

COMPARATIVE ANALYSIS OF LIQUEFIED NATURAL GAS (LNG) DISTRIBUTION SCHEME USING MILK-RUN AND HUB-SPOKE METHODS ON SMALL-SCALE LNG CARRIER IN EASTERN INDONESIA

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ABSTRACT

Liquefied natural gas (LNG) has been seen as a promising alternative in the face of these challenges. However, attention remains focused on the efficiency of LNG distribution, especially in the face of unpredictable demand fluctuations. Currently, with demands for increasing distribution efficiency, Indonesia, one of the largest LNG producers in Southeast Asia, faces a particular challenge in achieving efficiency in meeting domestic energy needs. To address the problem, the Indonesian government has initiated a program to streamline energy infrastructure development, focusing on LNG distribution in Eastern Indonesia. The study will use two distribution schemes, Milk-Run and Hub-Spoke, with different types of ship capacity to calculate operating costs. This study focuses on comparing the effectiveness of the two popular distribution schemes, the Milk-Run and the Hub-Spoke, especially in optimizing LNG distribution in the area. The data in this study was obtained from institutions that openly publish data in a digital system. The findings suggest that the Milk-Run distribution scheme was identified as an optimal solution for LNG delivery to multiple points from a single source for Northern and Southern Papua. The results of this study are expected to provide practical guidance to the parties concerned in their efforts to improve the efficiency of LNG distribution in eastern Indonesia and further study in other regions of Indonesia .

Keywords: Energy; LNG transportation; Maritime Economics; Maritime Logistics; Supply Chain; Sustainable Development

INTRODUCTION

Under these conditions, Liquefied Natural Gas (LNG) becomes one of the fuel initiatives that can provide solutions to the problems with fossil fuel use (Maritime, 2023). Furthermore, LNG infrastructure has a great potential for meeting demand. Unconsidered demand fluctuations sometimes make infrastructure unable to facilitate LNG distribution supply chain processes. Recently, this case occurred in the European region, where dozens of LNG carriers are waiting off the European coast due to restrictions on storage tanks for the regasification process. The root problem of this incident is the restriction of the regasification infrastructure, which prevents the unloading of cargo from being carried out on time. In the end, the price of LNG can rise significantly due to the barrier of waiting times and the swelling of the carriers' operating costs (CNN Indonesia, 2022). Thus, consideration of demand volumes and infrastructure capacity is critical in LNG supply chain planning.

Indonesia is one of the countries that holds a role as the country with the largest source of LNG in the Southeast Asian region. In addition to export routes, there is much potential to be developed in a mission to destroy domestic energy distribution. The geographical situation of an island state is a challenge to meeting domestic energy needs efficiently (APEC, 2020).

To meet the energy needs of an autonomous economy, the Indonesian government is planning a decommissioning program to build power plant infrastructure up to 35,000 MW. The plan will require good distribution chains and LNG demand in some small-scale areas, making LNG distribution using ships more profitable (PLN, 2021; Pratiwi et al., 2021).

In order to meet these requirements, the specifications of LNG carriers must have adequate dimensions and transport capacity to sustainably serve the supply chain to islands or landlocked areas. Thus, a small-scale LNG carrier (SSLNGC) with a tank capacity of less than 30,000 m³ has the advantage of distribution flexibility and lower investment value than a conventional LNG carrier (150,000 m³). This condition is considered to have an advantage in the operational application of the ship in domestic waters (APEC Energy Working Group, 2019).

The operation of SSLNGC as an LNG loading feeder in eastern Indonesia has been discussed in previous study (Nugroho et al., 2023; Murdiyanto, Amrullah, & Gaetama, 2021). The distribution of LNG from Ambon to several power plants in the Maluku and Papua regions was simulated using several heuristic methods. The models derived from such methods are considered the most effective in serving the demand for LNG cargo transportation.

Other study discusses optimizing small-scale LNG logistics to reduce the cost of production of power plants in Bangka, Belitung, and Pontianak (Kartohadjono & Aldrin, 2019). The Milk-Run distribution scheme, or Direct Shipment, proved more cost-effective than the Point-to-Point scheme.

Several related studies have discussed the Hub-Spoke distribution scheme for natural gas, LNG, and compressed natural gas (CNG) distribution cases (Nikolaou, 2010). The Hub-Spoke scheme is more profitable than other schemes, depending on the carrier's capacity, efficiency requirements, and availability of the regasification terminal.

However, the above studies has yet to discuss quantitative comparisons between one method and another to describe each method's characteristics. The advantages and disadvantages of each method in the cost context have yet to be discussed systematically at the inter-terminal or inter-port level. Discussions about these aspects and their relationship to transportation demand, carriers' capacity, and sailing distances can provide valuable information that can be used as a logistical reference.

Therefore, the study aims to compare the LNG distribution schemes using the Milk-Run and Hub-Spoke distributions to understand the characteristics of each method. In this study, the area of Indonesia that will be used as the object of study is Eastern Indonesia because it has many islands with little LNG demand, making Eastern Indonesia a region that meets the criteria for using small-scale LNG carriers as a means of transportation. Using data on LNG transportation demand, sailing distance, and carriers' capacity, the study provides heuristic insights related to the transportation efficiency of LNG. Thus, the study's results are expected to contribute to the logistical planning of the LNG distribution, especially on a small scale of demand, to support a sustainable supply chain in Eastern Indonesia. Furthermore, the information generated from the available data can serve as a reference for better decision-making in planning an optimal distribution scheme based on geographical conditions and local logistical needs.

METHOD

The distribution of LNG from the source location of the LNG plant to the location of LNG demand with transport capacity and terminal demand will affect the distribution scheme. Therefore, planning is necessary to choose the correct distribution pattern. The distribution pattern will affect the transport cost factor.

In this study, the distribution pattern schemes used are Milk-Run and Hub-Spoke. The Milk-Run scheme is a distribution pattern that involves collecting LNG from various sources and delivering it to customers via designated routes. The mode of transport used has sufficient capacity to distribute LNG to each point of demand. It will return to the original point, namely to the LNG terminal, to refill the

cargo and then redistribute.

The Hub-Spoke scheme is a distribution pattern that refers to the central terminal (Hub) as the point of collection of LNG from various sources and its delivery to various destinations through specific channels. The mode of transport used in this distribution pattern is LNG carriers with sufficient capacity to meet the needs of several generating locations and deliver to the LNG receiving terminal. The Hub that has accommodated LNG with a capacity according to the demand of all location points will be transported to each location using a small capacity LNG carrier according to the location's demand. This study will compare the two distribution methods, as illustrated in Figure 1.

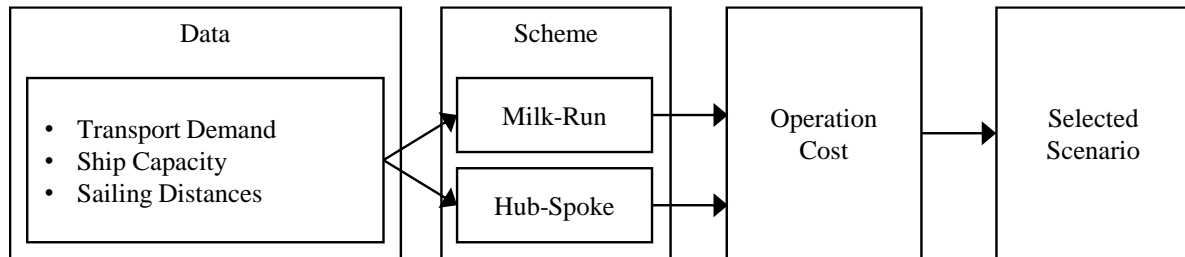


Figure 1. Research procedure

The steps of this study will follow the flowchart above, which guides the development of the distribution scheme with some constraints to be applied. Data collection on LNG demand, coordinates of each location point, and ship type will be obtained from a limited source: Company Q. We utilized the distance and time calculations for each location point for use in the next stage. This study will compare two main scenarios: the Hub-Spoke and Milk-Run methods. Both scenarios will consider SSLNGC with a 3000 and 7000 m³ capacities. The ship operating costs (OPEX) will be calculated based on the distribution scheme and ship type combination. The selected scenario will be the scenario with the lowest OPEX of all the scenarios that have been created.

Data

In this study, we obtained data from institutions that publish data in digital systems. We focus on openly available data to form a route optimization model and analyze the variables in the LNG distribution scheme. The following are the data used in this study:

1. Annual LNG demand data for each power plant in the Northern Papua and Southern Papua: 1 source terminal (Tangguh LNG) and 18 destination terminals (10 clusters), as shown in Table 1;
2. Shipping distance assumed for each inter-terminal route scenario: 100 shipping routes (referring to Company Q's limited sources);
3. Transport cost assumptions: Daily charter fee, SSLNGC with transport capacities: 3000 m³ (18,706 USD/day) and 7000 m³ (25,378 USD/day) (refer to the limited source of Company Q; IGU, 2023)

In this case, the LNG demand in (1) above is assumed not to fluctuate during the one year.

Distribution Scheme Model

Two distribution schemes, Milk-Run and Hub-Spoke, are simulated to provide an understanding of the distance attributes and ship operating costs resulting from both schemes in general. The Milk-Run scheme offers flexibility in loading and unloading sequences at multiple destination terminals (multi-unloading), where the ship does not have to return to the origin terminal. In the case of small transport demands, this scheme is feasible because the cargo can serve the demand at multiple terminals in a single ship. Therefore, given a specific ship size, the scheme will prioritize the route with the shortest distance to minimize the total cost. Figures 2(a) and 2(b) illustrate a sample scenario of the Milk-Run scheme.

Table 1. LNG demand in the Northern Papua and Southern Papua (PLN, 2021)

Region	No.	Cluster	Power Plant	BBTUD	10,000 m ³ /year	
Northern Papua	1	Manokwari	PLTMG Manokwari 2	3.23	8.22	
	2		MPP Manokwari	3.02		
	3		PLTMG Manokwari 3	1.97		
	4	Nabire	MPP Nabire	2.25	3.12	
	5		PLTMG Nabire 2	0.87		
	6	Serui	PLTMG Serui	0.92	0.92	1.40
	7	Biak	PLTMG Biak	2.19	4.14	
	8		PLTMG Biak 2	0.64		
	9		PLTMG Biak 3	1.31		
	10	Jayapura	MPP Jayapura	7.72	17.32	
	11		PLTMG Jayapura Peaker	2.98		
	12		PLTMG Jayapura	6.62		
Southern Papua	1	Langgur	PLTMG Langgur	1.67	1.67	25.36
	2	Dobo	PLTMG Dobo	1.00	1.00	15.18
	3	Saumlaki	PLTMG Saumlaki	0.86	0.86	13.06
	4	Merauke	PLTMG Merauke 1	3.89	3.89	59.07
	5		PLTMG Merauke 2			
	6	Timika	MPP Timika	0.98	0.98	14.88

Route variations will emerge from the Milk-Run scheme depending on the number of destination terminals and the volume of transport demand. The number will become significant as the route or destination terminals vary. In addition, the order in which destination terminals are visited will directly affect the total distance and time required for a ship's round trip.

In addition, the Hub-Spoke scheme offers single loading and unloading where the ship will return to the origin terminal for each destination terminal. This scheme is advantageous for ships sized to meet the transport demand. Cargo can be carried on demand for each return route, minimizing over-carriage. The illustration of the Hub-Spoke scheme is shown in Figure 2(c).

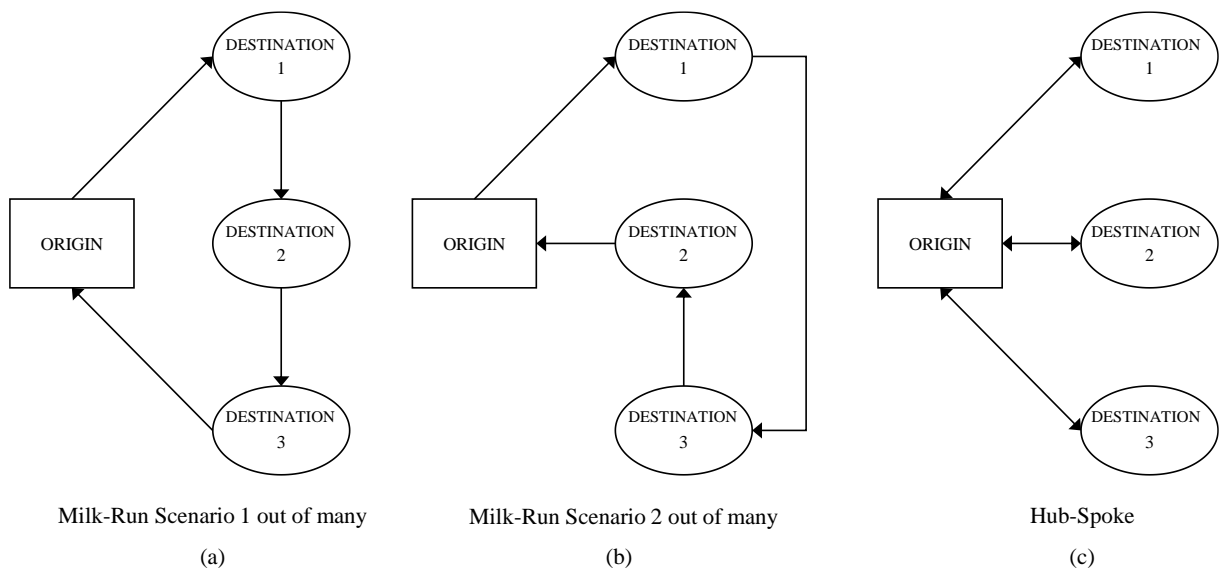


Figure 2. Illustration of Origin and Destination Terminals in Milk-Run and Hub-Spoke Schemes

The Hub-Spoke scheme does not provide any variation in the route selection element. With the ship returning to the origin terminal for each journey, the order of the destination terminals becomes irrelevant. Thus, with a predetermined ship size, the Hub-Spoke scheme will tend to minimize costs in any load or freight demand optimization scenario.

The discussion in this section will be formed based on several limitations and assumptions in applying the method described in the previous section. The following are some of the assumptions set in the simulation of the Milk-Run and Hub-Spoke distribution schemes:

1. The choice of LNG carriers with a capacity of 3000 and 7000 m³ is considered to be serviceable by the entire destination terminal, regardless of the main dimensions and specifications of the ship;
2. The demand for LNG does not change during the simulation of the distribution scheme, which is assumed to be one year ahead;
3. The speed of the transport ship is considered constant in both distribution schemes, Milk-Run and Hub-Spoke, especially in the Hub-Spoke scheme, where the speed of the ship when fully loaded and empty is considered the same: 15 knots (Najoan et al., 2018)
4. The round-trip route distance for each destination terminal is assumed to be uniform or the same; for example, a ship is assumed to travel 592 nm on the Tangguh-Manokwari and Manokwari-Tangguh routes.

Ship Operating Costs

In this study, the ship operating cost is simplified as a derivative of the total cruise distance and travel time required. Knowing the cruise distance and the assumed ship speed, the round-trip journey time (ot , day) can be estimated using the following equation:

$$ot = (s/v)/24 \quad (1)$$

where ot is the round-trip operating time of a ship serving a route (days), s is the voyage distance (nm) and v is the ship speed (kn, assumed to be 15 knots (Najoan et al., 2018)). Furthermore, the number of trips required to serve the entire transport demand is defined using the following equation:

$$td = \left\lceil \frac{d}{sc} \right\rceil \quad (2)$$

where td (n-trips) is the transport requirement of a plant with capacity d (m³) when served by a ship with capacity sc (m³) in one year (trips/year). On the other side, a ship with a certain speed has a limit on the number of transportations based on time or the number of days in a year. Therefore, the number of trips that a ship can make in one year can be estimated using the following equation:

$$ts = \left(\frac{365}{ot} \right) \quad (3)$$

where ts is the ability of a ship to serve a route with a specific transport demand in one year (trips/year). Therefore, the determination of the number of ships required (q , n-ships) can be formulated based on the LNG transport demand in one year, and divided by the ability of a ship with a certain capacity to make a round trip in one year, as shown in the following equation:

$$q = \left\lceil \frac{td}{ts} \right\rceil \quad (4)$$

Finally, OPEX or the rental cost of a ship or fleet to serve a particular route in one year (op , USD/y) in this study is defined as the following equation:

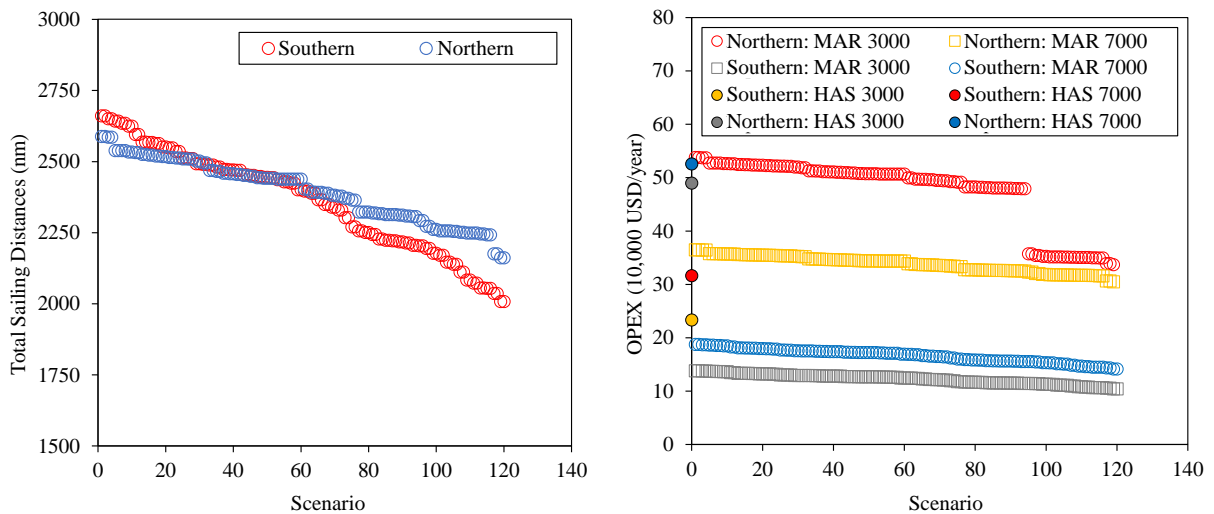
$$op = q \times (c \times ot) \quad (5)$$

where c is the charter cost of a ship or fleet (referring to Company Q limited sources, USD/d)

RESULT AND DISCUSSION

LNG demand data for Northern Papua consists of twelve power plants, and Southern Papua consists of six power plants (PLN, 2021). In Table 1, it can be seen that in one cluster, there are several power plants. In this study, the LNG demand data is the demand from clusters of several power plants with the same regional scope.

Applying the Hub-Spoke and Milk-Run schemes for SSLNGC with a capacity of 3000 and 7000 m³, 122 scenario variations for Milk-Run and two scenario variations for Hub-Spoke were generated for Northern Papua and Southern Papua. Each variant resulted in varying total voyage distance and OPEX, as shown in Figure 3.



*MAR: *Milk-Run* Scheme; HAS: *Hub-Spoke* Scheme.

*3000: SSLNGC with a capacity of 3000 m³; 7000: SSLNGC with a capacity of 7000 m³.

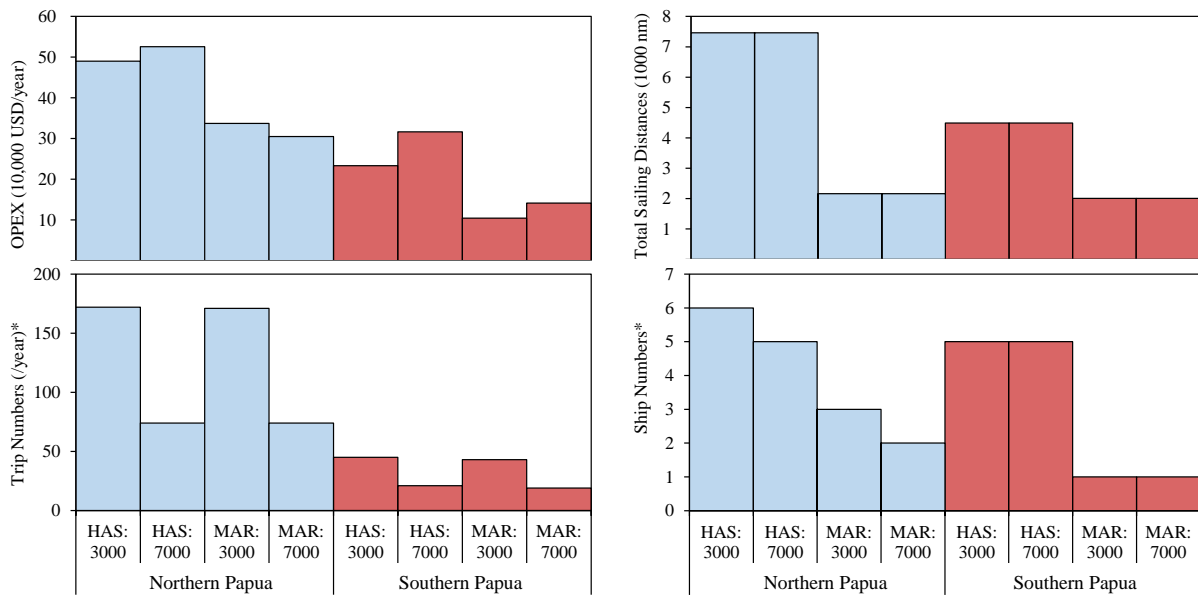
Figure 3. Total voyage distance and operating expenses (OPEX) for the Hub-Spoke scenario and the entire Milk-Run scenario

Selected Scenario

As discussed in the previous section, the selected scenarios can be determined by analysing the graphs of total voyage distance and OPEX against the scenario variations, considering the two distribution schemes described earlier. The selected scenario with the smallest OPEX for each scenario region and ship type is shown in Figure 4.

The simulation results show that for the Northern Papua, the Milk-Run scheme with a 7000 m³ ship is the leading choice because it has the lowest OPEX, amounting to 304,826 USD/year, a total distance of 2162 nm, and the number of ship trips of 74 trips/year. For the Hub-Spoke scheme, the best results in Northern Papua were obtained using a 3000 m³ ship with an OPEX of 490,105 USD/year, a total distance of 7460 nm, and 172 ship trips/year.

In the Southern Papua region, the Milk-Run scheme with a 3000 m³ ship is the leading choice because it has the lowest OPEX of 104,340 USD/year, a total distance of 2008 nm, and the number of ship trips of 43 trips/year. For the Hub-Spoke scheme, the best results in the Southern Papua were obtained using a 3000 m³ ship with an OPEX of 233,310 USD/year, a total distance of 4490 nm, and a total number of ship trips of 45 trips/year.



*HAS: Hub-Spoke Scheme; MAR: Milk-Run Scheme.

*3000: SSLNGC with a capacity of 3000 m³; 7000: SSLNGC with a capacity of 7000 m³.

Figure 4. Operating costs (OPEX), voyage distance, number of trips, and number of ship requirements of each selected scenario

The primary consideration in selecting the best scheme for the Northern Papua is to use the Milk-Run scheme with a 7000 m³ capacity ship because it has the lowest OPEX compared to other schemes, which is 304,826 USD/year. For the Southern Papua, the Milk-Run scheme with a shipping capacity of 3000 m³ is the choice because it has the lowest OPEX of 104,340 USD/year. From the selected scenarios for each region, a route map for each scheme has been generated, as shown in Figure 5.

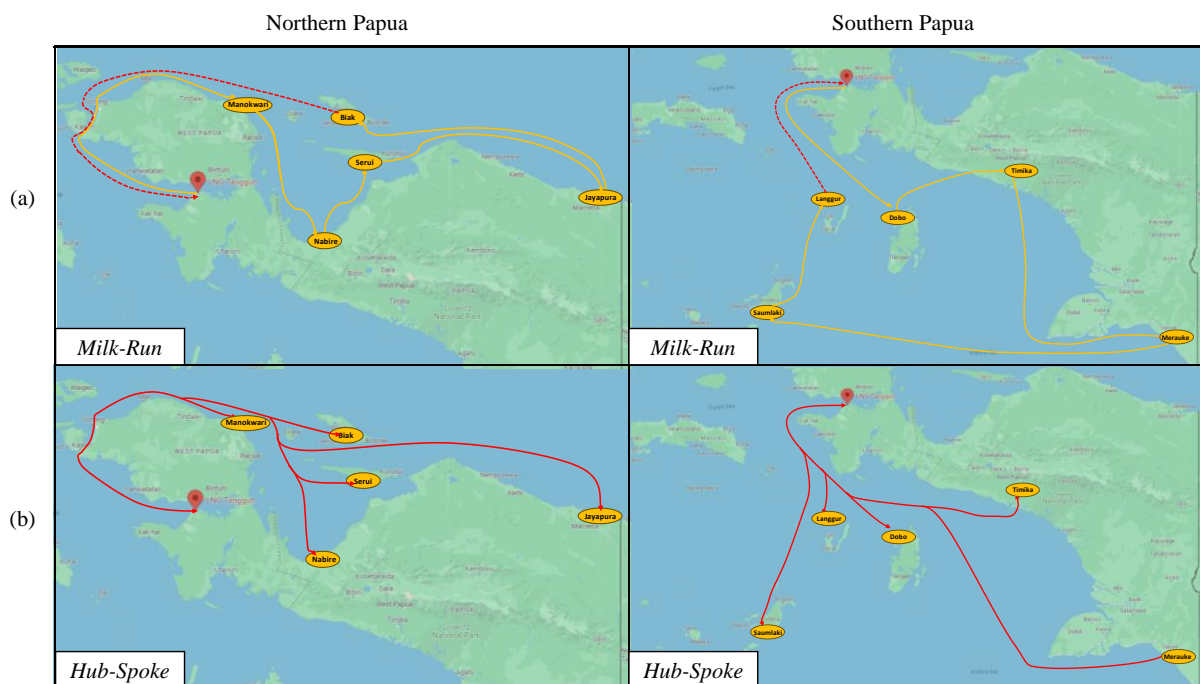


Figure 5. Visualisation of the selected schemes for the Northern Papua (Papua Utara) and Southern Papua (Papua Selatan)

CONCLUSIONS

Based on the simulation results to obtain the best LNG distribution scheme for the Northern and Southern Papua, the following conclusions were obtained:

1. For both regions, Northern and Southern Papua, it was found that using the Milk-Run scheme is an option in the case of LNG distribution to multiple points from a single source;
2. The choice of ships for each region is a 7000 m³ capacity ship with an OPEX of 304,826 USD/year for the Northern Papua and a 3000 m³ capacity ship with an OPEX consideration of 104,340 USD/year for the Southern Papua;
3. In this study, the weighting of a route is based only on the cost of chartering or operating a ship. In the future, this study can include other variables or functions. The purpose is to develop more realistic and dynamic towards various national and international shipping conditions;
4. This study has limitations; among them, we focus on a distribution scheme that is not related to fluctuations in power generation needs over time and conditions, including the Covid-19 pandemic;
5. In practice, a distribution scheme that combines the Milk-Run and Hub-Spoke schemes may occur concerning ship specifications and freight demand. In some cases, one of the schemes discussed in this study may not be possible due to terminal or port service limitations for specific ship dimensions;

As a next step, this study can provide a solid basis for developing an efficient and sustainable LNG distribution strategy, considering the critical factors mentioned earlier. This research is expected to provide practical guidance for various stakeholders in optimizing LNG distribution in Eastern Indonesia.

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