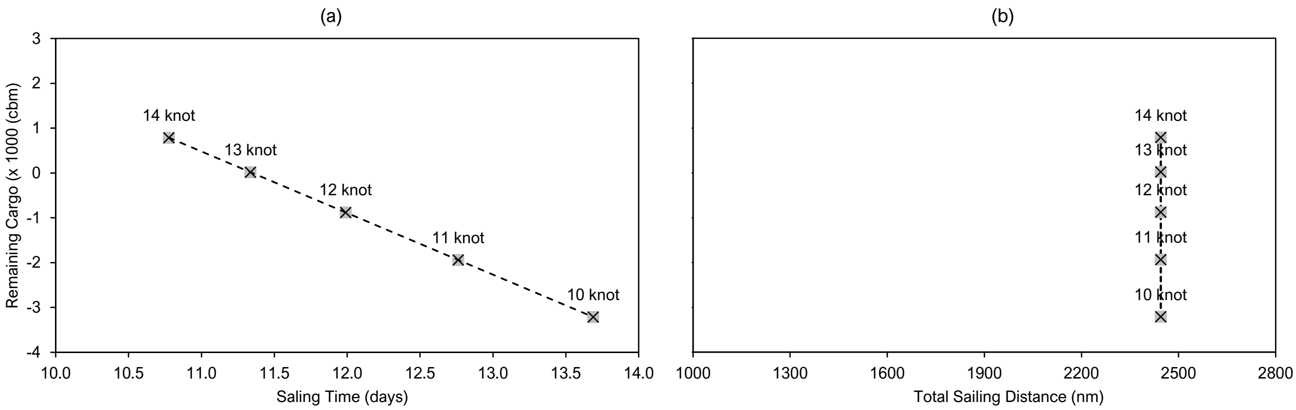

Figure 5. One sample route (Cluster 2) in ship speed selection: Remaining cargo and (a) sailing time (days) and (b) total sailing distance (nm)

The figures show that a speed of 13 knots is the optimum rate for distributing the cargo. This is based on the observation that at this speed the remaining cargo volume is close to 0 m³, which indicates that the cargo has been optimally and efficiently distributed and only little cargo remains on the ship. At lower speeds (10-12 knots), a negative value for the remaining cargo indicates inefficiency in the distribution process. At higher speeds (14 knots) there is still undistributed cargo remaining on ship. Therefore, 13 knots is the optimal speed for the most efficient distribution with the least remaining cargo. The total remaining cargo and the sailing distances resulting from iterating the model and varying the sailing speed for Cluster 1 (Nusa Tenggara) and Cluster 2 (Maluku) with an SSLNGC of 15,600 cbm are shown in Figure 6.

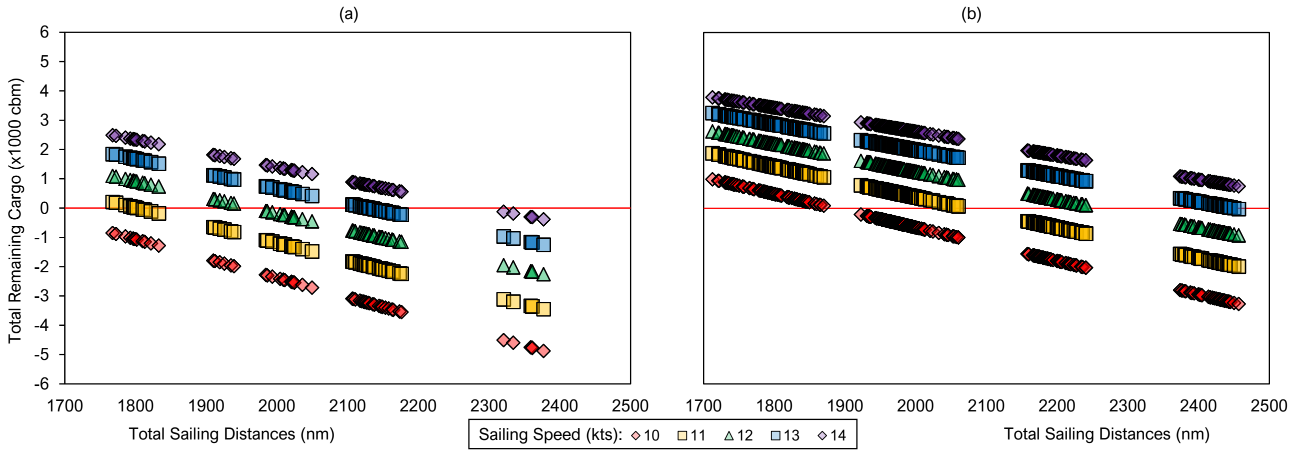

Figure 6. Total remaining cargo and sailing distances in various sailing speed in Clusters: (a) 1 (Nusa Tenggara) and (b) 2 (Maluku)

The total sailing distances were calculated from the variations in the route combination of distances between the points travelled by SSLNGC. The remaining total cargo is calculated by subtracting the vessel capacity from the total amount of LNG required for each trip, along with the resulting BOG. For Cluster 1 (Nusa Tenggara) and 2 (Maluku) with routes that meet all requirements, it can be concluded that the lowest route distance gives the highest total remaining cargo and the total trip distance gives the lowest total remaining cargo from the results of the existing iterations and there is a linear relationship between the two variables. Therefore, using the sailing speed in conjunction with the correct route selection can give the correct model for the distribution of LNG. Based on Table 4 shows the model with the lowest remaining total cargo.

Cluster	Ship Capacity (cbm)	Sailing Speed (knot)	Route	Total Sailing Distances (nm)	Total Remaining Cargo (cbm)
1	15,600	13	0-1-3-4-5-2-0	2130.8	4.23
2			0-2-5-4-6-1-3-0	2444.9	19.03

Table 4. Least remaining cargo scenarios for Clusters 1 and 2

3.2. Discussions

Based on the results of the LNG distribution model shown in Figure 6, with the objective of obtaining the lowest remaining cargo, there is an alternative in the proposed model: to obtain the least sailing distances travelled during a distribution operation.

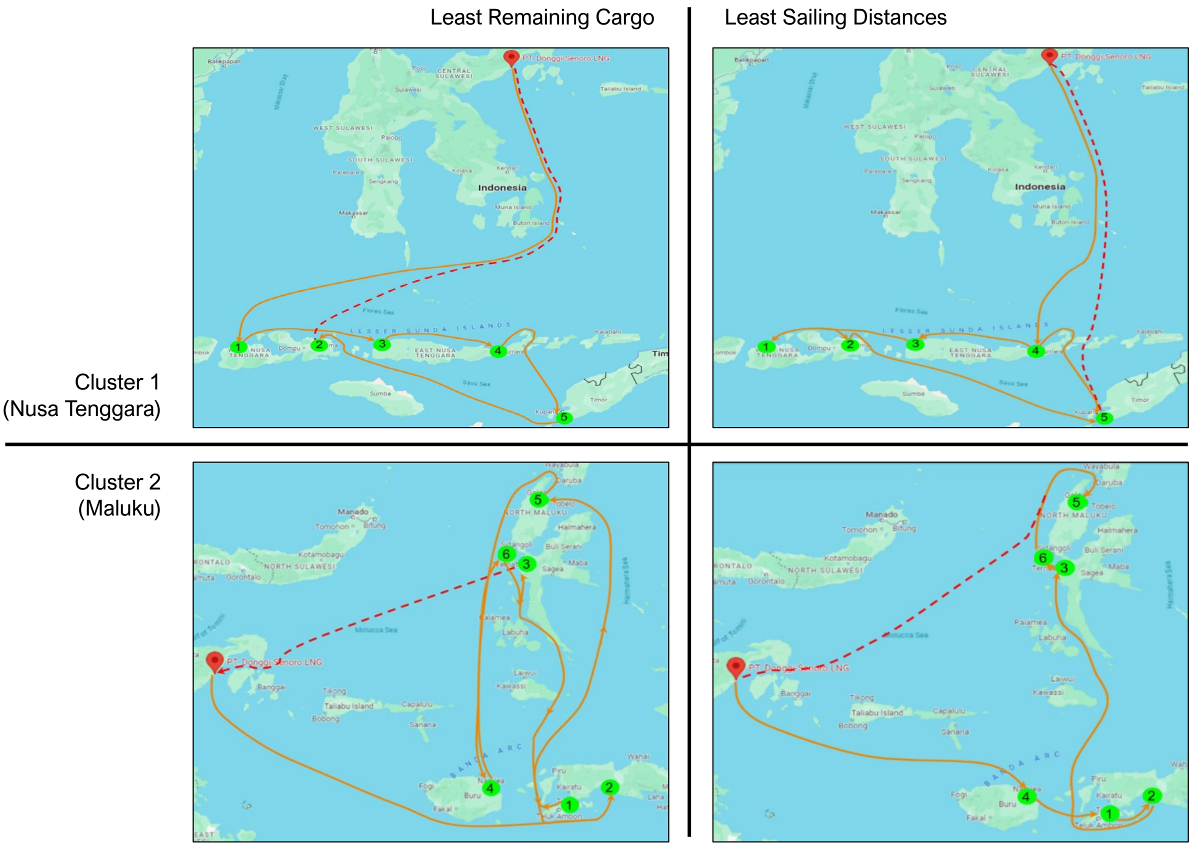

Figure 6. Route comparison of least remaining cargo and sailing distances (Google, 2024)

The table above compares the preferred routes shown on a map between two different objectives in the modelling with different objective references using the same ship scheme as in Table 5.

Cluster	Ship Capacity (cbm)	Sailing Speed (knot)	Route	Total Sailing Distances (nm)	Total Remaining Cargo (%)
1A	15600	13	0-1-3-4-5-2-0	2130.8	0.03
1B			0-4-3-1-2-5-0	1767.7	11.86
2A			0-2-5-4-6-1-3-0	2444.9	0.12
2B			0-4-1-2-3-6-5-0	1342.7	31.25

Table 5. Results of least remaining cargo and sailing distances

Cluster A represents the model with the lowest destination for total remaining cargo as used in the modelling of this study, and Cluster B represents the model with the lowest total distance. The results show the difference in the choice of route sequencing that affects the total remaining cargo and the sailing distances generated. An objective comparison between the lowest remaining cargo in the distribution and the lowest total distance gives different advantages in each outcome. With the lowest total distance, the advantage lies in the operating time, as time-dependent variables are more efficient. The lowest remaining load, on the other hand, offers advantages in terms of effectiveness in designing the distribution strategy, so that the chosen route can give a more effective picture of the load distribution. The comparison presented above can be used as an alternative method to determine the main objective of LNG distribution modelling. This is achieved by selecting two different objectives, which are then evaluated as potential outcomes.

4. CONCLUSION

This study evaluates the feasibility of using the SSLNGC transportation mode to meet the energy needs of power plants in the Indonesian archipelago. The study area, Nusa Tenggara and Maluku, is intended to illustrate the geographical conditions of Indonesia. By using a single ship with identical specifications and a range of available speeds, a combination of routes and speeds can be identified that is suitable to meet the needs of all power plants and maximize cargo on each round trip. Applying the existing conditions leads to the right combination of operating speed and route that provides the solution with the least residual cargo. The results of this study show that it is not possible to determine the optimal ship speed variation based on the lowest or highest speed, as the optimal operating speed varies depending on the specific circumstances. The objective of obtaining the lowest possible residual cargo requires a customized approach to ship speed. When determining the main objective of obtaining the lowest residual cargo at the shortest total distance, it is important to note that residual cargo and total distance are inversely related. The lowest possible residual cargo leads to the opposite effect: a higher total distance. This relationship can also be applied in the opposite direction. In a practical scenario applicable to this study, the determination model would be used to optimize the logistics and distribution routes for a fleet of ships. In order to develop a more adaptive SSLNGC transportation model that optimizes logistics and distribution routes, it is imperative that future studies explore optimization techniques such as genetic algorithms or machine learning to refine ship speed and route selection while accounting for seasonal demand fluctuations.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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