Revitalization of Environmentally Friendly Pinisi PELRA Fleet as a Feeder for Perintis Routes in 3TP Areas

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***Abstract*— Pelra Pinisi ships are increasingly being abandoned in freight transportation to 3TP (disadvantaged, outermost, remote, and border) regions, which are now predominantly served by perintis vessels. Unlike these perintis vessels, Pelra Pinisi ships do not receive similar government subsidies and face limitations in navigating currents and sea waves. This study proposes the revitalization of Pelra Pinisi ships through the implementation of a soft sail design to reduce emissions and fuel consumption, optimal route determination using a solver, and subsidy calculations to ensure competitiveness. The study was conducted in East Nusa Tenggara, covering six perintis routes and 24 ports. Survey data indicate that traditional Pelra vessels typically range from 30 to 40 meters in length. The proposed new designs include ships of 300 GT, 200 GT, and 100 GT, with lengths of 35.00 m, 22.75 m, and 17.50 m, respectively, and speeds of 12.5 knots, 7.8 knots, and 6.0 knots. Emission reductions were observed on the Kupang–Ndao and Kupang–Naikliu routes by 0.89%. The 300 GT vessel is optimal for the Kupang–Ndao and Labuan Bajo–Maumbawa routes, the 200 GT vessel for the Sabu–Raijua and Waikelo–Labuan Bajo routes, and the 100 GT vessel for several other routes.**

Keywords— Areas of 3TP, Environmentally Friendly, Maritime Transportation System, Pelra Pinisi Ship Design.

I. INTRODUCTION

Pinisi ship was designated as an Intangible Cultural Heritage of Humanity by UNESCO on December 7, 2017, during the 12th Session of the UNESCO Intergovernmental Committee for the Safeguarding of Intangible Cultural Heritage in South Korea. Pinisi ships have been used by Bugis sailors since the 1500s, navigating five continents, including routes to Vancouver, the Pacific Ocean, Australia, Madagascar, and Japan. Pinisi ships are characterized by their seven to eight sails and two main masts at the front and rear. Typically, these ships are constructed using four types of wood: ironwood, bitti wood, kandole/punaga wood, and teak [1].

According to Presidential Regulation No. 74 of 2021, Pinisi ships, as part of Pelra (People's Shipping), are ensured cargo availability by transporting a portion of goods procured using the State Budget, Provincial Budget, or Regional Budget, as well as goods managed by state-owned or regional-owned enterprises as needed [2]. Additionally, Pelra is planned to support public service obligations for freight transport to and from disadvantaged, outermost, remote, and border regions (3TP).

However, in the implementation of Presidential Regulation No. 74 of 2021, Pelra vessels have been increasingly abandoned for freight transport in 3TP regions. These areas are now served by perintis shipping routes utilizing steel vessels, which receive government subsidies, including lower fuel prices. In contrast, Pelra Pinisi ships do not receive subsidies and struggle to navigate currents and waves, leading to their declining use for freight transport.

Despite these challenges, Pelra Pinisi ships have the potential to reduce fuel consumption through sail utilization [3]. Beyond being a distinctive feature, sails provide additional propulsion, making these vessels more energy-efficient. Enhancing sail technology on Pinisi ships can improve environmental sustainability by reducing fuel consumption. Lower fuel usage decreases per-unit transportation costs, making tariffs and potential subsidies more affordable [4].

Additionally, Presidential Regulation No. 74 of 2021 mandates the empowerment of Pelra shipping through the construction of dedicated terminal [2]. These terminals should be equipped with docking and cargo handling facilities, warehousing, offices, commercial buildings, places of worship, fuel stations, electricity, potable water, sanitation, healthcare facilities, and other infrastructure supporting Pelra operations. They should also include marina facilities for docking yachts and ship maintenance. However, the implementation of these terminals remains unrealized.

Given these challenges, revitalization of Pelra Pinisi ships is necessary. This study proposes three key revitalization strategies: designing Pinisi ships with soft sails, optimizing routes for Pinisi ships in 3TP regions, and calculating the necessary subsidies. The implementation of soft sails aims to ensure lower emissions compared to perintis vessels. Route optimization seeks to align ship capacity with service needs in 3TP areas. Lastly, subsidy calculations are essential to ensure that Pelra Pinisi remains affordable for passengers and cargo owners while making them viable for government subsidies.

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II. METHOD

The methodology used in this study is a optimization based method using Microsoft Excel software. The optimization results will be used to determine the optimal ship size for each route, form clusters, and calculate the round-trip duration for each port. This methodology covers all activities that will be carried out to solve the problem or do the analysis process. For more details will be described as follows:

A. Problem Identification

This thesis writing begins with identifying and formulating problems regarding the work to be done as well as the limitations of the problem. This is to simplify the problem so as to facilitate the work and completion of this research.

B. Study of Literature

Collection of references materials that support this research acitivity, that is about existing perintis route, perintis ship size, perintis ship specific fuel oil consumption, perintis ship capacity, pinisi ship size, pinisi ship sail, and pinisi ship capacity.

C. Data Collection

The collection of supporting data to assist in the process of research is related to the existing pelra condition specifically types of cargo and loading conditions on pelra pinisi ships. Data collection is conducted through field surveys at Pelra Kalimas Port, Gresik Port, and Sunda Kelapa Port to ensure the accuracy and reliability of the research.

D. Ship Design

The Pinisi ships are designed in three different sizes: 300 GT, 200 GT, and 100 GT. These options provide

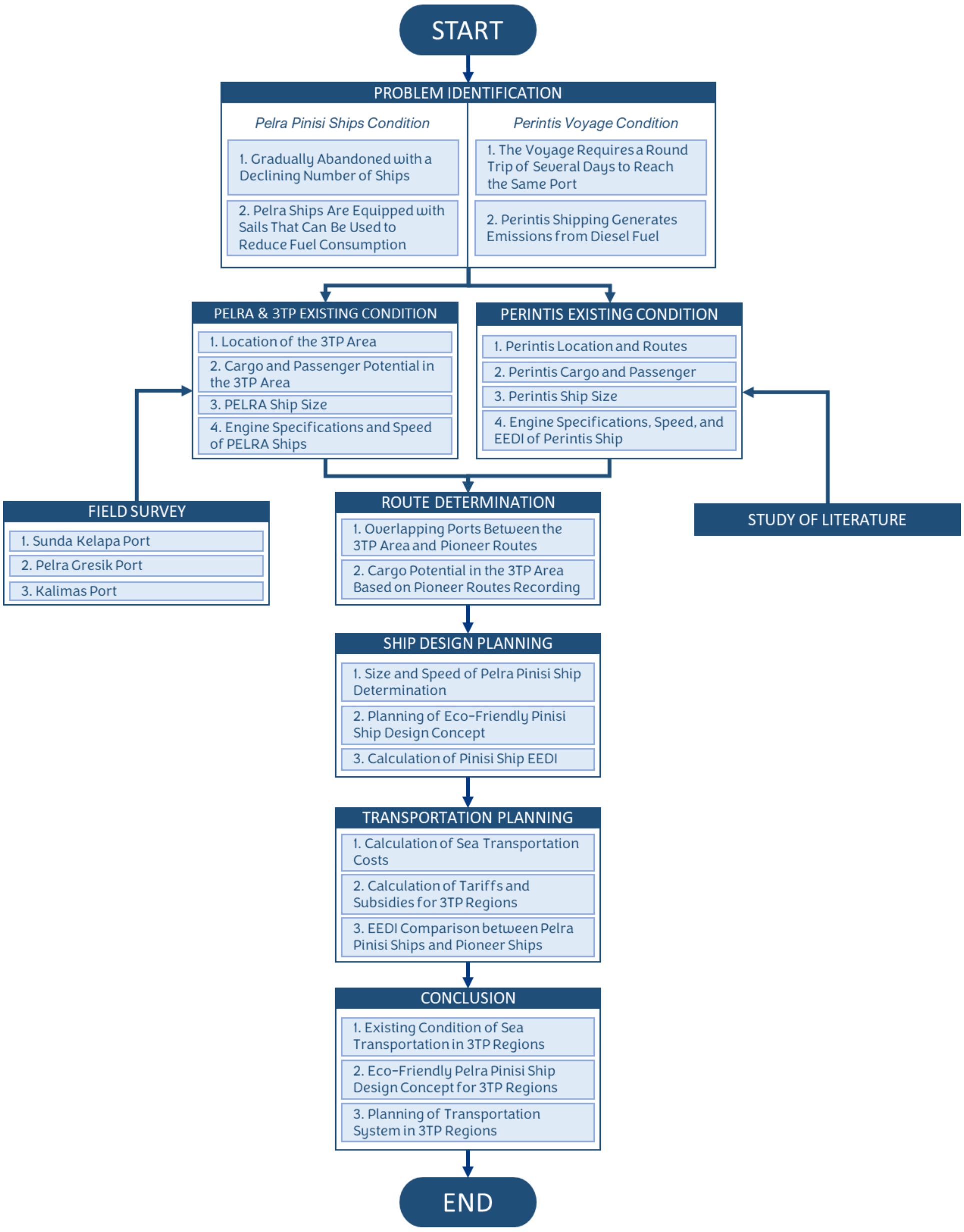

Figure. 1. Research Flowchart

flexibility in selecting the most suitable vessel for each route, depending on the number of passengers and the volume of cargo at each port. The 300 GT Pinisi ship can accommodate 58 passengers and carry 100 tons of cargo. The 200 GT Pinisi ship is capable of transporting 30 passengers and 50 tons of cargo. The 100 GT Pinisi ship is designed for 22 passengers and 25 tons of cargo.

Each ship incorporates an environmentally friendly concept and is equipped with a soft sail system that is estimated to reduce fuel consumption by up to 35 percent. [9], [10]. This innovation supports more sustainable maritime operations and helps lower operational costs. The estimated capital costs for each ship vary according to size. The 300 GT Pinisi ship costs approximately Rp 7,521,205,120, the 200 GT Pinisi ship costs around Rp 4,338,783,328, and the 100 GT Pinisi ship costs Rp 2,760,602,560.

In terms of performance, the 300 GT Pinisi ship operates at a speed of 12.5 knots with an Energy Efficiency Design Index (EEDI) of 214.52 grams of CO_2 per ton-nautical mile. The 200 GT ship travels at 7.8 knots with an EEDI of 355.04 grams of CO_2 per ton-nautical mile. The 100 GT vessel moves at 6.0 knots and has an EEDI of 435.46 grams of CO_2 per ton-nautical mile. These figures indicate that while all three ship sizes are designed with eco-friendly features, the 300 GT Pinisi ship has the best energy efficiency, making it more suitable for longer or busier routes with greater environmental performance.

E. Sea Transportation Optimization

Optimization is employed to determine the number of clusters, which are defined as combinations of multiple routes served by ships of the same size. Each cluster may follow either a port-to-port or multiport operational pattern, depending on factors such as sailing distance, passenger volume, and cargo load on each route. This approach ensures that vessel deployment is efficient and suited to the specific characteristics of each route. Moreover, optimization plays a key role in supporting the integration between the existing perintis shipping services and traditional Pelra Pinisi vessels. By aligning these systems, the overall maritime network can become more cohesive, efficient, and responsive to regional transportation needs [11].

There are several constraints in maritime transportation optimization, one of which is that the average port time at each port is determined to be two hours [12], [13]. The optimization of maritime transportation routes is conducted using the solver tool in Microsoft Excel and the linear programming method [14], [15]. There are several optimization method to solve transportation problem [7], [16], [17]. However in this study, optimization is modeled using mathematical equations to determine the optimal roundtrip for each route and the selection of the appropriate ship size. The

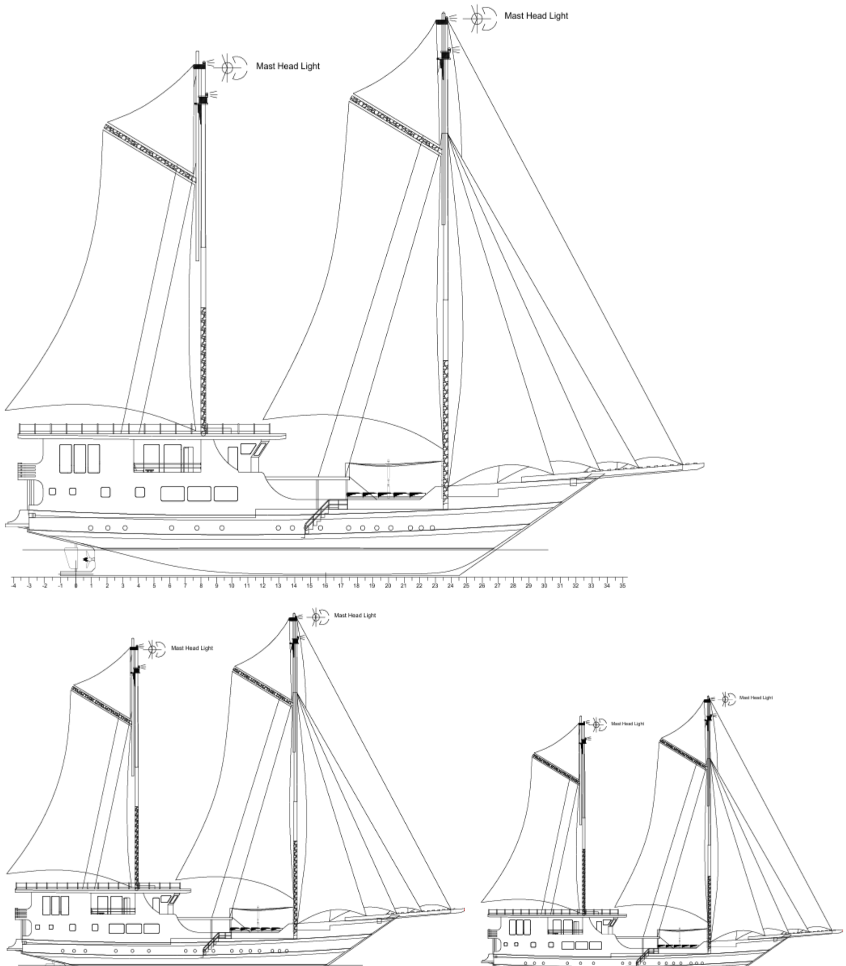

Figure. 2. 300 GT, 200 GT, and 100 GT Pelra Pinisi Ship Design

mathematical model for maritime transportation route optimization in this study is explained in the following section.

Index:

Origin	: i
Destination	: j
Ship Amount	: k
Distance	: J
Ship Speed	: V
Selected Ship Decision	: Y
Ship Price	: HK
Sail Price	: HL
Crew Salary	: GC
Maintenance Cost	: BPK
Fuel Consumption	: BB
Fresh Water Consumption	: AT
Passenger Carried	: PT
Cargo Carried	: DP

Formulation:

Seatime (Sijk)

$$\sum_{i=1}^{24}\sum_{j=1}^{24}\frac{\mathrm{Jij}}{\mathrm{Vk}} * 2 \text{ ; for k } = 1,2,3 \tag{1}$$

Porttime (Pijk)

2 for k = 1,2,3 (2)

Capital Cost (CC)

$$\sum_{k=1}^{3} Yk * (HKk + HLk) \tag{3}$$

Operating Cost (OC)

$$\sum_{k=1}^{3} Yk * (GCk + BPk) \tag{4}$$

Voyage Cost (VC)

$$\sum_{i=1}^{24}\sum_{j=1}^{24} Yk * (BBk + ATk)\ for\ k = 1,2,3 \tag{5}$$

Decision Variable

Ship Roundtrip Days : RTDij

Objective Function

Minimum Total Cost = (6)

$$\sum_{i=1}^{24}\sum_{j=1}^{24} Yk * (HKk + HLk) + Yk * (GCk + BPk) + Yk * (BBk + ATk)$$

Constraint:

$$RTDij \leq 14 \text{ for k} = 1,2,3 \tag{7}$$

$$PT \geq DP \text{ for k} = 1,2,3 \tag{8}$$

$$RTDij \geq 0 \text{ for k} = 1,2,3 \tag{9}$$

The results of the optimization will subsequently be used to calculate the Energy Efficiency Design Index (EEDI), which is an energy efficiency standard for ships developed by the International Maritime Organization (IMO). This index measures a vessel's energy efficiency based on its carbon dioxide (CO_2) emissions per transport capacity and distance traveled [18]. In general, the formula used to calculate the EEDI is as follows:

$$EEDI = \frac{P_{ME} \cdot C_{FME} \cdot SFC_{ME} + P_{AE} \cdot C_{FAE} \cdot SFC_{AE}}{Capacity \cdot V_{ref}} \tag{10}$$

Description:

P_{ME}	: Main Engine Power
CF_{ME}	: Main Engine Carbon Factor
SFC_{ME}	: Main Engine Specific Fuel Oil Consumption
P_{AE}	: Auxilary Engine Power
CF_{AE}	: Auxilary Engine Carbon Factor
SFC_{AE}	: Aux. Engine Specific Fuel Oil Consumption
Capacity	: Ship Capacity Deadweight
V_{ref}	: Ship Speed

III. Results and Discussion

The results obtained from the optimization process will include the optimum roundtrip days for each port, the optimum ship size, and the number of clusters for sea transportation. Additionally, the study compares the EEDI values of Perintis vessels and Pelra Pinisi ships at each port in East Nusa Tenggara to assess the reduction in EEDI resulting from the use of Pelra Pinisi ships. These results are derived from an optimization-based analysis.

A. Perintis Shipping in East Nusa Tenggara

From Figure. 3. we can see that East Nusa Tenggara is served by Perintis Shipping through six key routes: R23, R24, R25, R73, R86, and R88. All of these routes are based at Kupang Port, functioning as the central hub for regional maritime transportation.

Route R23 connects Kupang with Ndao, Sabu, Raijua, Ende, P. Ende, Maumbawa, Waiwole, Mamboro, and Waingapu, before retracing the same ports back to Kupang. This roundtrip covers a total distance of 894 nautical miles. The route is served by KM. Sabuk Nusantara 90, a vessel with a cargo capacity of 100 tons and a passenger capacity of 466. Operating at a service speed of 6.8 knots, the vessel has an Energy Efficiency Design Index (EEDI) of 110.74 g CO_2/ton·Nm. The estimated duration for a complete roundtrip ranges between 9 and 10 days.

Route R24 follows a longer and more complex itinerary, linking Kupang with Naikliu, Wini, Lirang, Ilwaki, Kisar, Romang, Leti, Lakor, Luang P. Kelapa, Sermata (Elo), Tepa, Kroing, and Saumlaki, before returning through the same ports. The total distance of this route is 1,364 nautical miles. KM. Sabuk Nusantara 67 operates this route, featuring a cargo capacity of 100 tons and accommodation for 466 passengers. It travels at 6.8 knots and has an EEDI value of 89.65 g CO_2/ton·Nm. Similar to Route R23, this roundtrip is completed in approximately 9 to 10 days.

Route R25 connects Kupang with Naikliu, Mananga, Lewoleba, Balauring, Baranusa, Kalabahi, and Atapupu, then retraces the same ports on the return leg. The route spans a total distance of 810 nautical miles and is served by KM. Sabuk Nusantara 108. This vessel has a cargo

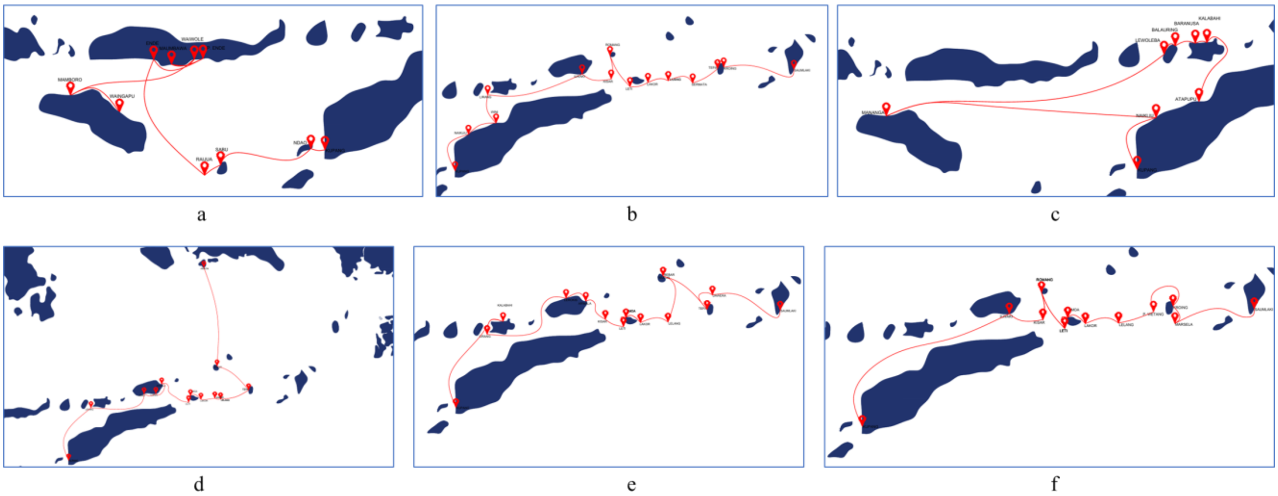

Figure. 3. (a) R23 Perintis Route, (b) R24 Perintis Route, (c) R25 Perintis Route, (d) R73 Perintis Route, (e) R86 Perintis Route, (f) R88 Perintis Route

capacity of 100 tons, can carry 466 passengers, and operates at a speed of 7.8 knots. Its EEDI value is 118.76 g CO_2/ton·Nm. Thanks to its higher speed, the roundtrip duration is shorter, approximately 6 to 7 days.

Route R73 is one of the longest, covering 1,560 nautical miles. It connects Ambon to Wulur, Tepa, Lelang/Elo, Luang, Lakor/P. Tamta, Moa, Leti, Kisar, Arwala, Ilwaki, Amau, Lirang, and Kupang, before making the return journey through the same ports. KM. Sabuk Nusantara 87 serves this route, with a capacity of 100 tons for cargo and 466 passengers. The vessel travels at 7.4 knots and has an EEDI value of 101.76 g CO_2/ton·Nm. Due to the extended distance and number of stops, the roundtrip takes between 12 and 20 days.

Route R86 follows a circular pattern linking Saumlaki, Dawera/Dawelor, Tepa, Wulur, Lelang/Elo, Lakor, Moa, Leti, Kisar, Arwala/Sutilarang, Lerokis, Lirang, Kalabahi, and Kupang, before looping back through the same locations. This route covers 1,524 nautical miles and is served by KM. Sabuk Nusantara 104, which offers a higher cargo capacity of 400 tons and a more limited passenger capacity of 160. It operates at 6.6 knots and has an EEDI rating of 140.35 g CO_2/ton·Nm. The estimated roundtrip time ranges from 10 to 12 days.

Route R88 connects Saumlaki with Marsela, Kroing,

P. Wetang/Herley, Lelang/Elo, Lakor, Moa, Leti, Romang, Kisar, Ilwaki, and Kupang, and then returns through the same sequence of ports. The route spans 1,332 nautical miles and is also served by KM. Sabuk Nusantara 104. On this route, the vessel accommodates 350 tons of cargo and up to 400 passengers. It operates at a faster speed of 12 knots and has a lower EEDI of 94.55 g CO_2/ton·Nm. Depending on conditions, the roundtrip takes approximately 11 to 19 days.

Together, these six maritime routes enhance connectivity across East Nusa Tenggara and surrounding regions, supporting both passenger mobility and regional logistics with consistent service schedules and standardized vessel capacities.

B. Clustering for Pelra Pinisi Ships

Based on sea transportation optimization, East Nusa Tenggara has been divided into 13 clusters, each served by one of three types of vessels: Pelra Pinisi 300 GT, Pelra Pinisi 200 GT, and Pelra Pinisi 100 GT.

The Pelra Pinisi 300 GT is identified as the most suitable vessel for three clusters: Cluster 1 (Kupang Port – Ndao Port), Cluster 2 (Labuan Bajo Port – Maumbawa Port), and Cluster 3 (Lewoleba Port – Larantuka Port – Laurentius Say Port – Marapokot Port).

The Pelra Pinisi 200 GT is optimal for two clusters: Cluster 4 (Sabu Port – Raijua Port) and Cluster 5 (Waikelo Port – Labuan Bajo Port).

Meanwhile, the Pelra Pinisi 100 GT is best suited to serve the remaining eight clusters: Cluster 6 (Ndao Port – Sabu Port – Raijua Port – Waingapu Port), Cluster 7 (Pulau Ende Port – Waiwole Port – Maumbawa Port – Waingapu Port – Mamboro Port – Mananga Port), Cluster 8 (Mananga Port – Waikelo Port), Cluster 9 (Pulau Ende Port – Ende Port – Larantuka Port), Cluster 10 (Marapokot Port – Reo Port – Labuan Bajo Port), Cluster 11 (Lewoleba Port – Balauring Port – Baranusa Port), Cluster 12 (Kalabahi Port – Baranusa Port – Wini Port), and Cluster 13 (Wini Port – Atapupu Port – Naikliu Port – Kupang Port). This clustering strategy allows for efficient allocation of vessels according to the specific needs of each route, thereby improving regional connectivity and maritime logistics.

Cluster 1 (Kupang Port – Ndao Port) spans a distance of 60 nautical miles, with an estimated sailing time of approximately 4.8 hours. Annually, the number of passengers at Kupang Port and Ndao Port is recorded at 13,050 and 7,102, respectively.

The annual cargo volume at Kupang Port reaches 7,102 tons, while Ndao Port handles around 2 tons. Based on optimization analysis, the ideal roundtrip duration for Cluster 1 is 1 day. With passenger and cargo tariffs set at Rp 17,600 and Rp 15,700, respectively, the total operational cost per vessel per year amounts to Rp 2,016,605,425. Meanwhile, the annual revenue is calculated at Rp 341,181,400, resulting in an annual subsidy requirement of Rp 1,675,424,025, or approximately Rp 5,077,043 per voyage.

Cluster 2 (Labuan Bajo Port – Maumbawa Port) covers a distance of 133 nautical miles, requiring an estimated sailing time of approximately 10.64 hours. Annually, the number of passengers at Labuan Bajo Port and Maumbawa Port is recorded at 286,036 and 366, respectively. In terms of cargo volume, Labuan Bajo Port handles 782.23 tons per year, while Maumbawa Port handles 69 tons. Based on optimization analysis, the optimal roundtrip duration for Cluster 2 is 1 day. The passenger and cargo tariffs for this route are set at Rp 28,300 and Rp 28,400, respectively. Consequently, the total annual operational cost for 15 vessels operating on this route amounts to Rp 30,389,955,847. The annual revenue generated is Rp 8,117,034,039, resulting in an annual subsidy requirement of Rp 22,272,921,808, or approximately Rp 4,499,580 per voyage per vessel.

Cluster 3 (Lewoleba Port – Larantuka Port – Laurentius Say Port – Marapokot Port) involves sequential distances of 36, 73, and 55 nautical miles, requiring estimated sailing times of approximately 2.88, 5.84, and 4.40 hours, respectively. The annual number of passengers at Lewoleba Port, Larantuka Port, Laurentius Say Port, and Marapokot Port is 1,793; 369,860; 40,979; and 987, respectively. Corresponding cargo volumes at these ports are 24 tons, 827.01 tons, 330.36 tons, and

184.54 tons, respectively. Based on optimization analysis, the optimal roundtrip duration for Cluster 3 is 1 day. Passenger tariffs for the Lewoleba – Larantuka, Larantuka – Laurentius Say, and Laurentius Say – Marapokot routes are set at Rp 10,900, Rp 17,800, and Rp 14,400, respectively, while the cargo tariffs are Rp 10,400, Rp 15,900, and Rp 13,200, respectively. With these tariffs, the Lewoleba – Larantuka route incurs an annual operational cost of Rp 40,270,355,318 for 20 vessels, generating annual revenue of Rp 4,040,074,941 and requiring an annual subsidy of Rp 36,230,280,377, equivalent to Rp 5,489,436 per voyage. The Larantuka – Laurentius Say route has an annual cost of Rp 40,365,558,153 for 20 vessels, with revenue of Rp 6,596,657,516 and a required subsidy of Rp 33,768,900,637 or approximately Rp 5,116,500 per voyage per vessel. Lastly, the Laurentius Say – Marapokot route incurs an annual cost of Rp 6,047,886,489 for 3 vessels, generating Rp 594,458,381 in revenue and requiring an annual subsidy of Rp 5,453,428,109, which amounts to approximately Rp 5,508,513 per voyage.

Cluster 4 (Sabu Port – Raijua Port) spans a distance of 14 nautical miles, with an estimated sailing time of approximately 7.8 hours. The annual number of passengers at Sabu Port and Raijua Port is 3,730 and 1,879, respectively. In terms of cargo volume, Sabu Port handles 54 tons per year, while Raijua Port handles 55 tons. Based on optimization analysis, the ideal roundtrip duration for Cluster 4 is 2 days. Both passenger and cargo tariffs are set at Rp 8,600. Under these rates, the total annual operational cost amounts to Rp 1,476,042,196. With annual revenue per vessel reaching Rp 32,542,400, the route requires an annual subsidy of Rp 1,443,499,796, equivalent to approximately Rp 8,748,484 per voyage per vessel.

Cluster 5 (Waikelo Port – Labuan Bajo Port) spans a distance of 70 nautical miles, with an estimated sailing time of approximately 8.97 hours. The annual number of passengers at Waikelo Port and Labuan Bajo Port is 9,624 and 286,036, respectively. In terms of cargo volume, Waikelo Port handles 432.42 tons annually, while Labuan Bajo Port manages 782.23 tons. Based on optimization analysis, the ideal roundtrip duration for Cluster 5 is 10 days. Passenger and cargo tariffs for this route are set at Rp 20,800 and Rp 18,200, respectively. At these rates, the total annual operational cost for two vessels is Rp 2,688,084,393, while the annual revenue is Rp 208,049,312. As a result, the required annual subsidy amounts to Rp 2,480,035,081, or approximately Rp 37,576,289 per voyage.

Cluster 6 (Ndao Port – Sabu Port – Raijua Port – Waingapu Port) encompasses routes covering distances of 60 and 96 nautical miles, with estimated sailing times of approximately 10 hours and 16 hours, respectively. The annual number of passengers at Ndao Port, Sabu Port, Raijua Port, and Waingapu Port is 944; 3,730; 1,879; and 193, respectively. Corresponding cargo

volumes are 2 tons, 54 tons, 55 tons, and 112.5 tons. Based on optimization analysis, the ideal roundtrip duration is 7 days for the Ndao–Sabu route and 3 days for the Raijua–Waingapu route. Passenger tariffs are set at Rp 16,100 and Rp 22,100, while cargo tariffs are Rp 14,500 and Rp 19,300, respectively. At these rates, the total annual operational cost for one vessel is Rp 1,391,841,388. The annual revenue generated is Rp 57,814,800, resulting in a required subsidy of Rp 1,334,026,588 per year, or approximately Rp 8,776,491 per voyage per vessel.

Cluster 7 (Pulau Ende Port – Waiwole Port – Maumbawa Port – Waingapu Port – Mamboro Port – Mananga Port) covers distances of 40, 24, 54, 47, and 9 nautical miles, with estimated sailing times of approximately 6.67, 4, 9, 7.83, and 1.5 hours, respectively. The annual number of passengers at Pulau Ende Port, Waiwole Port, Maumbawa Port, Waingapu Port, Mamboro Port, and Mananga Port is 1,146; 344; 366; 193; 91; and 3,412, respectively. The corresponding cargo volumes at these ports are 17 tons, 44 tons, 69 tons, 112.5 tons, 61 tons, and 67 tons. Based on optimization analysis, the ideal roundtrip duration for Cluster 7 is 14 days. The passenger fares for the respective segments are Rp 11,600 (Pulau Ende – Waiwole), Rp 8,600 (Waiwole – Maumbawa), Rp 14,200 (Maumbawa – Waingapu), Rp 14,000 (Waingapu – Mamboro), and Rp 7,800 (Mamboro – Mananga). The cargo tariffs for these segments are Rp 11,000, Rp 8,600, Rp 13,100, Rp 12,900, and Rp 8,000, respectively. With these rates, the total annual operational cost for one vessel is Rp 1,375,802,402. The annual revenue generated is Rp 17,780,800, resulting in a required annual subsidy of Rp 1,358,021,602, or approximately Rp 9,985,453 per voyage per vessel.

Cluster 8 (Mananga Port – Waikelo Port) spans a distance of 19 nautical miles, with an estimated sailing time of approximately 3.17 hours. The annual passenger volume at Mananga Port and Waikelo Port is 3,412 and 9,624, respectively. In terms of cargo, Waikelo Port handles 67 tons, while Labuan Bajo Port, indirectly linked through this network, handles 432.42 tons. Based on optimization calculations, the optimal roundtrip duration for Cluster 8 is 2 days. The passenger fare for this route is set at Rp 7,800, while the cargo tariff is Rp 8,000. With these rates, the total annual operating cost for one vessel is Rp 2,489,872,251. The route generates an annual revenue of Rp 27,149,600, resulting in a required annual subsidy of Rp 2,462,722,651, or approximately Rp 1,970,178 per voyage per vessel.

Cluster 9 (Pulau Ende Port – Ende Port – Larantuka Port) spans distances of 11 and 93 nautical miles, with estimated sailing times of approximately 1.83 and 15.5 hours, respectively. The annual passenger volume at Pulau Ende Port, Ende Port, and Larantuka Port is 1,146; 1,669; and 369,860, respectively. Correspondingly, the annual cargo volume at these ports is 17 tons at Pulau Ende, 39.5 tons at Ende, and 827.01 tons at Larantuka. Based on optimization calculations, the optimal roundtrip duration is 6 days for the Pulau Ende – Ende route and 4 days for the Ende – Larantuka route. The passenger fares for these routes are Rp 7,800 and Rp 21,600, respectively, while the cargo tariffs are Rp 8,000 and Rp 18,900. With these rates, the total annual operational cost for one vessel serving Cluster 9 is Rp 1,467,841,388. The route generates an annual revenue of Rp 45,871,750, resulting in a required annual subsidy of Rp 1,421,969,638, or approximately Rp 6,236,709 per voyage per vessel.

Cluster 10 (Marapokot Port – Reo Port – Labuan Bajo Port) spans distances of 107 and 54 nautical miles, with estimated sailing times of approximately 17.83 and 9 hours, respectively. The annual passenger volume at Marapokot Port, Reo Port, and Labuan Bajo Port is 987; 2,617; and 286,036, respectively. Meanwhile, the cargo volume at these ports is 184.54 tons at Marapokot, 1,191.97 tons at Reo, and 782.23 tons at Labuan Bajo. Based on optimization calculations, the optimal roundtrip duration is 6 days for the Marapokot – Reo route and 4 days for the Reo – Labuan Bajo route. The passenger fares for these routes are Rp 15,300 and Rp 14,200, respectively, while the cargo tariffs are Rp 13,500 and Rp 12,700. Given these rates, the total annual cost for operating one vessel in Cluster 10 is Rp 1,386,804,839. The route generates an annual revenue of Rp 69,891,842, resulting in a required annual subsidy of Rp 1,316,912,996, or approximately Rp 8,958,592 per voyage per vessel.

Cluster 11 (Lewoleba Port – Balauring Port – Baranusa Port) spans distances of 32 and 34 nautical miles, with estimated sailing times of approximately 5.33 and 5.66 hours, respectively. The annual passenger volume at Lewoleba Port, Balauring Port, and Baranusa Port is 1,793; 803; and 3,457, respectively. Meanwhile, the cargo volume at these ports is 24 tons at Lewoleba, 1 ton at Balauring, and 6 tons at Baranusa. Based on optimization calculations, the optimal roundtrip duration is 4 days for the Lewoleba – Balauring route and 8 days for the Balauring – Baranusa route. The passenger fares for these routes are Rp 10,100 and Rp 10,400, respectively, while the cargo tariffs are Rp 9,800 and Rp 10,100. With these rates, the total annual cost for operating one vessel in Cluster 11 is Rp 1,599,880,373. The route generates an annual revenue of Rp 26,705,800, resulting in a required annual subsidy of Rp 1,573,174,573, or approximately Rp 4,369,929 per voyage per vessel.

Cluster 12 (Kalabahi Port – Baranusa Port – Wini Port) covers distances of 35 and 87 nautical miles, with estimated sailing times of approximately 5.83 and 14.5 hours, respectively. The annual passenger volume at Kalabahi Port, Baranusa Port, and Wini Port is 7,288; 3,457; and 195, respectively. Meanwhile, the cargo volume is recorded at 33 tons at Kalabahi, 6 tons at Baranusa, and 1 ton at Wini. Based on optimization calculations, the optimal roundtrip duration for this cluster is 2 days. The passenger fares for the Kalabahi – Baranusa and Baranusa – Wini routes are Rp 11,000 and Rp 20,400, respectively, while the cargo tariffs are Rp 10,500 and Rp 18,000. Given these rates, the total annual operational cost for one vessel in Cluster 12 is Rp 1,433,805,651. The route generates an annual revenue of Rp 108,720,800, resulting in a required annual subsidy of Rp 1,325,084,851, or approximately Rp 6,830,334 per voyage per vessel.

Cluster 13 (Wini Port – Atapupu Port – Naikliu Port – Kupang Port) spans distances of 23, 66, and 58 nautical miles, with estimated sailing times of approximately 3.83, 11, and 9.67 hours, respectively. The annual passenger volume at Wini Port, Atapupu Port, Naikliu Port, and Kupang Port is 195; 1,575; 1,373; and 13,050, respectively. The corresponding cargo volumes are 1 ton at Wini, 48 tons at Atapupu, 9 tons at Naikliu, and 19.46 tons at Kupang. Based on optimization calculations, the optimal roundtrip durations for the routes within this cluster are 14 days for Wini – Atapupu, 4 days for Atapupu – Naikliu, and 5 days for Naikliu – Kupang. The passenger fares for these routes are Rp 8,400, Rp 16,500, and Rp 16,100, respectively, while the cargo tariffs are Rp 8,500, Rp 14,900, and Rp 14,500. Given these rates, the total annual operational cost for one vessel serving Cluster 13 is Rp 1,400,804,839. The annual revenue is Rp 50,585,000, resulting in a required subsidy of Rp 1,350,219,839 per year, or approximately Rp 8,386,459 per voyage per vessel.

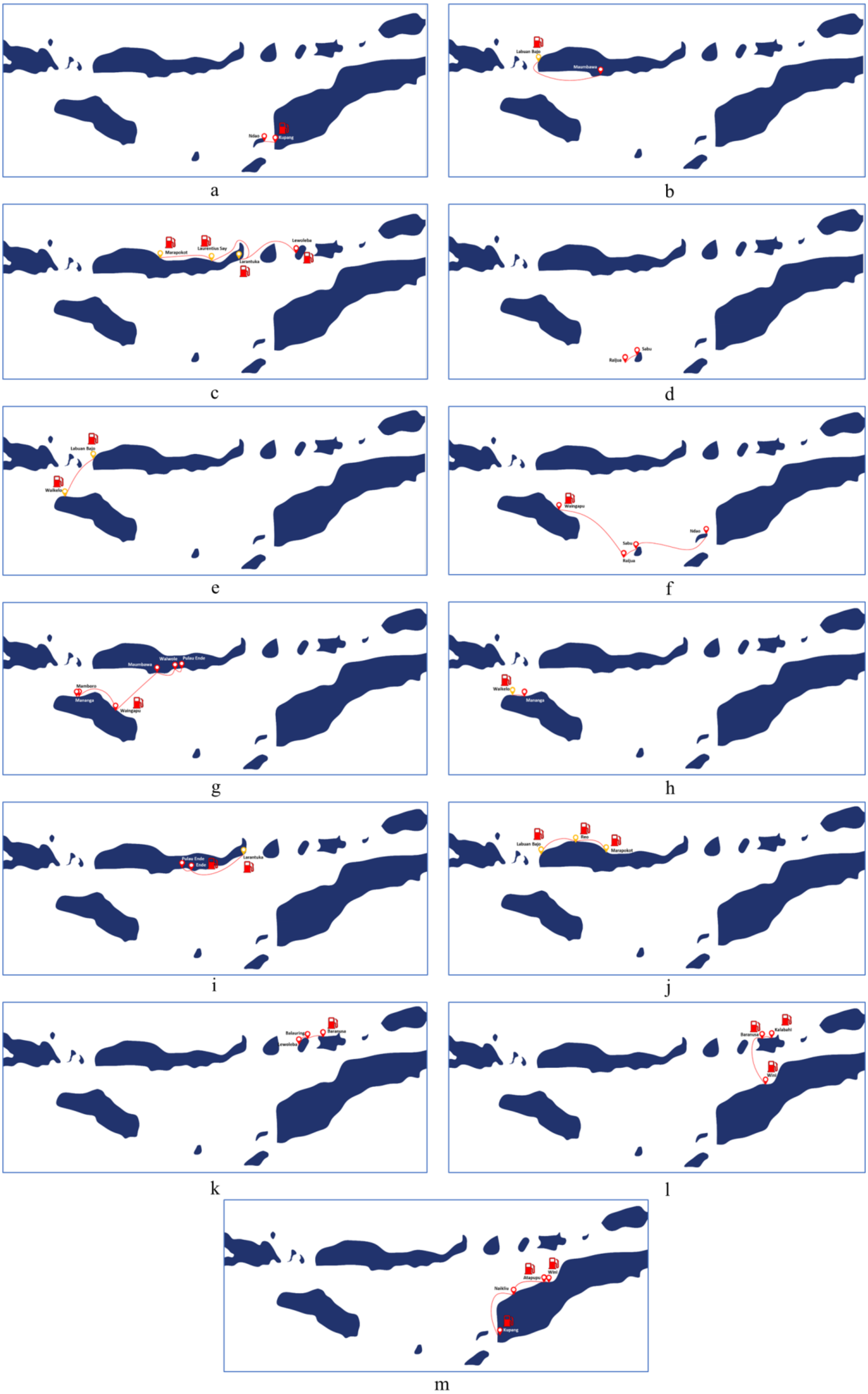

Figure. 4. (a) Cluster 1, (b) Cluster 2, (c) Cluster 3, (d) Cluster 4, (e) Cluster 5, (f) Cluster 6, (g) Cluster 7, (h) Cluster 8, (i) Cluster 9, (j) Cluster 10, (k) Cluster 11, (l) Cluster 12, (m) Cluster 13

TABLE 1.
COMPARISON OF EEDI VALUE

Port	EEDI (g CO2 /ton.Nm)		EEDI Reduction Percentage
	Perintis Vessels	Pinisi Vessels	
Kupang	655.810	649.982	0,89%
Ndao	110.742	435.459	-293.22%
Sabu	110.742	355.038	-220.60%
Raijua	110.742	435.459	-293.22%
Waingapu	110.742	435.459	-293.22%
Maumbawa	110.742	435.459	-293.22%
Waiwole	110.742	435.459	-293.22%
Pulau Ende	110.742	435.459	-293.22%
Ende	110.742	435.459	-293.22%
Mamboro	110.742	435.459	-293.22%
Mananga	118.758	435.459	-266.68%
Baranusa	118.758	435.459	-266.68%
Kalabahi	259.109	435.459	-68.06%
Wini	89.648	435.459	-358.74%
Atapupu	118.758	435.459	-266.68%
Naikliu	208.407	435.459	-108.95%
Balauring	118.758	435.459	-266.68%
Lewoleba	118.758	435.459	-266.68%

C. EEDI Values Comparison

The environmentally friendly Pinisi ship is specifically designed to reduce the Energy Efficiency Design Index (EEDI) values currently produced by perintis vessels. By analyzing the operational routes of these perintis vessels alongside the feeder routes served by the Pinisi ships, a comparative assessment of EEDI values at each port can be conducted. This comparison enables the evaluation of environmental performance and supports the transition toward more sustainable maritime transportation.

In Table. 1. each port is currently serviced by perintis vessels, and calculations have been conducted to estimate the potential reduction in Energy Efficiency Design Index (EEDI) values if these routes were instead operated by Pelra Pinisi ships. For example, Kupang Port is presently served by KM. Sabuk Nusantara 90, KM. Sabuk Nusantara 67, KM. Sabuk Nusantara 108, KM. Sabuk Nusantara 87, KM. Sabuk Nusantara 104, and KM. Sabuk Nusantara 28 on perintis voyages. In this study, it is proposed that Kupang Port be serviced by 300 GT and 100 GT Pelra Pinisi vessels. Likewise, Ndao Port, currently served by KM. Sabuk Nusantara 90, is planned to be serviced by 300 GT and 100 GT Pelra Pinisi vessels. Sabu Port, which is also currently serviced by KM. Sabuk Nusantara 90, is proposed to be served by 100 GT and 200 GT Pelra Pinisi ships. Similarly, Raijua Port, currently served by KM. Sabuk Nusantara 90, is planned to be served by 100 GT and 200 GT Pelra Pinisi vessels. Waingapu Port, also presently serviced by KM. Sabuk Nusantara 90, is proposed to be operated by a 100 GT Pelra Pinisi ship under this study.

Additionally, Maumbawa Port is currently serviced by KM. Sabuk Nusantara 90 and is planned to be served by 100 GT and 300 GT Pelra Pinisi ships. Waiwole Port, also served by KM. Sabuk Nusantara 90, is planned to be served by a 100 GT Pelra Pinisi vessel. Pulau Ende Port is presently operated by KM. Sabuk Nusantara 90 and is likewise scheduled to be served by a 100 GT Pelra Pinisi ship. The same applies to Ende Port, which is currently serviced by KM. Sabuk Nusantara 90 and is proposed to be served by a 100 GT Pelra Pinisi vessel in this study.

Mananga Port is currently serviced by KM. Sabuk Nusantara 108 and is planned to be operated by a 100 GT Pelra Pinisi ship. Similarly, Baranusa Port is served by KM. Sabuk Nusantara 108 and is also proposed to be served by a 100 GT Pelra Pinisi vessel. Kalabahi Port is currently serviced by both KM. Sabuk Nusantara 108 and KM. Sabuk Nusantara 104, with a 100 GT Pelra

Pinisi vessel planned for the study. Wini Port is presently served by KM. Sabuk Nusantara 67 and is also planned to be serviced by a 100 GT Pelra Pinisi ship.

Atapupu Port is currently serviced by KM. Sabuk Nusantara 108, while Naikliu Port is serviced by both KM. Sabuk Nusantara 67 and KM. Sabuk Nusantara 108; both ports are planned to be served by 100 GT Pelra Pinisi vessels. Balauring Port and Lewoleba Port, which are currently served by KM. Sabuk Nusantara 108, are likewise proposed to be operated by 100 GT Pelra Pinisi vessels in this study.

An analysis of EEDI reductions shows that most Pinisi ships do not achieve lower EEDI values compared to existing perintis vessels. This is largely due to the smaller deadweight of Pinisi ships, which contributes to relatively higher EEDI figures. As a result, Pinisi vessels, under current specifications, do not yet qualify as environmentally friendly alternatives for most perintis routes. However, there is potential for selective deployment routes such as Kupang Port – Ndao Port and Kupang Port – Naikliu Port demonstrate a small EEDI reduction of 0.89%, indicating that Pinisi vessels could still be considered environmentally friendlier options on these specific routes.

D. Discussion

The revitalization of Pinisi ships in the industry still faces various challenges, despite having promising prospects [19]. Various challenges, such as the high cost of fleet restoration, limited skilled labor, lack of supporting infrastructure, and competition with modern vessels, can hinder its development [19]. On the other hand, the increasing needs of society necessitate the revitalization of Pelra Pinisi vessels by developing a more cost-effective design. This would enable Pelra Pinisi vessels to become national ships and be included in government programs [20].

Fundamentally, Pelra Pinisi vessels have the potential to be revitalized as feeders for maritime highways and perintis shipping routes [21]. As a feeder for maritime highways and perintis shipping routes, Pelra Pinisi vessels are intended to empower lower economic communities and preserve wooden ships as a national heritage [22]. This is evidenced by the presence of the maritime highways and perintis shipping routes program, which has had a positive impact on the economy in Eastern Indonesia. [23]. Integration and connectivity between traditional Pelra Pinisi shipping and government shipping programs such as maritime highways and perintis shipping routes program are essential to reduce price disparities and ensure the availability of transportation in underdeveloped, remote, outermost, and border (3TP) regions [24]. Meanwhile, perintis shipping, which is specifically intended to serve 3TP (underdeveloped, frontier, outermost, and remote) regions, requires relatively long roundtrip days and is sometimes not optimal [25], [26]. Therefore, an optimal roundtrip days calculation is required for the revitalization of Kapal Pelra Pinisi.

Each cluster operates under different roundtrip durations, which are determined through maritime transportation optimization. The maximum allowable roundtrip duration is limited to 14 days, as perintis vessels are designed to serve each port within a 14-day cycle. Each route is optimized to determine the minimum necessary roundtrip duration based on the needs of the local population, rather than adhering strictly to the 14-day maximum. However, for some ports, a 14-day cycle remains necessary due to optimization results, primarily influenced by the relatively low volume of passengers and cargo originating from those locations.

Generally, it can be inferred that the greater the number of passengers and cargo at a port, the shorter the required roundtrip duration. Ports operating on a 14-day cycle include Pulau Ende Port, Waiwole Port, Maumbawa Port, Waingapu Port, Mamboro Port, Mananga Port, Waikelo Port, Wini Port, and Atapupu Port. In contrast, the shortest roundtrip duration—just one day—is observed at several ports including Kupang Port, Ndao Port, Labuan Bajo Port, Maumbawa Port, Lewoleba Port, Larantuka Port, Laurentius Say Port, Marapokot Port, Sabu Port, and Raijua Port.

Additionally, the government subsidy per voyage per vessel across clusters ranges from IDR 4 million to IDR 9 million. Notably, Cluster 5 (Waikelo Port – Labuan Bajo Port) receives the highest subsidy, amounting to IDR 37 million per voyage. This is attributed to the relatively low number of voyages conducted annually, which results in a higher subsidy per trip. Conversely, Cluster 8 (Mananga Port – Waikelo Port) receives the lowest subsidy, at just IDR 1 million per voyage. This is due to the cluster's higher frequency of trips, shorter travel distances, and a greater number of passengers, all contributing to reduced subsidy requirements.

IV. Conclusion

The reduction of shipping emissions through the revitalitation of Pelra Pinisi vessels will only be effective on specific routes with relatively high passenger and cargo volumes. A greater number of passengers and cargo necessitates the selection of larger vessels as the optimal choice. Pelra Pinisi vessels need to be designed with sufficient size to achieve a lower Energy Efficiency Design Index (EEDI). Consequently, smaller Pelra Pinisi vessels are unable to attain significantly lower EEDI values. Further research is needed to determine the optimal Pelra vessel size that can achieve a lower EEDI than perintis vessels, particularly on routes that have not yet demonstrated a decrease in EEDI in this study.

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