Revolutionizing Maritime Transport: A Blueprint for Sustainable Mobility - Conceptualizing an Electric Roll-On/Roll-Off (RO-RO) Ferry System for India's National Waterway 3

Aravind K.R [1], C.B. Sudheer [2]

{aravind@cusat.ac.in[1], sudheer@cusat.ac.in[2]}

Affiliation: Department of Ship Technology, Cochin University of Science and Technology, Kochi 22, Kerala, India [1,2]

Abstract. Maritime transportation is a pivotal point in global trade, underpinning economic activities across the globe. However, the reliance on conventional diesel-powered ferries raises pressing environmental concerns, from air pollution to greenhouse gas emissions. This paper endeavours to chart a sustainable and innovative course by presenting a comprehensive concept design for an electric Roll-On/Roll-Off (Ro-Ro) ferry tailored explicitly for National Waterway 3 in India. The study delves deeply into the feasibility, potential environmental impact, and economic viability of transitioning to an electric Ro-Ro ferry system. By focusing on this specific waterway and considering a prototype ship which is in service, the paper addresses localized concerns but also contributes to the broader conversation about adopting green solutions in maritime transportation.

Keywords: Electric ferry; Energy efficiency; inland waterway transport; carbon allowance; ship power system.

1 Introduction

The Earth faces mounting environmental challenges due to human activities [1,2], especially from transportation's significant contributions to global warming and air pollution [3,4]. Handling the bulk of international trade, the maritime sector currently contributes 3% of anthropogenic greenhouse gas emissions [8,9]. However, projections foresee a drastic surge of 150–250% in carbon dioxide emissions by 2050 [8], directly conflicting with the Paris Climate Agreement. Notably, the shipping sector is responsible for significant SO_2 (13–15%) and NO_x (12–13%) emissions, posing risks to the environment and human health [10]. These emissions, stemming from marine engine fuel combustion, include harmful

ICSETPSD 2023, November 17-18, Coimbatore, India

DOI 10.4108/eai.17-11-2023.2342868

substances like SOX, NOX, CO, PM, and GHGs such as CO2, CH4, and N2O emissions [11].

In response, the International Maritime Organization (IMO) implemented stringent standards, including the EEDI, SEEMP, and ECAs, to enforce regulations in specific regions [12, 13, 14]. Beyond environmental concerns, ship exhaust significantly affects human health, notably in ports and shipping routes [15, 16]. Consequently, decarbonization emerges as a primary research goal in the maritime industry [17], focusing on enhancing energy efficiency to reduce fuel consumption, thereby curbing GHG emissions and pollutants [18]. Effective measures like voluntary speed reduction have shown promise in cutting CO2 emissions [19, 20]. Exploring alternative fuels (biodiesel, hydrogen, electricity, etc.) and transitioning to hybrid or integrated propulsion systems gain traction [21, 22, 23].

Unfortunately, the Inland Water Transport system in India is in its infancy for addressing this pressing issue. This study pioneers a vision for revolutionizing maritime transportation along India's National Waterway 3 from Kottapuram to Kollam, incorporating Udyogamandal and Champakara Canal [24]. It proposes a comprehensive design for an electric RO-RO ferry, underlining the urgency to address environmental challenges posed by traditional diesel-powered vessels in urbanized cities like Cochin, Kerala. The study emphasizes the practicality, environmental benefits, and economic viability of transitioning to an electric ferry system.

2 Methodology

The investigation was conducted utilizing a prototype ship currently operational on the Bolgatty to Willington Island route in Cochin. The actual fuel consumption data for the vessel was extracted from the engine log spanning a one-month duration. This study serves as a foundational dataset for evaluating potential fuel savings achievable through transitioning to renewable energy sources. Retrofitting the existing vessel is deemed technically impractical due to the substantial weight of the steel hull already in place. In light of these constraints, the authors opted to formulate a concept design that integrates considerations of weight, sustainability, and efficiency. The resultant solar-electric Roll-on/Roll-off (Ro-Ro) ferry design represents a noteworthy progression in maritime technology, with a pronounced emphasis on sustainable practices and operational efficacy.

3 Details of The Prototype Vessel

The prototype Roll-on/Roll-off (Ro-Ro) vessel, M/V C.V. Raman, holds the distinction of being the largest and most energy-intensive ship navigating the Willington and Bolgatty Island route. The Principal Particulars of the vessel is given on Table 1.

Table 1. Principal Particulars of the Prototype Vessel

Type	**Double Ended Catamaran**
Length Overall (LoA)	56.0 m
Length Between Perpendicular (LBP)	54.0 m
Breadth	13.50 m

Depth mld	3.0 m
Design Draft	1.80 m
Design Speed	8 knots in deep water
Main propulsion	2 x 250 kW @100 % MCR
Generator	90 kW Gensets (Greaves Make)
Vehicle Capacity	9 nos. 20ft trucks 3 nos. 40ft trailer trucks (15 TEU in total)
Passenger Capacity	30 Pax and 8 Crew Members

Fig 1. The prototype vessel at the Bolgatty Jetty

From the deck log book data, it was evident that the vessel routinely conducted 14 to 16 trips daily, with each trip between Willington and Bolgatty averaging a duration of approximately 30 minutes. The recorded data indicated an average container number ranging from 5 to 8 TEUs per trip. Additionally, examination of the engine log data unveiled an average daily fuel consumption of approximately 358 liters of high-speed diesel per voyage.

4 Details Of The Concept Design Of The Vessel Developed

The decision to forego retrofitting, driven by the impracticality posed by the significant weight of the current steel hull, led the authors to pursue the development of an innovative conceptual design. Drawing inspiration from the M/V C.V. Raman, this novel design aims at tailored optimization for efficient integration of solar electric systems. Emphasizing weight optimization, sustainability, and operational efficiency, the proposed approach strategically addresses these crucial considerations.

Upon analyzing the deck log book data from the prototype vessel, it was evident that the average container transport ranged between 5 to 8 TEUs, despite the vessel's maximum capacity of 15 TEUs. This observation prompted the decision to optimize the concept for a targeted capacity of 7 TEUs, aligning it more closely with observed operational trends. Furthermore, considering the material of construction of the prototype vessel as marine- grade mild steel, the recommended concept proposes the utilization of marine-grade aluminium of 5000 series or an equivalent grade. This shift in material aims to achieve weight reduction, facilitating the incorporation of solar electric systems into the vessel's design.

Table 2: Principal Particulars of the concept Solar Electric Ro-Ro vessel.

Type	**Double Ended Catamaran**
Length on Deck	35.0 m
Breadth on Deck	10.0 m
Depth mld	1.8 m
Design Draft	0.8 m
Design Speed	6 knots in deep water
Main propulsion	2 x 40 kW pods
Battery	2 x 60 kWh lithium-titanium-oxide (LTO)
Vehicle Capacity	3 nos. 20ft trucks 2nos. 40ft trailer trucks (7 TEU in total)
Generator	50 kW Gensets
Passenger Capacity	75 Pax and 5 Crew Members

4.1 Choice of materials and carrying capacity for the proposed design

The solar-electric RO-RO ferry, featuring an aluminium (marine grade 5000 series or equivalent) double-ended catamaran design, represents a strategic approach to optimizing stability, efficiency, and environmental impact. The choice of aluminium, known for its lightweight yet robust properties, significantly contributes to reduced energy consumption during operation. This design also incorporates a double-ended configuration, enhancing manoeuvrability and mitigating the necessity for complex turning manoeuvres, thereby saving energy and time. With a carefully calibrated carrying capacity of80 tons, the ferry is engineered to efficiently accommodate both passengers and cargo. This design choice minimizes the need for multiple trips, resulting in substantial energy savings, reduced emissions, and heightened operational efficiency. The vessel's versatility in handling various cargo types, including vehicles and goods, renders it well- suited to meet the diverse transportation needs of the region.

4.2 Choice of materials and carrying capacity for the proposed design

In the pursuit of enhanced sustainability and operational efficiency, the design of the solar-electric Roll-on/Roll-off (RO-RO) ferry prioritizes the seamless integration of solar energy, utilizing sunlight to propel the vessel's operations. This integration is meticulously orchestrated to maximize energy capture and utilization, ensuring sustained and eco-friendly performance throughout its operational cycle.

A distinctive feature of the solar-electric RO-RO ferry is the strategic placement of solar panels (Fig2) across its deck and superstructure. These panels are positioned thoughtfully to receive direct exposure to the sun's rays. for the majority of the vessel's operational time.This strategic orientation facilitates optimal energy absorption and conversion, effectively channelling sunlight into electrical energy to power various on-board systems.

4.3 Battery bank selection

The solar-electric Roll-on/Roll-off (RO-RO) ferry relies on strategically positioned solar panels as its primary energy source. To ensure continuous and reliable power advanced lithium-titanium-oxide with a total capacity of 120 kWh (two banks of 60 kWh lithium-titanium-oxide or LTO batteries) store excess solar energy during peak sunlight hours. These batteries act as reservoirs, providing energy during periods of reduced sunlight or at night. The batteries are approved by leading IACS classification societies and are arranged independently in each demi-hull, offering redundancy to prevent propulsion system blackouts.

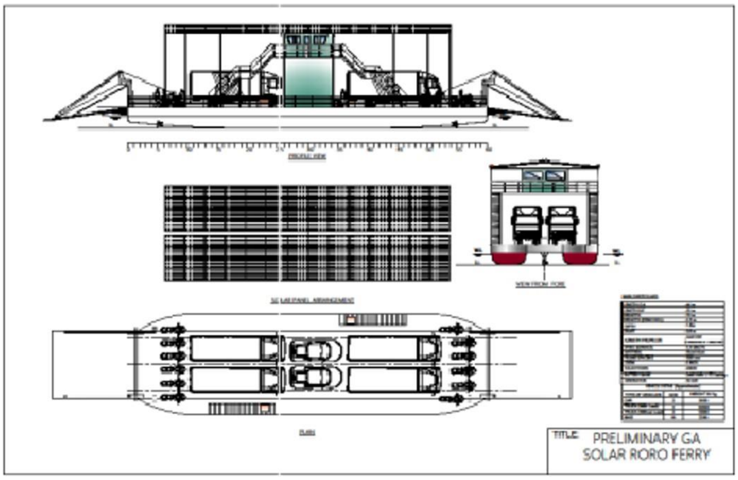

Fig 2. Preliminary General Arrangement drawing efficiency. The vessel's versatility in handling various

Continuous monitoring and remote state-of-charge readings in the wheelhouse ensure efficient battery management. The batteries are cooled and ventilated to maximize their life expectancy. This integrated approach not only highlights the technological advancements in battery systems but also underscores the vessel's autonomy from traditional energy sources. With over 150 hybrid and full battery ships globally, the solar-electric RO-RO ferry stands as a sustainable transportation model, setting a benchmark for eco-conscious design practices in the maritime industry [25].

4.4 Selection of propulsion system and its efficiency

The selection of the dual-podded propulsion system for the vessel is a strategic decision tailored to the specific operational needs and environmental challenges specified. This system, comprising 2 x 40 kW azimuth podded propulsion units, perfectly complements the double-ended ferry design. It enables efficient propulsion in both forward and reverse irections, ensuring superior manoeuvrability and operational adaptability. Furthermore, the incorporated electric motors are engineered to endure rigorous environmental conditions, capable of functioning in up to 30 degrees Celsius temperature, 95% relative humidity, and resistant to salt and chemical corrosion prevalent in tropical coastal regions. The system's motor options range from direct mechanical connection diesel engines or electrical motors powered by generators (commonly diesel engines) elsewhere on the ship. These motors deliver input power within the range of 330-3700 KW with RPM rangingbetween 1500-2100 and 720-1200, respectively [26].

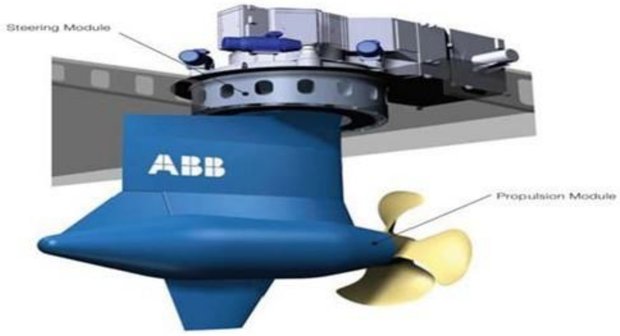

Fig 3. Basic arrangement of the Azipod XO (Ref: ABB Oy, Marine and Cranes)

Furthermore, the azimuth propulsion system undergoes certification through the type approval process of a leading International Association of Classification Societies classification societies (IACS). This certification ensures that the propulsion system meets the stringent standards set by the industry, affirming its reliability, safety, and adherence to regulatory requirements.

5 Cost Comparison Analysis Of Diesel And Solar Propulsion System For Ro-Ro Ferries

The initial costs of the project are pivotal in determining its feasibility and potential benefits. This encompasses various components, including design, construction, solar panel installation, lithium-titanium-oxide integration, and the implementation of an electric podded propulsion system. In the design and engineering phase, architectural plans and engineering blueprints are developed, requiring professional expertise to ensure. Structural integrity, energy efficiency, and overall functionality. The construction phase involves skilled labour and materials to bring the project to life. Solar panel installation costs are influenced by panel type and efficiency. Lithium-ion battery integration involves the batteries and infrastructure for consistent power supply. An electric podded propulsion system, if needed, includes costs for motors, pods, control systems, and installation. Ancillary costs like permits, land acquisition, project management, and contingencies overlooked.

5.1 Capital expenditure

The building cost incurred for the construction of the Solar ferry is analysed by splitting up the components of the ferry in to sub systems and analysing the cost of each component. The detailed split up is given on the Table 3.

Table 3: Capital expenditure for the solar Ro-Ro ferry

ITEM	DETAILS	(" COST IN LAKHS ")/((" INR) ")
Aluminium Hull	about 33T@3.5 lakhs/tonne for marine grade (5000 and 6000 series) and 11 akh/tonne for fabrication	148
Superstructure	GRP	15
Solar Panels	30kW poly-cryst alline solar panels, chargc controllcr, cabling ctc	22
Balleries and cabling	60kWhxx2 sets, LTO B atteries, cabling and connection, plug in charge etc.	250
Electric Propulsion Motors	Motos in Pods 2 Nos., 600 V DC System, Power Management system	290
B ack up generator	50kW Generator, low noise; battery charging system	20
Other Electric	Lighting, Dlepth sounder, GPS, safety devices	10
Outfitting	Mooring & Lambda nchoring fittings	15
Installation	Installation. charge of each equipment	10
Approval charges	Design, Statutory approvals, tests, trials, registration	10
	Sub Total	790
Manufacturers M	**argin 15%**	118
	TOTAL	908

5.2 Operational Costs

The assessment of the operational expenditure pertaining to the prototype diesel ferry's (M/V C.V. Raman) operating along a designated route involves a field study and an examination of engine log data spanning a month. Table 4 presents a sample subset of the engine log data. This dataset illustrates an average fuel consumption of 358 liters encompassing both the primary and auxiliary engines.The actual consumption value in litres is converted in terms of grams/kwh to calculate the Specific Fuel Oil Consumption (SFOC). The SFOC was arrived as 200g/kwh which is matching with the fuel consumption calculated for the concept design.The Break Power (PB) of the prototype is 500 kw @100 % Maximum Continuous Rating (MCR). The engine power for the new concept deign is analysed and optimised as per the preliminary resistance calculation data and the field data obtained. The Break Power (PB) for the concept design is derived as 108 hp which is 80 kw. Based on the data given on Figure 5, the operational cost for operating a diesel ferry is calculated. The yearly energy cost incurred for operating the diesel option is INR 84 lakhs against the very nominal energy cost of INR 1500/day (Figure 4) or INR 5lakhs/yearfor the solar alternative. It's evident that the yearly savings accounts for an amount of INR 84 lakhs for the solar ferry when compared with the diesel option.

Time	FWD - Port Main Engin			Azimuth Thruster		Thruster Hydraulic Power Pack		AFT - Star Board Main Engine				Azimuth Thruster		Thruster Hydraulic Power Pack	
	RPM	CW PR	CW Temp	Temp	Pressure	Temp	Pressure	RPM	LO Temp	CW PR	CW Temp	Temp	Pressure	Temp	Pressure
8.00	656	0.8	32	25	0	25	18	650	33	0.9	32	25	0	26	18
11.00	1100	0.8	74.1	48	21.3	48	24	1200	81	0.9	74	49	21.2	47	24
13.00	1210	0.8	74	50	21.3	49	36	1110	81.1	0.9	74	50	21.3	50	36
13.45	650	0.8	67	45	0	47	18	650	68	0.9	67	47	0	45	18
18.00	1100	0.8	74	50	21.3	49	32	1210	81.1	0.9	74	50	21.3	50	32
20.40	1200	0.8	74	49	31.4	50	43	1100	81	0.9	74	49	21.2	44	49

Running Hours				Time
	Port M/E	STBD M/E	A/E 1	A/E 2
Previous	65.4	65.4	81.2	103
Current	9.9	9.9	12.8	
Total	75.3	75.3	94	

	Consumption					
	Diesel	M/E Oi	A/E Oi	Thruster Hyd Oil	Winch Hyd Oil	Fresh Water
Previous	11210				5781.1	5491
Received					5779.1	5789
Consumed	358				3817.7	3830.5
Balance	10852				4301.6	

Fig.4 Sample engine log data collected from M/V C.V. Raman

Figure 4 gives an outline detailing the diverse cost considerations linked to the operational costs of a solar ferry.The economic viability of the solar Ro-Ro concept was thoroughly assessed through a comprehensive break-even analysis.Resultsgiven on Fig 5 indicate that the break-even point can be attained within a timeframe of 10 years, starting from the initiation of operations.

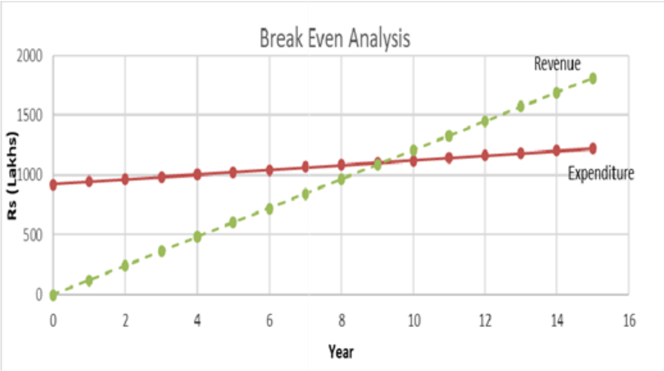

Fig.5 Break – Even analysis for the solar Ro-Ro ferry

Item	Unit	Amount
Vessel capacity	DWT	50
Vessel Speed	Knots	5.5
Power Required	kW	45
Trip Time	hrs	0.25
Energy Required per Trip	kWh	11.25
Cost of Grid per kWh	Rs./kWh	7.5
No of Trips per Day	Nos	32
Energy Required per Day	Daily	360
Solar Panel size	kW	40
Average Energy from Sun per day	kWh	160
Energy required from Grid per day	kWh	200
Percentage of Energy from Sun	%	44.4
Energy Cost per day	Rs	1500
Maintenance cost @ 5% of Energy cost	Rs	75
Total Fuel + Maintenance per Day	**Rs**	**1575**
Number of Staff per day		4
Per Day Rate of Staff	Rs	1000
Cost of Staff per day	Rs.	**4000**
Total Operating Cost per day	Rs	**5575**
Running Days per year	Days	360
Annual Operating Cost	Rs	2007000
Vessel Cost	Rs (Lakhs)	**924**
Depreciation		10%
Depreciation value	Rs	9237375
Average Revenue per Trip	Rs	1310
Occupancy		80%
Total Revenue per day	**Rs**	**33536**
Total Profit per day	**Rs**	**27961**
Total annual Operating cost	**Rs (Lakhs)**	**20**
Total Annual Revenue	**Rs (Lakhs)**	**121**
Total Annual Profit	**Rs (Lakhs)**	**101**

Fig.6 Operational c st components and the revenue for the Solar Ro-Ro ferry

Item	Unit	Amount
Propulsion time engine load	hp	108
	kW	80
Non-propulsion time engine load	hp	67
	kW	50
SFOC	gm/kWh	200
Propulsion time	hrs	8
Daily fuel consumption	kg	208
Daily fuel consumption (@ 0.85 gm/litre)	litres	244
Annual fuel consumption (@ 360 days /year)	litre	89,317
Annual fuel cost (Rs. 75/litre)	Rs (Lakh)	84
Comparable energy cost for Electric (@ Rs. 1500/day)	Rs. (Lakh)	5
Saving per year	Rs. (Lakh)	79

Fig.7 Economic analysis comparing with Diesel option

6 Environmental Benefits Of Solar Ferry When Compared With The Diesel Option

One of the key findings in this study underscores the substantial mitigation potential for CO2 emissions achievable through alternative fuel choices in marine vessels. By assessing the CO2 produ tion diesel fuel, it was determined that 1 litre of diesel generates 2.64 kg of CO2 gas[27]. Extrapolating this and the data given on Table 6 it is evident that an equivalent diesel engine utilized in this vessel would annually emit a staggering 235,797 kilograms (235 tonnes) of CO2. Over the typical 20-year lifespan of a vessel, this translates to a substantial mitigation of 4,700 tonnes of CO2 be ng prevented from entering the environment. This significant reduction showcases the profound environmental benefit of opting for alternative fuels or propulsion systems in maritime transportation. These findings underscore the urgency and potential impact of transitioning toward greener, lower-emission options to curtail the environmental impact of marine transport.

7 Conclusion

The study outlined a pioneering vision for transforming maritime transportation within National Waterway 3 in India by proposing a comprehensive design for an electric Roll-On/Roll-Off (Ro-Ro) ferry. It underscored the urgency of addressing environmental challenges posed by traditional diesel-powered vessels and emphasized the feasibility, environmental impact, and economic viability of transitioning to an electric ferry system. Leveraging a methodology that utilized a prototype ship operational on the Bolgatty to Willington Island route in Cochin, actual fuel consumption data was obtained, forminga foundational dataset for evaluating potential fuel savings achievable through transitioning to renewable energy sources. The study acknowledged the impracticality of retrofitting the existing vessel due to substantial steel hull weight, leading to the formulation of a concept design that integrates weight, sustainability, and efficiency considerations. This research provides a strategic roadmap for sustainable maritime transportation, serving as a catalyst for further development and implementation of green technology in the maritime sector. Future endeavours involving detailed engineering assessments, comprehensive lifecycle evaluations, and extending the study to other waterways aim to foster a more sustainable future for global trade and transportation.

Acknowledgments. The authors gratefully acknowledge the support provided by the Kerala Shipping and Inland Navigation Corporation (KSINC) and Kerala State Water Transport Department (KSWTD)and necessary data for the successful completion of this research.

References

[1] European Court of Auditors (ECA). Inland Waterway-Transport in Europe: No Significant Improvements in Modal Share and Navigability Conditions Since 2001. Available online: https://www.eca.europa.eu/Lists/ECADocuments/ SR15_01/SR15_01_EN.pdf (accessed on 15 2021).

[2] Wiegmans, B.; Witte, P.; Spit, T. Inland port performance: A statistical analysis of Dutch inland ports. Transp. Res. Procedia 2015, 8, 145 [CrossRef]

[3] Christodoulou, A.; Christidis, P.; Bisselink, B. Forecasting the impacts of climate ch inland waterways. Transp. Res. Part D Transp. Environ. 2020, 82, 102159.

[4] Xing, S.; Xinping, Y.; Bing, W.; Xin, S. Analysis of the operational energy efficiency for inland river ships. Transp. Res. Part D Transp. Environ. 2013, 22, 34–39.

[5] Anˇci´c, I.; Perˇci´c, M.; Vladimir, N. Alternative power options to reduce carbon footprint of ro passenger fleet: A case study of Croatia. J. Clean. Prod. 2020, 271, 122638.

[6] Lindstad, H.; Jullumstrø, E.; Sandaas, I. Reductions in cost and greenhouse gas emissions with new bulk ship designs enabled by the Panama Canal expansion. Energy Policy 2013, 59, 341– 349. [CrossRef]

[7] Miola, A.; Ciuffo, B. Estimating air emissions from ships: Meta-analysis of modelling approaches and available data sources.Atmos. Environ. 2011, 45, 2242–2251. [CrossRef]

[8] Ammar, N.R.; Seddiek, I.S. Eco-environmental analysis of ship emission control methods: Case study RO-RO cargo vessel. Ocean.Eng. 2017, 137, 166–1673. [CrossRef]

[9] Chen, J.; Fei, Y.; Wan, Z. The relationship between the development of global maritime fleets and GHG emission from shipping. J.Environ. Manag. 2019, 242, 31–39. [CrossRef]

[10] Keuken, M.P.; Moerman, M.; Jonkers, J.; Hulskotte, J.; Denier van der Gon, H.A.C.; Hoek, G.; Sokhi, R.S. Impact of inland shippingemissions on elemental carbon concentrations near waterways in The Netherlands. Atmos. Environ. 2014, 95, 1–9. [CrossRef]

[11] Ya-li, C.; Xia, W.; Cheng-qi, Y.; Wen-wen, X.; Wen, S.; Guang-ren, Q.; Zhi-meng, X. Inland Vessels Emission Inventory and theemission characteristics of the Beijing-Hangzhou Grand Canal in Jiangsu province. Process. Saf. Environ. Prot. 2018, 113, 498–506.

[12] International Maritime Organization. Resolution MEPC.176(58), London, UK. 2008. Available online:https://wwwcdn.imo.org/localresources/en/ KnowledgeCentre/IndexofIMOResolutions/MEPC Documents/MEPC.176(58).pdf (accessed on 17 September2021).

[13] Chen, L.; Yip, T.L.; Mou, J. Provision of Emission Control Area and the impact on shipping route choice and ship emissions.Transp. Res. Part D Transp. Environ. 2018, 58, 280–291. [CrossRef]

[14] Emission Standards: IMO Marine Engine Regulations. Available online: https://dieselnet.com/standards/inter/imo.php#s (accessed on 5 October 2021).
[15] Sofiev, M.; Winebrake, J.J.; Johansson, L.; Carr, E.W.; Prank, M.; Soares, J.; Vira, J.; Kouznetsov, R.; Jalkanen, J.-P.; Corbett, J.J.Cleaner fuels for ships provide public health benefits with climate tradeoffs. Nat. Commun. 2018, 9, 406. [CrossRef] [PubMed]
[16] Gobbi, G.P.; Di Liberto, L.; Barnaba, F. Impact of port emissions on EU-regulated and non-regulated air quality indicators: The case of Civitavecchia (Italy). Sci. Total Environ. 2020, 719, 134984. [CrossRef]
[17] Rehmatulla, N.; Calleya, J.; Smith, T. The implementation of technical energy efficiency and CO2 emission reduction measures in shipping. Ocean. Eng. 2017, 139, 184–197. [CrossRef]
[18] Bouman, E.A.; Lindstad, E.; Rialland, A.I.; Strømman, A.H. State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping—A review. Transp. Res. Part D Transp. Environ. 2017, 52, 408–421. [CrossRef]
[19] Corbett, J.J.; Wang, H.; Winebrake, J.J. The effectiveness and costs of speed reductions on emissions from international shipping.Transp. Res. Part D Transp. Environ. 2009, 14, 593–598. [CrossRef]
[20] Lindstad, H.; Asbjørnslett, B.E.; Strømman, A.H. Reductions in greenhouse gas emissions and cost by shipping at lower speeds.Energy Policy 2011, 39, 3456–3464. [CrossRef]
[21] Perˇci´c, M.; Vladimir, N.; Fan, A. Life-cycle cost assessment of alternative marine fuels to reduce the carbon footprint in short-sea shipping: A case study of Croatia. Appl. Energy 2020, 279, 115848. [CrossRef]
[22] Anˇci´c, I.; Vladimir, N.; Runko Luttenberger, L. Energy efficiency of ro-ro passenger ships with integrated power system. Ocean Eng. 2018, 16, 350–357. [CrossRef]
[23] Psaraftis, H.N.; Zis, T.; Lagouvardou, S. A comparative evaluation of market based measures for shipping decarbonization. Marit. Transp. Res. 2021, 2, 100019.,
[24] Praveen S; Jegan J, Key Issues & Challenges for Inland Water Transportation Network in India, IJSRD - International Journal for Scientific Research & Development| 2015, Vol. 3, Issue 10
[25] DNVGL. Energy Transition Outlook P50;DNVGL: Oslo, Norway, 2019
[26] VirendraDesai-Patil, Abhishek Ayare, Bhushan, Mahajan, Sushmita Bade; A Review of Azimuth Thruster, SSRG International Journal of Mechanical Engineering (SSRG – IJME) – October 2015Volume 2 Issue 10
[27] Ecoscore. (2020). How to calculate the CO2 emission from the fuel consumption? Retrieved from https://ecoscore.be/en/info/ecoscore/co2