Received: 18 July 2021 | Revised: 7 October 2021 | Accepted: 22 October 2021
DOI: 10.1002/sd.2269

RESEARCH ARTICLE

Sustainable Development WILEY

Economic and environmental feasibility of re-routing the Indo-Sri Lankan shipping channel: A green initiative of sustainable development

Jayakrishna Kandasamy[1] | Simon Peter Nadeem[2] | Anil Kumar[3] | Vimal K.E.K[4] | Hrishikesh Bedekar Nikhil[1] | Nikhilkumar Himatlal Solanki[1]

[1]School of Mechanical Engineering, VIT University, Vellore, Tamil Nadu, India
[2]Centre for Supply Chain Improvement, University of Derby, Derby, UK
[3]Guildhall School of Business and Law, London Metropolitan University, London, UK
[4]Department of Mechanical Engineering, National Institute of Technology, Patna, Bihar, India

Correspondence
Anil Kumar, Guildhall School of Business and Law, London Metropolitan University, London, UK.
Email: a.kumar@londonmet.ac.uk

Abstract

As the maritime industry forms the common means of heavy freight transportation, the efficient and strategic management of sea routes from an economic and environmental perspective has become a major concern to achieve sustainable development goals (SDGs). By applying marine engineering principles and quantifying metrics such as energy efficiency design, index/existing vessel design index, energy efficiency operational index, carbon footprints, fuel consumption, voyage times and emission this study aims to explore the merits of the Indo-Sri Lankan shipping canal project over the existing route circumnavigating Sri Lanka. The quantification was performed by studying the design and operational indices of marine vessels, based on the metrics considering the major ports in India. The socio-political, environmental and economic benefits reported in this study advocate the significance of this route to the maritime industry in meeting SDGs.

KEYWORDS
carbon footprint, energy efficiency, green supply chain, operational index, Sethusamudram canal project, sustainable development goals

1 | INTRODUCTION

The development of a canal for maritime navigation through the Gulf of Mannar, Palk Strait and Palk Bay has been a topic of discussion for decades (Ramesh, 2004). The Indo-Sri Lankan Shipping Canal Project or the Sethu Samudram Canal Project (SSCP) as it is commonly known has sparked socio-economic, political and religious controversies (Ramesh, 2004). The region concerned with the canal especially the Coromandel Coast is indeed of deep historic value (Ramesh, 2004). Although the ports in this region had a shorter existence with the small fleet and vessel sizes historically, they played a very important role during the rise or fall of kingdoms such as the Chola regime, Pandya or the Vijayanagar Empire; as well as the Dutch, Portuguese and the English rule in the region. The SSCP was first proposed in 1860 to reduce the total distance by circumnavigating Sri-Lanka (then Ceylon) for ships or vessels from the west coast bound for the east coast of India (Ramesh, 2004). Since then several instances have posed a threat to the commissioning of the project because of reasons such as sedimentation and environmental hazards (Rajendran, 2005; Ramesh, 2004; Rodriguez, 2007; Rodriguez et al., 2007). It has been deemed unviable after its most recent form of the proposal in 2013.

The SSCP envisages the creation of a ship canal to suit different drafts namely, 9.15, 10.7 and 12.8 m through dredging/excavation in Adams Bridge and parts of Palk Bay. These drafts are provided to facilitate the easy movement of vessels as per dimensions. The underlying idea is that the proposed navigation route will originate from Tuticorin new harbour in the Gulf of Mannar (GOM) using available navigation depths (>20 m) up to the south-east of Pamban Island and pass through a canal that will be dredged in Adams Bridge within the international boundary.

In this context, this study aims to explore the merits of the SSCP sea route over the existing route circumnavigating Sri Lanka. To achieve this aim the following research questions (RQ's) are defined:

> **RQ1.** *What environmental and economic advantages do the SSCP offer that contributes towards the development of sustainable networks in maritime logistics?*

> **RQ2.** *Which paradigm shifts in the environmental, economic, and socio-political domains could be observed after the implementation of SSCP that are crucial towards achieving sustainable development goal (SDGs)?*

To address the above research questions, the following objectives are set

- To conduct a comparative analysis to identify the environmental and economic benefits of SSCP.
- To identify the factors to evaluate the SSCP's alignment with SDGs for long-term sustainability.
- To identify the potential benefits through quantification of environmental and economic factors related to SSCP.

The novelty of this study is that it serves as an analytical analogy between the SSCP route, and the current route being followed by circumnavigating Sri Lanka on several fronts such as environmental, economic, socio-political, and socio-economic. Initially, the vessels following the routes were identified based on technical specifications to calculate existing vessel design index (EVDI) and energy efficiency design index (EEDI) for existing and new vessels respectively. The operational efficiency of the vessels was then mapped according to the energy efficiency operational index (EEOI). Furthermore, the indices calculated initially were used to determine the carbon footprint along the routes by considering fixed voyages.

The unique contributions of this study provide insight into the environmental impact and carbon footprint traced by following the SSCP route and its advantages over existing maritime routes. Besides the direct costs incurred during the voyage such as fuel and maintenance, the environmental impact is also important in assessing the economic effects of the construction of SSCP in an age where green economies have become a centre of attention. Secondly, the methodology applied helps in establishing a relationship between environmental and economic factors used for comparing the routes and selecting the optimum solution. This makes the study relevant in crediting the SSCP for its environmental and economic benefits when compared with the existing route, which involves the circumnavigation of vessels around Sri Lanka. The absence of a trade-off between environment and economics is highlighted by the potential existence of SSCP. The study will also help in accomplishing the SDG's in specific climate action (SDG13) and life below water (SDG14) by focusing on sustainable natural resource management by conserving the marine resources and national development strategies (Allen et al., 2021; Cormier & Elliott, 2017; Recuero Virto, 2018).

The research is structured in five sections, where Section 2 explores relevant literature, Section 3 presents the adopted methodology, Section 4 elaborates on the possible impacts the SSCP could have on the environment and economy. Section 5 explicitly illustrates the research findings in the form of numerical data and charts that aid in deriving important inferences. Section 6 concludes the paper with the benefits of the study, its limitations and recommendations.

2 | LITERATURE REVIEW

Multiple databases such as IEEE Xplore, Springer, Scopus, Taylor and Francis, Science Direct, Wiley, Emerald were filtered using the keywords. As result, a large number of published articles were available but concerning the area of the research reported, 227 papers were initially shortlisted from data sources; subsequently, 62 articles were selected considering the scope and aim of this study.

2.1 | Sethu Samudram Canal project

The SSCP suggests that the route will run parallel to the International Medial Line (IML) (Rajendran, 2005; Ramesh, 2004; Rodriguez, 2007; Rodriguez et al., 2007). The construction of SSCP would require dredging in an 89 km stretch for a width of 300 m and a depth of 12 m for ships less than 30,000 dead weight tonnage (DWT) with draft restricted to 10 m. Further increasing of drafts would be feasible as Rodriguez et al. (2007) suggest that the canal project proposals are permissible for greater loading conditions such as 50,000–100,000 DWT. An engineering marvel such as the 'Panama Canal' would be an appropriate example in demonstrating alternatives modified for the movement of greater loads through it. The alternatives can contribute towards the development of robust canal design, also resistant to erratic changes in the surroundings (Carse, 2012; McCullough, 1977). The alternatives would also solve some of the problems neglected in the earlier proposals such as the necessity of constant dredging for maintaining the canal depth annually. The proposals from 1998 to 2005, which neglected these facts, were rejected by National Environmental Engineering Research Institute (NEERI) after Environmental Impact Assessment (EIA) report (Rajendran, 2005; Ramesh, 2004; Rodriguez, 2007; Rodriguez et al., 2007). Ramesh (2004) also suggested that the dredged sediments could be dumped in the region of the Bay of Bengal due to the sufficient depth and shelf of 40 m. Moreover, one of the main religious and political reasons behind disapproval of the project is a mythological belief concerning the epic 'Ramayana', which considers the bridge to be a sacred site (Griffith, 2008). Similarly, the negligence of factors such as the occurrence of cyclonic weather conditions, erratic changes in weather in the region where the Gulf of Mannar biological reserve is located, damage to coral reefs, and inappropriate EIA led to the disapproval of the proposal, making it environmentally and financially impractical and unviable (Novo-Corti et al., 2015; Ramesh, 2004).

The existing route circumnavigating Sri Lanka is shown in Figure 1a and the proposed Sethusamudram canal route is shown in Figure 1b. Though it has been proven a shorter route for marine

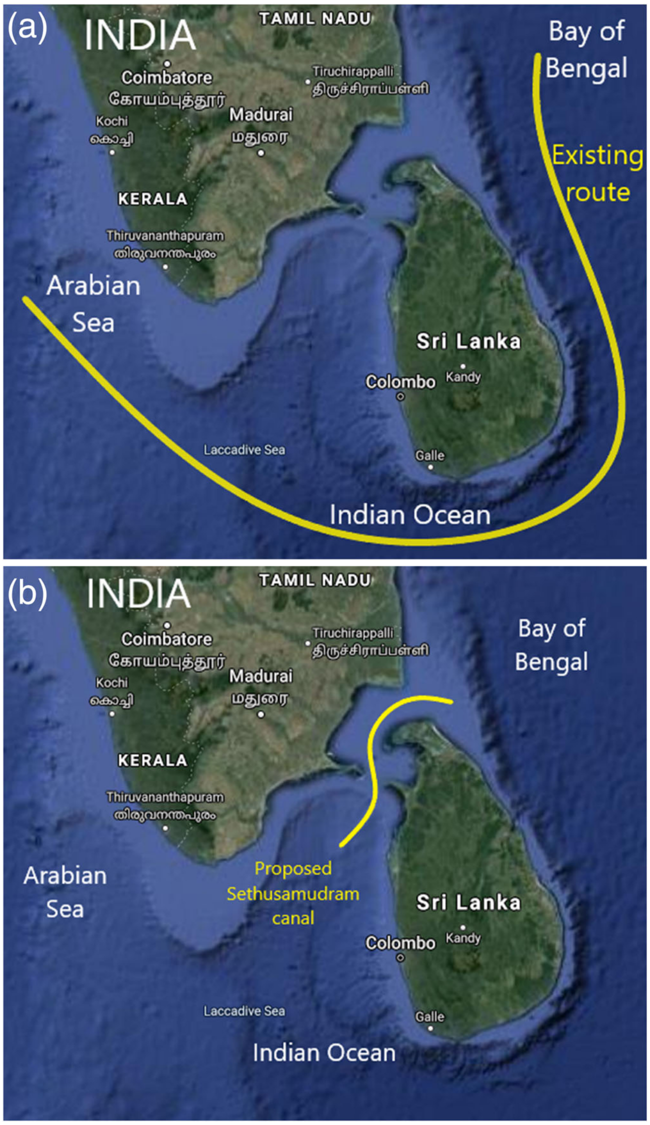

FIGURE 1 (a) Existing route circumnavigating Sri Lanka. (b) Proposed Sethusamudram canal route [Colour figure can be viewed at wileyonlinelibrary.com]

vessels than by circumnavigating Sri Lanka, there is more to its statistical side of environmental and economic benefits.

Given the unpredictable nature of the economic cycles of the maritime industry, the construction of an international canal shortening the route will bring much respite to businesses in the field by reducing the consumption of resources, increasing work opportunities and also by reducing emissions which have become a significant addition to the cost incurred by a business after the evolution of ‘Green Economics’ (Hermeling et al., 2015; Tichavska and Tova, 2015).

2.2 | Sustainable development initiative in the marine industry

The recent trends in the maritime industry mark the beginning of new and cleaner approaches such as ‘Green supply chains’ and ‘Sustainable Development’ (Bonilla et al., 2010; Krozer et al., 2003; Mickwitz et al., 2008; Sarkis, 2003; Suki et al., 2021). The maritime industry is showing a gradual change concerning the recent regulations of the International Maritime Organisation (IMO). The use of environmentally cleaner fuels, systems and conduct has become more significant than before due to the degradation of the environment on planet earth (Bonilla et al., 2010; Brynolf et al., 2014; Chuah et al., 2017; Gold & Seuring, 2011; Krozer et al., 2003; Mickwitz et al., 2008; Nanaki & Koroneos, 2012; Qorri et al., 2021; Ziegler & Hansson, 2003). To overcome these environmental issues the IMO provides several measures such as EEDI/EVDI, EEOI, CO_2 footprint, and Emissions factor to assess the environmental impact (International Maritime Organization, 2014). Technically, the introduction of newer, modified and cleaner marine fuels has largely contributed towards achieving the goals of these ideologies (Arctic Climate Change Economy and Society [ACCESS], 2014). Incidentally newer, better and more efficient engines are being introduced that are also compatible with the new varieties of fuels (Basurko et al., 2013; Geerlings & Van Duin, 2011; Halog et al., 2001; Krozer et al., 2003; Mickwitz et al., 2008; Saengsupavanich et al., 2009; Utne, 2009). Moreover, the impact of sustainable operations is not limited to the environment but further extends to human health and economic growth (Khan et al., 2020).

Similarly, the new methods such as calculation of environmental indices applicable to maritime machinery, marine engines and fuels to evaluate their financial implications would help to emphasise factors such as carbon credit and carbon footprint (Bouman et al., 2017). The carbon credit and carbon footprint have gained much importance in determining the taxes to be levied on firms and macro economies causing pollution over a certain acceptable limit. Natural calamities are altogether interconnected and climate change is an influential factor (Novo-Corti et al., 2015). For instance, earthquakes, tsunamis, the reversal of winds and currents, and most recently the drought in South Africa are alarming indications (Masante et al., 2018). The mapping and analysis of emissions would be a great opportunity to determine the financial differences rising from existing and potential maritime routes after the implementation of SSCP (Govindan & Soleimani, 2017; Halog et al., 2001).

As discussed, there are combinations of environmental and economic factors justifying that the SSCP route yields better results. Several pieces of research have contributed towards the elaboration of these economic and environmental factors from both technical and commercial perspectives. At first, surveys and detailed studies have been conducted in which all the events ranging from the history of the region to its recent conditions along with government actions and policies have been addressed thereby bringing transparency to the entire situation (Ramesh, 2004). There have been significant and widespread discussions about the past activities, political and social influences that had an impact on the proposed project and vice versa. Few pieces of research have reported the dimensional and design parameters of the canal according to the proposals and the possible maintenance related problems that could be faced in the future during its existence (Rajendran, 2005; Ramesh, 2004; Rodriguez, 2007;

Rodriguez et al., 2007). Moreover, the problem of sedimentation and related natural regimes, and the solution of constant dredging and its impact on a nation's capital is also discussed (Ramesh, 2004). Various environmental species and landmarks in the region and the probable changes that would take place due to the canal are carefully pinpointed (Rajendran, 2005; Ramesh, 2004; Rodriguez, 2007; Rodriguez et al., 2007). Ramesh (2004) further discussed aspects such as geomorphology, behaviour and phenomena under the study of tectonics, wave and tide regimes, by identifying the natural factors and their impact on the canal. The collection of literature mentioned above has played an important role in spreading awareness about the project so far. Similarly, EIA and technical feasibility reports (TFR) have been simultaneously considered and deemed leading to an incomplete approval or rejection of the project despite both reports have had claimed the project to be safe at some point in time in the past (Ramesh, 2004). Moreover, it has become clearer in recent times that the development of the maritime industry while adhering to the SDG's, depends on massive infrastructure building and radical innovations (Wang et al., 2020). According to Wang et al. (2020), investments in logistics infrastructure could lead to the evolution of a sustainable maritime ecosystem. In this manner, the SSCP could be seen as a justifiable investment and a step towards achieving SDGs.

Secondly, it is difficult to understand and analyse the entire scenario based on background studies and factual information on related events. A clear understanding and in-depth study of marine engineering, emissions, and the study of fuels are equally necessary. The basic design and working of ships and marine vessels were well comprehended from the book titled 'Marine Engineering' by Harrington (1992). Basics of marine engines, design of components, working parameters and conditions such as power and fuel consumption and important technical data on Marine Engineering is derived fundamentally. Furthermore, the basic data and information obtained need to be applied to analyse how these variables have an impact on the environment. Widespread discussions on environmental norms are leading to the new set of rules as well as revisions and additions to earlier policies such as the grade, type and mixtures of fuel, engine working conditions, manufacturing requirements, and the overall regulations of navigation. For instance, a study conducted by Marine Environment Protection Committee (MEPC) under IMO reflected on methods by which carbon dioxide reduction factors could be determined using 'EEDI/EVDI' index, one of the main indices under energy efficiency of ships. Eventually, a measure of a ship's operational efficiency also known as the 'EEOI' was obtained which gave the industry a broader perspective on the amount of fuel consumed for a voyage carrying a designated load as per limits (International Maritime Organization, 2009). The EEDI/EVDI, CO_2 footprint and EEOI indices were further used to fix limits on the indicators to control pollution and environmental damages for which the industry had been responsible earlier (International Maritime Organization, 2009, 2014). The estimation of indices of individual vessels of different types makes it possible in determining the possible contributions that the project could offer (Bouman et al., 2017). Few studies have also reported (Arctic Climate Change Economy and Society (ACCESS), 2014; Psaraftis & Kontovas, 2009; Trozzi, 2010) that the total cost and gaseous emissions especially GHG by different kinds of marine vessels are mapped to estimate the amount of carbon dioxide emitted and the related costs incurred as per MEPC standards (Giorgiutti et al., 2014; International Maritime Organization, 2009). The impact of these variables on global and arctic climate change has been studied. The rate of melting of polar ice caps and other impact analyses on the endangered regions in the world and the responsibility of the maritime community in the future can be well noticed (Arctic Climate Change Economy and Society (ACCESS), 2014). Furthermore, the Ministry of Transport and Communications, Finland (Kalli et al., 2009) estimated the Sulphur content in oil and fuel bunkers. Acomi and Cristian (2014) studied the impact of these fuels on the operational efficiency or EEOI indices of vessels for different voyages. The Hindustan Petroleum Marine Fuels Product Digest (HPMFPD) has also provided accurate data related to marine fuels such as Physico-chemical properties, which are further used in performing calculations related to vessel emissions (Hindustan Petroleum Corporation Ltd., 2009). Eventually, several other organisations involved in maritime affairs and environmental studies have presented a clear understanding and mathematical working of these parameters. These studies have elaborated on the mathematical formulation required to keep account of the indices and parameters prescribed by the IMO (Kedzierski & O'Leary, 2012; MAN Diesel & Turbo, 2012).

The mathematical formulation is derived from a collection of data associated closely with the Marine Engineering field wherein the focused topics are design and working parameters of engines, which give an insight into different scenarios such as power, efficiency, propeller design and so forth. More insight into the analytical field relevant to EEOI is given by (Hon et al., 2016) mostly dealing with the mathematical formulation. This survey of literature has made it possible to determine and make use of the parameters, indices and regulations to analyse the impact that the SSCP will have on completion. A complete perspective consisting of technical, environmental and economic factors provides a more open outlook towards the project (Chang & Danao, 2017).

The literature survey presents a variety of studies ranging from addressing the possible problems faced while constructing SSCP to the methodology of assessment of environmental and economic impacts. However, the lack of a report collectively addressing environmental and economic issues and their influence over each other has served as the basis for this study. The study also uniquely addresses the quantification of environmental and economic factors related to SSCP, which helps clarify most of the doubts regarding the project, by pinpointing benefits inferred from the comparative analysis.

3 | NUMERICAL FORMULATION AND METHODOLOGY ADOPTED

The objective of this study is to measure certain environmental indices and their impact on the cost for two maritime routes in the Indian subcontinent namely the SSCP and the normal course of navigation followed at present by circumnavigating Sri Lanka. The route yielding better results in terms of environment and economy will emerge as a better route nearing a sustainable future. The analytical contents are divided into the following categories to quantify the environmental and economic factors discussed earlier in the study and to draw a plausible conclusion as seen in Figure 2. These parameters are used to compare the results that the routes yield. Based on these results, the potential existence of a canal as a better sea route for vessels bound for the east coast of India from the west or vice versa can be justified and concluded.

The calculation of various indices for the routes is greatly influenced by literature containing a significant amount of technical data. Numerous principles underlying marine engineering and naval architecture influence the derivation of indices. The calculations depend on propeller design; Power transmitted by main and auxiliary engines, carrying capacity, design speed and carbon conversion factors. The procedure also involves a certain amount of assumptions discussed in detail for a particular index or factor in the following sections. Furthermore, the use of various tools for the calculation of cost and time estimation has also been explained. Figure 3 shows the numerical formulation and methodology adopted in this study.

3.1 | The significance of vessel indices-EEDI/EVDI

EEDI and EVDI are directed towards setting energy efficiency requirements with the former being applicable to new vessels and the latter to existing vessels (International Maritime Organization, 2014). EEDI has become a parameter of climate measure all over the world and is considered essential during the design of new vessels (International Maritime Organization, 2014). This index is developed for the most energy-intensive segments of the world merchant fleet (International Maritime Organization, 2012). Similarly, the EEDI also makes the mapping of CO_2 possible through CO_2 footprint analysis. Equation (1) represents the formula for the calculation of EEDI using dependent factors.

$$\text{EEDI} = \frac{\text{Power Installed} \times \text{Specific Fuel Consumption} \times \text{Carbon conversion}}{\text{Available capacity} \times \text{Speed}}. \tag{1}$$

(Kedzierski & O'Leary, 2012).

The IMO introduced the EEDI to determine the amount of CO_2 produced for every tonne of cargo carried a nautical mile. EEDI mainly depends on:

- The total power of the engine—from main and auxiliary engines
- Specific fuel consumption of engines
- Carbon conversion—a variable based on the carbon content in fuel and used as a conversion factor between fuel consumption and CO_2.
- Speed-speed of the ship
- Available capacity-load carrying capacity deadweight or gross tonnage of a ship

While calculating EEDI the speed of the ship is assumed the design speed whereas for EVDI in existing vessels the index can be calculated at a particular speed of operation. In certain cases, a conversion factor 'f_i' for specific design cases such as 'ice class' is also considered (Arctic Climate Change Economy and Society (ACCESS), 2014). However, such conditions and operation-specific factors have not been considered in this study.

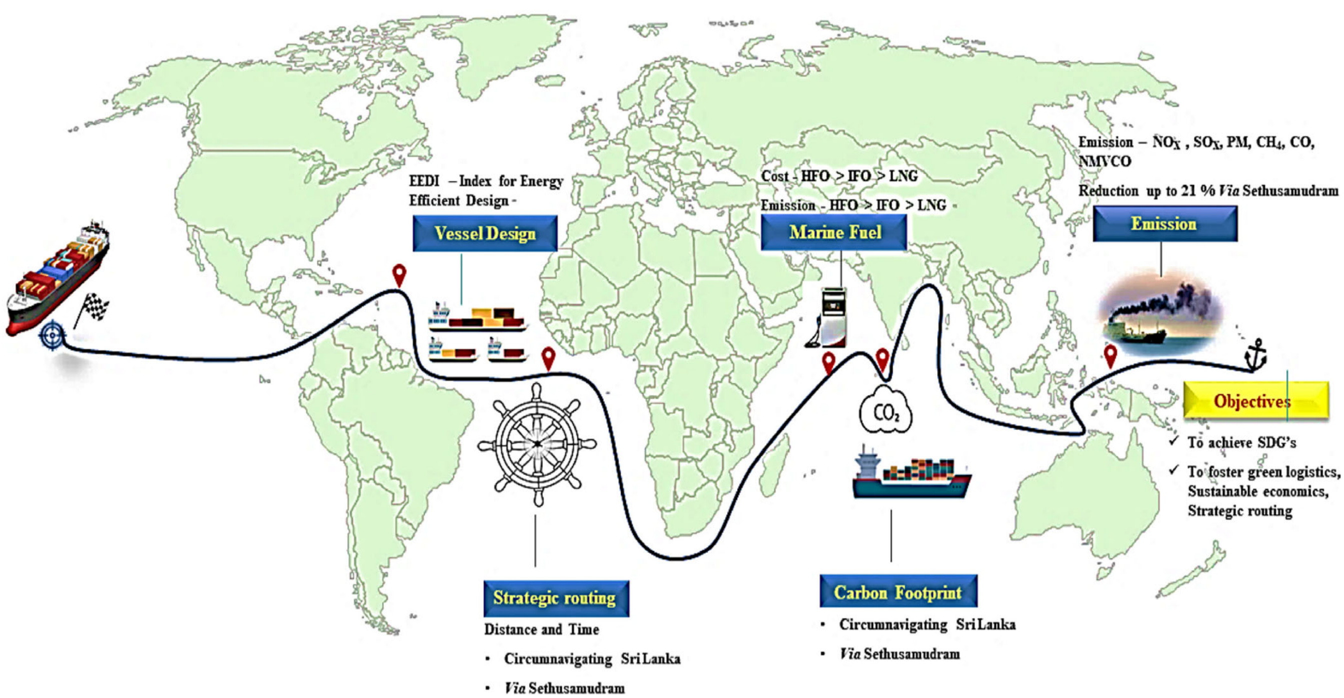

FIGURE 2 Categories to quantify the environmental and economic factors [Colour figure can be viewed at wileyonlinelibrary.com]

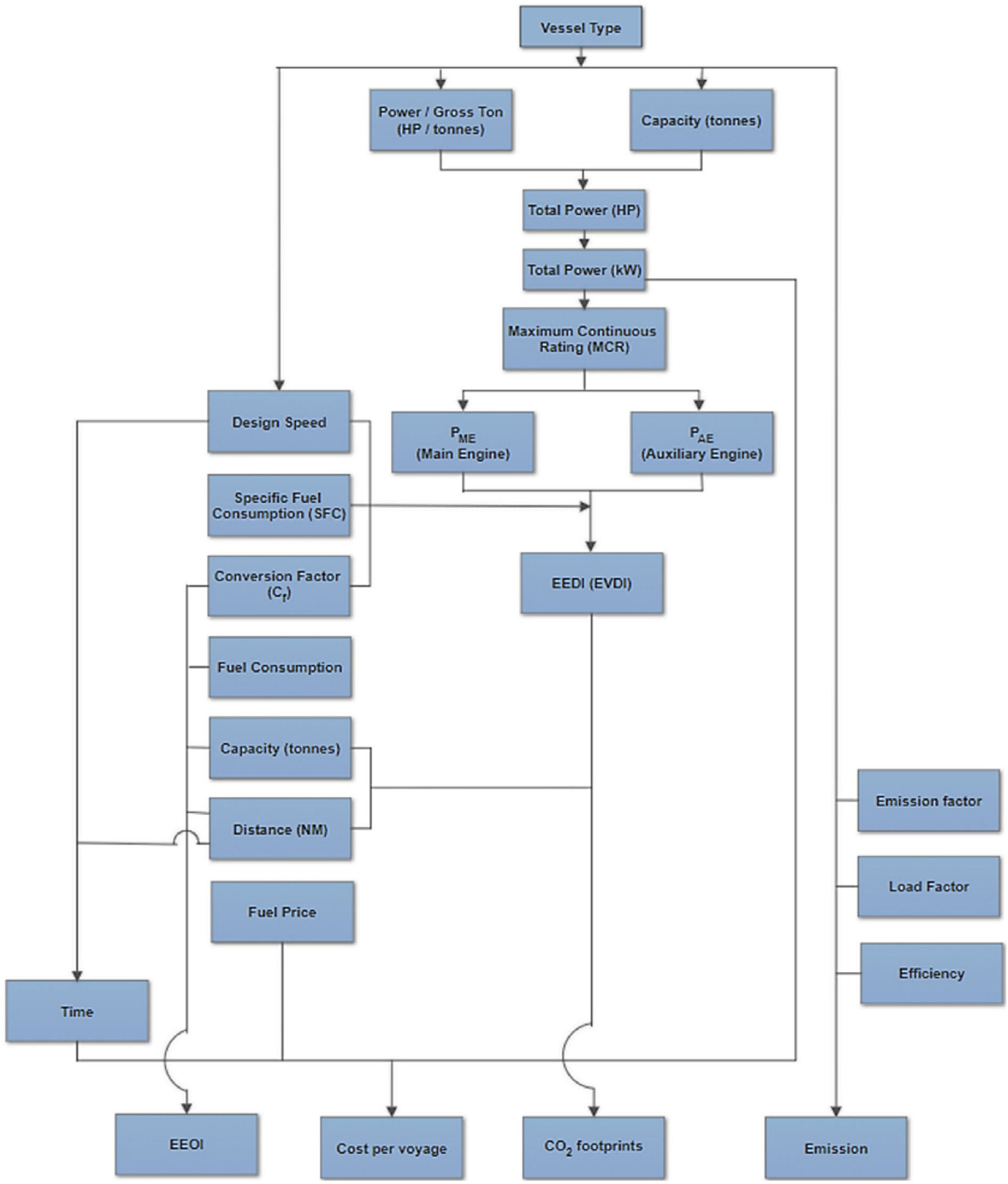

FIGURE 3 Flowchart depicting the method of calculation of findings discussed in the study, namely-time, energy efficiency operational index, cost per voyage, CO_2 footprint and emission [Colour figure can be viewed at wileyonlinelibrary.com]

The main difference between EVDI and EEDI can be credited to how data is collected for their calculation. The data for EVDI can be collected from all possible material sources such as existing vessels whereas the data for EEDI is collected from research and design calculations of ships to be designed and manufactured in the near future. The various parameters such as power installed, specific fuel consumption, carbon conversion, speed and available capacity that are taken into consideration while calculating the EEDI and EVDI are tabulated in Tables 1–6.

Several shipping organisations such as Hapag Lloyd have certified their fleet according to the EVDI standards for existing vessels and EEDI standards for new additions to the fleet (Kedzierski & O'Leary, 2012). This action has been completely voluntary, as it has been observed that these standards are being increasingly recognised in the industry and have fostered competition for maintaining better fleets. It must also be noted that these are not the measures of operational efficiency or performance and are not indicators of the same in

TABLE 1 Values of MCR and SFC at various engine ages for the main engine

Engine age	MCR_{ME} (kW)	SFC_{ME} (g/kWh)
Pre-1983	>15,000	205
	5000 to 15,000	215
	<5000	225
1984–2000	>15,000	185
	5000 to 15,000	195
	<5000	205
2001–2007	>15,000	175
	5000 to 15,000	185
	<5000	195

Abbreviations: MCR, maximum continuous rating; ME, main engine; SFC, specific fuel consumption.

TABLE 2 Calculation of P_{AE} for two different MCR_{ME} values

MCR_{ME} (kW)	P_{AE} (kW)
>10,000	$(0.025MCR_{ME}) + 250$
<10,000	$0.05MCR_{ME}$

Abbreviations: AE, auxiliary engine; MCR, maximum continuous rating; ME, main engine.

TABLE 3 Values of SFC according to MCR_{AE} values

Engine age	MCR_{AE} > 800 kW	MCR_{AE} < 800 kW
Any	220 g/kWh	230 g/kWh

Abbreviations: AE, auxiliary engine; MCR, maximum continuous rating; SFC, specific fuel consumption.

TABLE 4 Carbon conversion factor (C_F) values for different marine fuels

Fuel type	Carbon content	C_F (t-CO_2/t-fuel)
Diesel gas oil (DGO)	0.875	3.206
Light fuel oil (LFO)	0.86	3.15104
Heavy fuel oil (HFO)	0.85	3.1144
Intermediate fuel oil (IFO)		3.1
Propane	0.819	3.000
Butane	0.827	3.030
Liquified natural gas (LNG)	0.75	2.750

TABLE 5 Specific fuel consumption (SFC) values at different engine ages

Engine age	SFC (g/kWh)
Pre 1983	225
1984–2000	205
2000–2007	195
Auxiliary engine	220

any manner. The relevance of 'Operational efficiency' is best represented by the EEOI discussed in Section 3.2 of this study. The European Union along with the IMO has proposed an (MRV) scheme with monitoring, reporting and verification as to its pillars. This will set standards for emissions and will help organisations manage their fleets in a better way (Kedzierski & O'Leary, 2012). The mapping of emissions has also received attention lately and involves certain mathematical methods. GHG emissions rating by RIGHTSHIP (a leading maritime environmental assessment and risk management company) and Algebra of Emissions by IMO are such techniques for the assessment and mapping of emissions. The GHG emission ratings are vessel-specific and require authentic statistical data such as the number of vessels belonging to a category in a geographical radius at a given time. The data is then processed with the calculation of a Z-score equated to a negative logarithm of the EVDI (RIGHTSHIP, 2013). However, this yields only the GHG rating of a vessel in its working. As the changes in emissions factor for different gases varying with the two different routes are to be addressed in the study, only the 'Algebra of emissions' technique was followed.

3.1.1 | Method of calculation of EEDI or EVDI

The calculation of EEDI or EVDI plays an important role to analyse several scenarios. Firstly, as the name suggests the efficiency of the design can be inferred from the index. Secondly, the indices play a major role in the calculation of CO_2 footprints that further affect carbon debts or loans that are to be paid as fines to the nations holding carbon credit with negative or zero-footprint (Godil et al., 2021). For instance, a country producing more CO_2 per year can borrow a carbon loan from a country producing lesser CO_2 to repay the charges levied for polluting the environment. This study consists of the calculation of EEDI or EVDI (both having the same mathematical formulation with the prior being calculated for new vessels and the latter for existing vessels) indices for the following kinds of vessels namely: Lighter, tanker, cargo, bulk carrier, and container.

The steps involved in calculating EEDI or EVDI (RIGHTSHIP, 2013) are as follows:

Firstly, the value of specific power was determined for each vessel adopted from the book by Harrington (1992). The design speed from Table 6 is used as a reference parameter to find out the specific power. The value of the specific power obtained is in HP/gross ton and must be converted to horse power (HP) by considering its arithmetic product with the capacity of the vessels and later converted into kW from HP. Moreover, the specific power can be split into two components namely the 'power of the main engine' and the 'power of the auxiliary engine'. Equation (2) represents the formulation of specific power.

$$P = P_{\text{Main Engine(ME)}} + P_{\text{Auxiliary Engine(AE)}}, \quad (2)$$

where P is the specific power and P_{ME} and P_{AE} are powers of the main and auxiliary engine respectively. The purpose of splitting the specific

TABLE 6 Specific power, design and capacity of different vessels

Vessel	Specific power (kW)	Design speed V_{ref} (knots or NM/h)	Capacity (DWT)
Lighter	769	7.482	5500
Tanker	7656.73	14.5	50,000
Tanker	11,318.66	14.5	100,000
Tanker	23,968.92	14.5	300,000
Cargo	5992.23	17.5	15,000
Bulk carrier	16,370	14.7	75,000
Container (Feeder)	18,302.85	21	31,000
Container (Panamax)	23,226.43	22	37,000

power into components is to determine their relationship with maximum continuous rating (MCR) and specific fuel consumption (SFC) to be able to quantify all unknown parameters in the problem. Tables 2 and 3 show the calculation of P_{AE} and SFC values based on maximum continuous rating MCR_{AE} values considered. Equations (3) and (4) represent the formulation of power for the auxiliary engine and main engine respectively.

$$P_{AE} = (0.025MCR_{ME}) + 250, \quad \text{if } MCR_{ME} > 10,000\,kW$$

$$= 0.05\,MCR_{ME}, \quad \text{if } MCR_{ME} < 10,000\,kW, \tag{3}$$

$$P_{ME} = 0.75\,MCR_{ME}. \tag{4}$$

As specific power is known, it can be used to calculate MCR_{ME}.

The MCR_{ME} calculated earlier can be used to select the SFC_{ME} value from Table 1. The calculations are considered for the three engine ages ranging from Pre-1983, 1984–2000, and 2001–2007.

Similarly, for the auxiliary engine, power is calculated as,

The SFC_{AE} values can be considered from the P_{AE} or MCR_{ME} values calculated using Table 2.

As a part of this study, the EEDI or EVDI index has been calculated by considering the engine ages and varieties of fuels used by different vessels. Table 4 shows the carbon conversion factors for different fuels that are used in the engines.

Similarly, Table 6 illustrates the specific power, design speed and capacity of different vessels where the vessel was assumed to be sailing at a velocity equal to that of the design speed for determining the indices at optimum sailing conditions, as it is impossible to calculate the indices at every instance during the voyage.

Lastly, the power, SFC, C_f, for main and auxiliary engines derived from earlier calculations can be substituted in Equation (5) to get the EEDI or EVDI of a vessel.

$$\text{EEDI or EVDI} = \frac{(P_{ME} \times SFC_{ME} \times C_{f_{ME}}) + (P_{AE} \times SFC_{AE} \times C_{fAE})}{\text{Capacity} \times \text{Velocity}}. \tag{5}$$

A total of 48 EEDI or EVDI indices were collectively calculated for the vessel types stated in Section 3.1.1 for two engine ages; some of them were manufactured before the year 2000 and some after. The variation of the indices with the use of diesel, heavy fuel oil (HFO), liquified natural gas (LNG) and intermediate fuel oil (IFO) has also been considered. Although, the EEDI and EVDI stand for newer and older vessels respectively, both the indices are calculated using the same mathematical procedure and formulation.

The theoretical background of MCR and design speeds was obtained from MAN Turbo (2012). Harrington (1992) discusses in detail the selection of parameters in propeller design for most commonly used vessels. Although the propeller design is an important aspect of marine engineering, it has not been emphasised in the study for EEDI, EVDI or EEOI calculation as it is focused on the calculation of other important factors impacting maritime logistics to justify the existence of a canal with the help of mathematical indicators that show a significant difference in value when used in the case of current sea routes and the case of the existence of a canal.

3.2 | Significance of EEOI and CO_2 footprint

The EEOI Index or the 'energy efficiency operational indicator' is an indication of a ship's efficiency during operations. It mostly depends on a vessel's activities and also its working and maintenance. The use of the same has been previously opposed by various organisations in the industry stating that data used can be misleading if different ships carry different cargo as the United States proposed MEPC 64/5/6 to set standards for EEOI and it was also a part of Ship Energy Efficiency Management Plan (SEEMP). The guidelines and assumptions for the calculation of EEOI have been discussed at various levels such as a report submitted by International Maritime Organisation (2009), and the International Maritime Organisation (2014) According to Acomi and Cristian (2014), heavy fuel oil (HFO) presents a lesser EEOI number than marine gas oil (MGO) and light fuel oil (LFO), that is, HFO has a lesser polluting index and is less expensive than MGO and LFO. However, this claim was later proven incorrect. It was inferred that particulate matter from emissions is observed to be much lesser in light fuel oils than in heavy fuel oils. According to Giorgiutti et al. (2014), several indirect factors such as cleaning the hull and propeller can have a significant impact on the operational index. Also, fouling and operational conditions along with cleanliness can impact the total fuel consumption and related emissions, and indirectly influence the total cost of the voyage inclusive of maintenance. Taking into consideration all factors, Hon et al. (2016) developed a way to analytically formulate the EEOI along with all technical and non-technical parameters, which are also reflected in fuel savings {http://shippingefficiency.org/fuel-savings-calculator}.

According to International Maritime Organisation (2014), International shipping emitted 796 million tonnes of CO_2 in 2012, which accounts for no more than about 2.2% of the total emission volume for that year. By contrast, in 2007, before the global economic downturn, international shipping is estimated to have emitted 885 million tonnes of CO_2, which represented 2.8% of the global emissions of CO_2 for that year. The statistics of emissions suggest that ships were responsible for approximately 85% of CO_2 emissions from international shipping and together they represent the first-ever mandatory global regime for CO_2 emission reduction in an entire industry sector.

At present, sustainable development has received a lot of attention and after reflecting on the principles of sustainable and responsible development, the countries started a system of keeping the number of emissions low, specifically CO_2 and CO resulting in the birth of Carbon economies and the study of green economics. This vast field keeps account of emissions produced by a nation and then with the aid of several factors influencing mathematical models, converts it into currency. This valuation of emissions especially that of carbon results in creditor-debtor economics wherein the nations with positive footprints are indebted to the nations showing a negative or lower carbon footprint. To survive financially and environmentally in such economic conditions, India and the neighbouring nations will soon have to cut down their emissions to reduce pollution and contamination caused especially due to maritime affairs. The SSCP will play a major role in achieving this goal.

3.2.1 | Calculating the EEOI, CO_2 footprint and fuel consumption

According to RIGHTSHIP EVDI is an estimate of CO_2 emitted per tonne nautical mile travelled. Equation (6) represents formulation for CO_2 footprint.

$$CO_2\ \text{footprint} = \text{EVDI} \times \text{nautical miles travelled} \times \text{tonnes carried}. \quad (6)$$

The sea distances in nautical miles required to compute CO_2 footprint and EEOI were obtained using an online platform {http://www.marinevesseltraffic.com/2013/07/distance-calculator.html}.

The marine traffic tool represents the sea routes (as shown in Figure 4) that are based on actual voyage data under real conditions, unlike other tools that generate data by algorithmic routing. Owing to this, the platform considers actual maritime traffic at a given point of time along with weather, safer waterways following regulations for maritime navigation. Satellite images, statistics of vessels including types of vessels in number and the vessels bound to arrive at a particular feature at a point of time can be referred from the platform in the form of live feeds. The details of vessel owners can also be referred to in a few cases. Although the routes are not optimal, they are realistic and play an important role in providing valid data for this study.

However, the SSCP would evolve and develop coastal villages and towns into ports, the major existing ports in India on the west and east coasts were considered in this study, as it would provide a preliminary idea of the environmental and financial benefits that the canal project would provide. Hence, the distances for routes around Sri Lanka and by SSCP were obtained for combinations between the following ports on the eastern and the western side of the canal.

The change in routing plans between the ports mentioned above can function as a CO_2 emissions reduction strategy (Wang et al., 2013; Cariou, 2011; Liao et al., 2010). Therefore, the analytical approach of calculating CO_2 emissions will serve as a meaningful basis for the socioeconomic evaluation of the SSCP. This strategy was implemented earlier and showed meaningful results for the port of Taipei as discussed by Liao et al. (2010).

According to International Maritime Organisation (2009) report, the EEOI is used as an indicator for measuring CO_2 emissions and performance. It is stated to be an important factor in controlling global emissions in the future. Moreover, the IMO guidelines have also stated

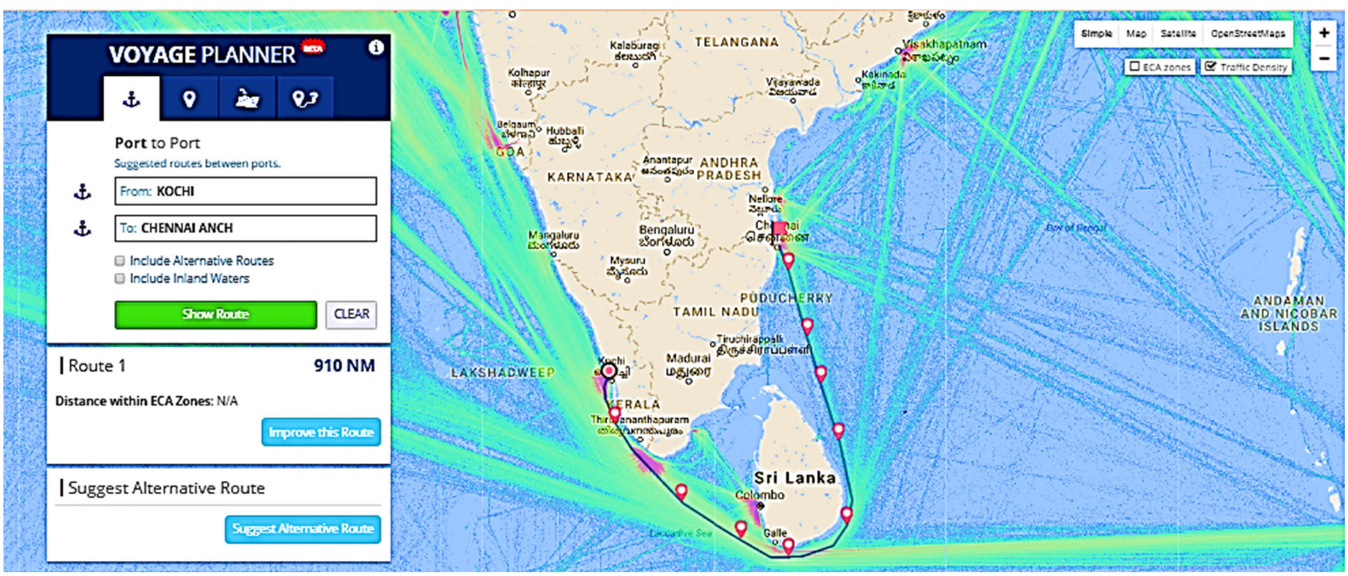

FIGURE 4 Marine traffic tool [Colour figure can be viewed at wileyonlinelibrary.com]

the kind of ships that could be examined for the calculation of EEOI along with the voyage statistics and the amount of cargo carried to the destination. Equation (7) represents the generalised form of EEOI.

$$\text{EE OI} = \frac{\sum_j FC_j \times C_{Fj}}{m_{cargo} \times D}. \quad (7)$$

(International Maritime Organization, 2009)

where,

- J is the type of fuel considered
- FC_j is the mass of fuel 'f' consumed
- C_{Fj} is the fuel mass to CO_2 mass conversion factor for fuel j
- m_{cargo} is the mass of cargo carried for a voyage
- D is the distance of voyage sailed

According to RIGHTSHIP (2013) in Equation (6) the values of EVDI are obtained from Table 6, tonnes carried are considered according to capacity, which is also similar for EEOI.

To calculate the mass of fuel consumed for a voyage another online platform by Better Fleet was referred {http://shippingefficiency.org/fuel-savings-calculator}. The platform is based on a study conducted by (Hon et al., 2016).

The fuel savings simulator can be used to calculate the total amount of fuel consumed for a given voyage by adjusting the settings shown in Figure 5. The calculator works on an algorithm by the Better fleet that takes input in the form of parameters such as operating days a year, power installed, design and operating speeds and so forth. In this study, a general situation without any savings conditions was considered wherein the propulsion power or power of the main engine along with the time taken to complete a voyage between ports enlisted in Table 7 and the fuel price for 14 February 2018 were entered. The fuel prices for IFO bunkers at the ports listed in Table 7 were obtained from http://livebunkers.com. The website provides precise costs of fuel bunkers at several ports spread across the world. The bunker prices are also supplemented by daily-obtained sales data of a type of fuel at different ports over the world.

Finally, after setting the various parameters according to the data obtained, the Better fleet fuel savings calculator shows the total cost of fuel. This total 'Fuel Bill' on dividing with the cost of a unit bunker yields the mass of fuel consumed in a metric tonne. The title of the field 'annual fuel bill' on the platform are not assumed to be the fuel costs incurred annually as the operating days are set to a value, the calculation of which is discussed under 'Voyage time and fuel cost'. While calculating the EEOI, the vessels were assumed to carry a load equal to the capacity of each vessel and m_{cargo} is considered equal to the vessel capacities. The carbon conversion factors (C_{Fj}) have been considered from IMO 8217 standards as mentioned in the report by International Maritime Organisation (2009). The 'HFO' was widely used in the maritime industry until the IMO under MEPC 72 discussed the regulations about diversification of fuels and fuel mixtures to cleaner fuels after 2019. Although HFO is available at extremely low prices in comparison to other fuels, it has posed a serious threat to the environment. Most of the emissions from HFO ISO 8217 used in engines contain a large amount of Sulphur and Particulate matter 5% and 0.15% by mass respectively and have been significantly involved in pollution till recent times (Trozzi, 2010). Therefore, the focus has shifted from economic and polluting marine oils to cleaner and comparatively expensive fuels such as LNG, MGO, MDO, and so forth. However, the use of such cleaner fuels at present is limited, as the vessel, owners do not completely agree to the sudden shift in the use of oils to be viable due to a significant difference in the cost of bunker prices between cleaner or expensive and inexpensive fuels. Though LNG is relatively affordable, the evolution of engines and relevant technology is currently in a nascent phase. Therefore, an optimum solution was sought and the use of intermediate fuel oil (IFO) comprising of a mixture of oils was suggested by IMO. It comparatively bears a higher cost and a maximum Sulphur content of 3.5% as per

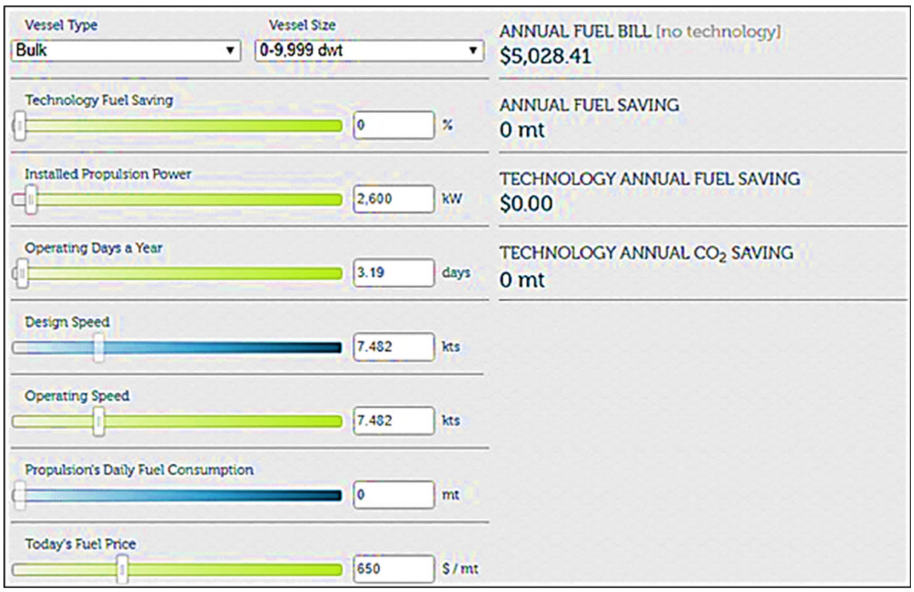

FIGURE 5 Better fleet annual fuel costing and CO_2 and fuel savings calculator [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 7 Major ports in India along the eastern and western sides of the SSCP

Eastern side of the canal	The western side of the canal
Porbandar (Por)	Krishnapatnam (Kr)
Mundra (Mun)	Kakinada (Ka)
Hazira (Haz)	Haldia (Hal)
Mumbai (Mum)	Vishakhapatnam (Viz)
Kochi (Kch)	Chennai (Ch)
Tuticorin (Tut)	-

guidelines of MARPOL and IMO as a temporary solution until technological advancements pave the way for cleaner and cheaper fuels to enter markets on a wider scale. Further details regarding the properties of IFO have been discussed in the study by (Hindustan Petroleum Corporation Ltd., 2009). Therefore, IFO 380 cST has been considered for calculations related to the CO_2 footprint as the widespread use of much cleaner fuels such as MGO and LNG at reasonable prices is awaited globally.

4 | ECONOMIC AND ENVIRONMENTAL IMPACT OF SSCP ON MARITIME NAVIGATION

4.1 | Estimation of cost and time

The cost and time estimation for a voyage plays an important role in selecting the most optimum route to the destination. The routes under study exhibit a significant difference in cost and time. The costs considered are mainly expenses on fuel required to complete a voyage exclusive of maintenance and overhead costs whereas the time calculated represents the time taken by a vessel to complete the entire voyage, that is, the time taken by a vessel to reach the port of entry at the destination from the port of exit. The calculation of such fuel costs and voyage time has been done with the help of an online tool developed by 'Better fleet' {http://shippingefficiency.org/fuel-savings-calculator}. The online tool takes into consideration various factors such as Ship speed, design speed, Fuel saving settings, and so forth. Moreover, another source of information {http://livebunkers.com} has been referred to obtain the cost of bunkers and has an updated database of fuel costs ranging over some time at different portside locations all over the world. The bunker prices of IFO 380 cSt are primarily focused on in this study. To calculate the time taken for a voyage, the nautical distances along sea routes were noted down by referring to http://www.marinevesseltraffic.com/2013/07/distance-calculator.html. The online platform calculates distances along sea routes by entering the port of exit and port of entry and enables the user to manually plot the route following navigation guidelines and offshore limits. The platform also provides live satellite images of ports and live port traffic along various sea routes, ports and anchorage points all over the world. It keeps an accurate record of ships in the harbour and expected arrivals to the port along with the live feeds of percentage categorisation of vessels by type such as Tanker, Bulk carrier, and so forth. The live information can also be obtained by entering the latitudinal and longitudinal location of a place. The differences observed in cost and time while following the two routes bound for the same destination was a primary and logical reason for the suggestion of a canal in the Palk Bay and the Gulf of Mannar region (Rodriguez et al., 2007). Rodriguez et al. (2007) also elaborate on an accurate account of the time saved including the delay due to speed limits in the canal.

The voyage time has been calculated by the mathematical relation between distance, time and speed as expressed in Equation (8). The time taken for a voyage is calculated by dividing the total distance by the vessel speed, which is assumed equal to the design speed. The reason behind this assumption is that the marine vessel is usually throttled at different velocities throughout the voyage and instantaneous speeds observed throughout the voyage are difficult to be recorded for further calculation due to errors in measuring readings and other inaccuracies. Therefore, to optimise the results and conduct a theoretical study on emissions and indices, the vessel speeds were assumed equal to the design speeds because the design speeds correspond to an engine load of 80%–85% of maximum engine power (Winnes et al., 2020). If engines are used at, lower or higher loads the specific fuel consumption increases. Therefore, the validity and accuracy of further calculations are significantly affected by considering optimum values such as that of design speeds.

$$\text{Voyage Time} = \frac{\text{Distance in nautical miles}}{\text{Vessel speed in knots}}. \quad (8)$$

Secondly, the time calculation from Equation (8). plays an important role in determining the cost incurred to complete a voyage exclusive of maintenance or waiting charges and mainly covering the fuel charges. The time taken to complete the voyage was then used to fill the field 'Operating days a year' upon its conversion into days. These settings along with the filling of all the remnant fields as discussed in Sections 3.1 and 3.2 generates the total fuel cost titled 'Annual Fuel Bill' in the same window visible in Figure 5.

4.2 | Algebra of emissions

International Maritime Organisation (2014) has emphasised the changing trends of fuels used in the industry and a shift towards cleaner fuels. This report also holds statistical records of various vessel types and emission types from different fuels. The importance of enforcing various laws and the globalisation of indices and emissions regulation were also considered in this report. Furthermore, the study conducted by (Trozzi, 2010) contains a detailed theoretical emission estimation procedure to be adopted for calculating emissions of different kinds such as NO_x, particulate matter (PM) and so forth. Similarly, the international regulations on emissions and the impact of design and performance aspects of vessels on the power and emissions are also discussed.

Winnes et al. (2020) elaborated on the emission factors for different emissions and their variation with different oils and performance factors such as engine MCR. Lastly, Psaraftis and Kontovas (2009) explained the concept underlying the mathematical Equation (9). Provides a clear explanation of the calculation of emissions according to operational days spent in the sea annually by the vessel. The application of the mathematical relation to finding the variation of emissions with types of vessel and the duration of the voyage has been explained in Section 5.5.

Sea kilometres in a year (km): *sDV*.

Total fuel consumption in a year (tonnes): *(sF + pG)D*.

Total CO_2 in a year (tonnes): *3.17(sF + pG)D = 3.17[s(F-D) + G]D*.

Total tonne-km's in a year: *(wW) (sDV)*.

$$CO_2 \text{ per tonne} - \text{km}: 3.17[F + (p/s)G]/wWv, \quad (9)$$

(Psaraftis & Kontovas, 2009).

The total number of nautical miles travelled by vessel in a year is obtained by *sDV* in which *sD* is the number of sea days in a year and *V* is the vessel speed. In Equation (9). the average payload is *wW* and *s/p* is the sea to port time ratio. *F* represents the total fuel consumption by the main and auxiliary engine and *G* is the fuel consumption at ports. Therefore, Equation (9). precisely represents the CO_2 per tonne-km for a load of *W* in DWT for total annual journeys including waiting time at ports. The limitation of this equation is that it can only be applied when accurate annual data for vessel voyages is available and is limited for a single voyage.

The study of these emissions is an important step towards the justification of a better sea route especially in the case of SSCP. The difference in emissions will indicate a better route that could be accepted as a better alternative in terms of reduced emissions. This will foster green economies and supply chains.

4.2.1 | Quantification of emissions

Many secondary factors such as engine problems, speed, and the sulfur content in the fuel affect the emissions of undesirable substances during a voyage (European Comission, 2002). However, all parameters are in Equation (10). Are considered at design speed to perform calculations at ideal conditions. IFO 380 is the type of fuel considered as discussed in Section 3.2.1. The quantification is carried out only based on primary factors given in Equation (10). To simulate ideal conditions.

$$EF_{ijk} = EF_{ij} \times LF_{jk} \times \frac{KW_j}{\eta_j} \times T_{jk}, \quad (10)$$

(Arctic Climate Change Economy and Society (ACCESS), 2014)

where,

- E_{ijk} are emissions of type *i* from vessel *j* on route *k* in gram [g]
- EF_{ij} is the emissions factor for emissions of type *i* on vessel *j* in [g/kWh]
- LF_{jk} is the average engine load factor for vessel *j* on route *k* and takes into account periods of manoeuvring, slow cruise, and full cruise operations;
- KW_j is the rated main engine power in kilowatts [kW] for vessel *j*, η_j is the engine efficiency
- T_{jk} is the duration of the voyage for vessel *j* on route *k* in hours

The values of E_{ijk} or emissions in grams have been calculated for a variety of emission factors of seven different effluents and in the case of voyages between Mumbai and Chennai because a port on either side of the canal must be considered for observing the difference in results between the two routes under discussion. The values of emissions factor and engine load factor have been obtained from International Maritime Organisation (2014) and Kalli et al. (2009). The load factor has been considered '1' as it is the ratio of ship speed to design speed and in case of maximum load conditions, both should be considered equal as discussed under Section 4.1. The calculation of time has also been discussed earlier under Section 4.1 and the same values for routes have been referred for the algebra of emissions. Lastly, the power of the main engine at a theoretical efficiency of 75% was considered according to Harrington (1992) that suggests the usual efficiency of performance of main engines to be 75%–80%. These calculations provide further clarity in the selection of a better sea route based on environmental and economic factors.

5 | STUDY FINDINGS

5.1 | Energy efficiency design index/existing vessel design index

The EEDI is an estimated measure of CO_2 emitted per tonne nautical mile travelled. Therefore, it is an important factor affecting the carbon footprint of a marine vessel over a designated route and its importance has been highlighted earlier in Section 3.1.1. Table 8 represents the EVDI or EEDI values calculated for vessels as discussed in Section 3.1.1. The variation in EVDI or EEDI can be observed for the four marine fuels currently in use namely Intermediate Fuel Oil (IFO), Heavy Fuel Oil (HFO), Diesel, and Liquefied Natural Gas (LNG). These results have also been calculated considering two engine ages that is engines manufactured before and after 2000, as inferred from Table 8. The fraction of engines that are being currently manufactured for vessels being designed currently was classified under EEDI indices. Vessels possessing significant power per unit capacity load carried indicate higher values of EEDI. Also, it is observed that the index values are highest for diesel followed by HFO and IFO and then by LNG. As EEDI is a measure of carbon emission, the carbon footprint can be computed by multiplying EVDI with voyage distances and load carried. Higher values of the index are alarming and are said to have detrimental effects on the environment (RIGHTSHIP, 2013).

5.2 | Carbon footprints

The calculation of footprints was considered for voyages between seven major port cities on the western side of the canal and five major port cities on the eastern side of the canal. Simultaneously, iterations

TABLE 8 EEDI and EVDI (in gm CO_2/tonne nautical miles [NM]) varying with tonnes carried

Engine age	Ships fuels	Lighter (barge)	Tanker (50,000 DWT)	Tanker (100,000 DWT)	Tanker (300,000 DWT)	Cargo	Bulk carrier	Container (feeder)	Container (Panamax)
Pre 2000	Diesel	13.46	7.29	5.38	3.63	15.75	9.79	18.54	18.81
	HFO	13.07	7.08	5.23	3.36	15.31	9.03	18.01	18.27
	LNG	11.54	6.25	4.62	3.11	13.51	8.4	15.9	16.13
	IFO	13.01	7.05	5.20	3.51	15.23	9.47	17.93	18.19
Post 2000	Diesel	11.77	6.33	4.67	3.12	13.69	8.43	15.95	16.18
	HFO	11.43	6.15	4.54	3.03	13.3	8.19	15.5	15.72
	LNG	10.1	5.43	4.01	2.68	11.75	7.23	13.68	13.88
	IFO	11.38	6.12	4.52	3.02	13.24	8.15	15.42	15.65

TABLE 9 CO_2 footprints (in million gm CO_2) for voyages to a combination of ports via Sethu Samundaram

		Barge		Tanker 50,000		Tanker 100,000		Cargo		Bulk carrier		Container	
Ports	Distances	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000
Por-Ch	1420	102	89	501	435	738	642	324	282	1009	868	956	822
Por-Kr	1502	107	94	529	460	781	679	343	298	1067	918	1011	870
Por-Ka	1696	121	106	598	519	882	767	387	337	1205	1037	1141	982
Por-Hal	2158	154	135	761	660	1122	975	493	429	1533	1319	1452	1250
Por-Viz	1682	120	105	593	515	875	760	384	334	1195	1028	1132	974
Mun-Ch	1560	112	98	550	477	811	705	356	310	1108	954	1050	903
Mun-Kr	1632	117	102	575	499	849	738	373	324	1159	998	1098	945
Mun-Ka	1793	128	112	632	549	932	810	410	356	1273	1096	1207	1038
Mun-Hal	2259	162	141	796	691	1175	1021	516	449	1604	1381	1520	1308
Mun-Viz	1800	129	113	635	551	936	814	411	357	1278	1100	1211	1042
Haz-Ch	1351	97	85	476	413	703	611	309	268	960	826	909	782
Haz-Kr	1400	100	88	494	428	728	633	320	278	994	856	942	811
Haz-Ka	1609	115	101	567	492	837	727	368	320	1143	984	1083	932
Haz-Hal	2032	145	127	716	622	1057	918	464	404	1443	1242	1368	1177
Haz-Viz	1582	113	99	558	484	823	715	361	314	1124	967	1065	916
Mum-Ch	1239	89	78	437	379	644	560	283	246	880	757	834	717
Mum-Kr	1287	92	81	454	394	669	582	294	256	914	787	866	745
Mum-Ka	1480	106	93	522	453	770	669	338	294	1051	905	996	857
Mum-Hal	1945	139	122	686	595	1011	879	444	386	1381	1189	1309	1126
Mum-Viz	1448	104	91	510	443	753	654	331	288	1028	885	975	838
Kch-Ch	573	41	36	202	175	298	259	131	114	407	350	386	332
Kch-Kr	666	48	42	235	204	346	301	152	132	473	407	448	386
Kch-Ka	840	60	53	296	257	437	380	192	167	597	513	565	486
Kch-Hal	1281	92	80	452	392	666	579	293	254	910	783	862	742
Kch-Viz	880	63	55	310	269	458	398	201	175	625	538	592	510
Tut-Ch	320	23	20	113	98	166	145	73	64	227	196	215	185
Tut-Kr	386	28	24	136	118	201	174	88	77	274	236	260	224
Tut-Ka	580	42	36	204	177	302	262	133	115	412	355	390	336
Tut-Hal	992	71	62	350	304	516	448	227	197	705	606	668	574
Tut-Viz	636	46	40	224	195	331	287	145	126	452	389	428	368

TABLE 10 CO2 footprints (in million gm CO_2) for voyages to a combination of ports via circumnavigating Sri Lanka

		Barge		Tanker 50,000		Tanker 100,000		Cargo		Bulk carrier		Container	
Ports	Distances	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000
Por-Ch	1765	126	110	622	540	918	798	403	351	1254	1079	1188	1022
Por-Kr	1815	130	114	640	555	944	820	415	360	1289	1109	1222	1051
Por-Ka	1969	141	123	694	603	1024	890	450	391	1398	1204	1325	1140
Por-Hal	2401	172	150	846	735	1249	1085	549	477	1705	1468	1616	1390
Por-Viz	2000	143	125	705	612	1040	904	457	397	1421	1223	1346	1158
Mun-Ch	1830	131	115	645	560	952	827	418	363	1300	1119	1232	1060
Mun-Kr	1907	136	119	672	584	992	862	436	379	1354	1166	1283	1104
Mun-Ka	2076	149	130	732	635	1080	938	474	412	1474	1269	1397	1202
Mun-Hal	2413	173	151	851	738	1255	1091	551	479	1714	1475	1624	1397
Mun-Viz	2088	149	131	736	639	1086	944	477	415	1483	1276	1405	1209
Haz-Ch	1616	116	101	570	494	840	730	369	321	1148	988	1088	936
Haz-Kr	1692	121	106	596	518	880	765	387	336	1202	1034	1139	980
Haz-Ka	1862	133	117	656	570	968	842	425	370	1322	1138	1253	1078
Haz-Hal	2199	157	138	775	673	1143	994	502	437	1562	1344	1480	1273
Haz-Viz	1880	135	118	663	575	978	850	429	373	1335	1149	1265	1089
Mum-Ch	1503	108	94	530	460	782	679	343	298	1068	919	1012	870
Mum-Kr	1579	113	99	557	483	821	714	361	314	1121	965	1063	914
Mum-Ka	1749	125	109	617	535	909	791	400	347	1242	1069	1177	1013
Mum-Hal	2086	149	131	735	638	1085	943	477	414	1482	1275	1404	1208
Mum-Viz	1751	125	110	617	536	911	791	400	348	1244	1070	1178	1014
Kch-Ch	910	65	57	321	278	473	411	208	181	646	556	612	527
Kch-Kr	986	71	62	348	302	513	446	225	196	700	603	664	571
Kch-Ka	1156	83	72	407	354	601	523	264	230	821	707	778	669
Kch-Hal	1493	107	93	526	457	776	675	341	297	1060	913	1005	865
Kch-Viz	1156	83	72	407	354	601	523	264	230	821	707	778	669
Tut-Ch	753	54	47	265	230	392	340	172	150	535	460	507	436
Tut-Kr	830	59	52	293	254	432	375	190	165	590	507	559	481
Tut-Ka	1000	72	63	353	306	520	452	228	199	710	611	673	579
Tut-Hal	1333	95	83	470	408	693	603	305	265	947	815	897	772
Tut-Viz	1008	72	63	355	308	524	456	230	200	716	616	678	584

were performed for the two routes considered in this study that is, by SSCP and the other by circumnavigating Sri Lanka are tabulated in Tables 9 and 10 respectively.

It can be observed from Tables 9 and 10 that an increase in distances and vessel capacity results in a higher CO_2 footprint. In certain routes, a difference of 10^7–10^8 grams of CO_2 or multiples of 10^8 grams of CO_2 can be observed for distances travelled by circumnavigating Sri Lanka and by following the geographical route prescribed under the discussions on Sethusamudram or SSCP. This implies that when IFO380 cSt (centistoke) is used, CO_2 within the range of 10–100 tonnes (depending on ports) is emitted during a voyage by circumnavigating Sri Lanka and these emissions could be reduced by constructing a canal near Adams Bridge as discussed earlier. Figure 6 shows the drastic reduction in CO_2 footprint via SSCP for Barge, Bulk carrier, Container and Tanker of capacities 50,000 DWT and 100,000 DWT.

Table 11 gives a brief account of EEOI values indicative of the operational efficiencies of the vessels. Although, the index is also indicative of CO_2 emissions it also depends on other important factors such as fouling and maintenance of the vessel. Therefore, it might be seen that there is no significant difference in EEOI values obtained by travelling on the two routes under observation as the ratio of fuel consumption and distance sailed remains constant in the index even though the values of fuel mass to CO_2 conversion factor changes that is if the distance sailed increases the fuel consumption also increases in a commensurate manner such that it compensates to yield a ratio that is similar to the ratio yielded over smaller fuel consumption and distance. However, real constraints such as maintenance, equipment life and corrosion may cause a variation in the observed value and change the operational factor thereby causing a variation in the emissions as at times older engines emit more hazardous substances (Acomi & Cristian, 2014).

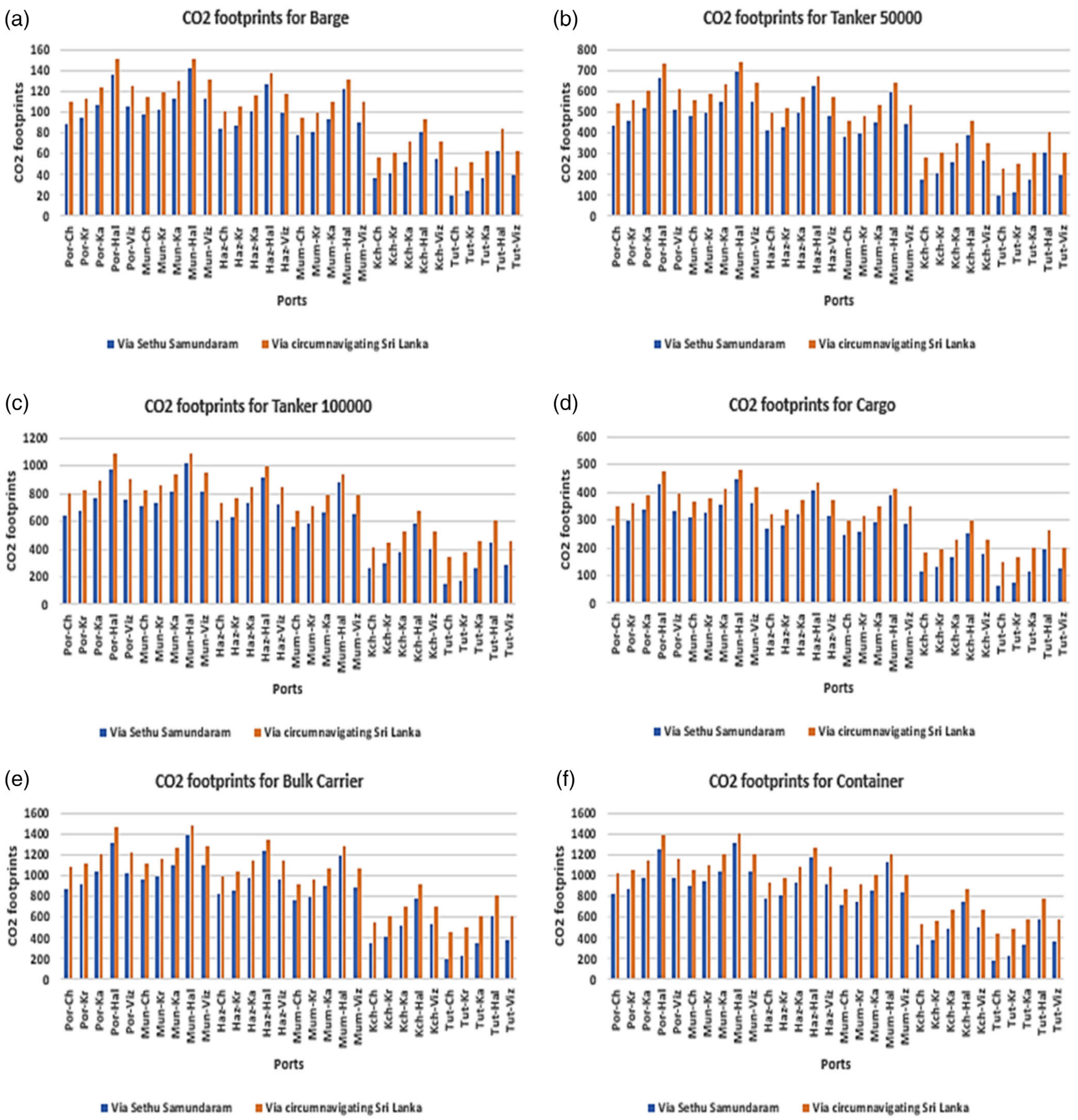

FIGURE 6 CO_2 footprints (in million gm CO_2) comparison for voyages between a combination of ports (a) barge (b) tanker of 50,000 DWT (c) tanker 100,000 DWT (d) cargo (e) bulk carrier (f) container [Colour figure can be viewed at wileyonlinelibrary.com]

5.3 | Time and distance

Table 12 gives the time and distance for a combination of routes between ports along with its variation with respect to the design speed of vessels. It can be inferred from Table 12 that a difference of 200–300 nautical miles exists between the two routes. Moreover, it is also observed that the time taken while travelling via the SSCP routes is one/two days shorter than the current route being followed.

5.4 | Fuel costs

Table 13 provides the fuel cost calculation for voyages for a combination of ports by different vessels and Figure 7 shows its graphical representation. The reason for considering a combination of five busy routes for percentage savings on fuel costs observed in Table 14 is the amount of marine traffic frequenting the ports daily {http://www.marinevesseltraffic.com/2013/07/distance-calculator.html}. Apart from the amount of traffic that

TABLE 11 EEOI values for voyages by different vessels to a combination of ports

Ports	Distance		Time				Fuel consumption		EEOI	
	Via Sethu	Via SL	Via Sethu		Via SL		Via Sethu	Via SL	Via Sethu	Via SL
			Hrs	Days	Hrs	Days				
Barge										
Mun-Ch	1560	1830	208.5	8.69	244.59	10.19	3.98	4.66	1.44E-06	1.44E-06
Mun-Hal	2259	2413	301.92	12.58	322.51	13.44	5.76	6.15	1.44E-06	1.44E-06
Mum-Ch	1239	1503	165.6	6.9	200.88	8.37	3.16	3.83	1.44E-06	1.44E-06
Mum-Hal	1945	2086	259.96	10.83	278.8	11.62	4.96	5.32	1.44E-06	1.44E-06
Tanker (50,000 DWT)										
Mun-Ch	1560	1830	107.59	4.48	126.21	5.26	102.65	120.52	4.08E-06	4.08E-06
Mun-Hal	2259	2413	155.79	6.49	166.41	6.93	148.7	158.78	4.08E-06	4.08E-06
Mum-Ch	1239	1503	85.45	3.56	103.66	4.32	81.57	98.98	4.08E-06	4.08E-06
Mum-Hal	1945	2086	134.14	5.59	143.86	5.99	128.08	137.25	4.08E-06	4.08E-06
Tanker (100,000 DWT)										
Mun-Ch	1560	1830	107.59	4.48	126.21	5.26	168.01	197.26	3.34E-06	3.34E-06
Mun-Hal	2259	2413	155.79	6.49	166.41	6.93	243.39	259.89	3.34E-06	3.34E-06
Mum-Ch	1239	1503	85.45	3.56	103.66	4.32	133.51	162.01	3.34E-06	3.34E-06
Mum-Hal	1945	2086	134.14	5.59	143.86	5.99	209.64	224.64	3.34E-06	3.34E-06
Cargo										
Mun-Ch	1560	1830	89.14	3.71	104.57	4.36	119.01	139.53	1.58E-05	1.58E-05
Mun-Hal	2259	2413	129.09	5.38	137.89	5.75	172.57	184.12	1.58E-05	1.58E-05
Mum-Ch	1239	1503	70.8	2.95	85.89	3.58	94.63	114.84	1.58E-05	1.58E-05
Mum-Hal	1945	2086	111.14	4.63	119.2	4.97	148.52	159.42	1.58E-05	1.58E-05
Bulk carrier										
Mun-Ch	1560	1830	106.12	4.42	124.49	5.19	245.69	287.94	6.51E-06	6.50E-06
Mun-Hal	2259	2413	153.67	6.4	164.15	6.84	355.75	380.22	6.51E-06	6.51E-06
Mum-Ch	1239	1503	84.29	3.51	102.24	4.26	195.11	236.8	6.51E-06	6.51E-06
Mum-Hal	1945	2086	132.31	5.51	141.9	5.91	306.28	328.52	6.51E-06	6.51E-06
Container Panamax										
Mun-Ch	1560	1830	70.91	2.95	83.18	3.47	236.87	277.82	1.27E-05	1.27E-05
Mun-Hal	2259	2413	102.68	4.28	109.68	4.57	343.66	366.95	1.27E-05	1.27E-05
Mum-Ch	1239	1503	56.32	2.35	68.32	2.85	188.69	228.04	1.28E-05	1.27E-05
Mum-Hal	1945	2086	88.41	3.68	94.82	3.95	295.48	317.16	1.27E-05	1.27E-05

the ports observe, the cost of IFO per bunker at the ports is an important factor for considering the five major ports in peninsular India. The fuel bunker prices were obtained from a website containing up to date bunker prices {http://livebunkers.com/} on 14 February 2018. The decision of choosing Porabandar-Haldia, Mundra-Chennai, Hazira-Krishnapatnam, Mumbai-Chennai and Kochi-Krishnapatnam as the five routes for calculation of percentage savings on fuel costs via SSCP was based on the number of bunkers of fuel sold at respective ports on 14 February 2018. The number of bunkers of fuel sold to individual vendors for the five selected ports was much higher than the other routes making them busy and significant in the study of fuel cost savings.

Naturally, due to the reduction of distance and time, a significant difference between fuel costs can be seen for the two different routes in Table 13 and Figure 8. Although it must be noted that these costs are merely fuel-related and are exclusive of the maintenance and operational costs or even costs incurred at anchorages or berths located midway at berths or port facilities availed during halts. It can be inferred from Table 13 that while sailing the five busy routes mentioned in Table 14 considered fuel cost savings vary from 11% to as high as 48% across three major varieties of vessels namely, bulk carrier, container Panamax and cargo, chosen based on their load-carrying capacity, which is higher than other vessels. Figure 8 show the percentage reduction in fuel costs via SSCP for Tanker, Bulk carrier, and Container respectively.

TABLE 12 Time and distance data for voyages for a combination of ports

Ports	Distance		Time																							
			Barge				Tanker 50,000 DWT				Tanker 100,000 DWT				Cargo				Bulk carrier				Container Panamax			
			Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating	
	Via Sethu	Via SL	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days
Por-Ch	1420	1765	189.79	7.91	235.90	9.83	97.93	4.08	121.72	5.07	97.93	4.08	121.72	5.07	81.14	3.38	100.86	4.20	96.60	4.02	120.07	5.00	64.55	2.69	80.23	3.34
Por-Kr	1502	1815	200.75	8.36	242.58	10.11	103.59	4.32	125.17	5.22	103.59	4.32	125.17	5.22	85.83	3.58	103.71	4.32	102.18	4.26	123.47	5.14	68.27	2.84	82.50	3.44
Por-Ka	1696	1969	226.68	9.44	263.16	10.97	116.97	4.87	135.79	5.66	116.97	4.87	135.79	5.66	96.91	4.04	112.51	4.69	115.37	4.81	133.95	5.58	77.09	3.21	89.50	3.73
Por-Hal	2158	2401	288.43	12.02	320.90	13.37	148.83	6.20	165.59	6.90	148.83	6.20	165.59	6.90	123.31	5.14	137.20	5.72	146.80	6.12	163.33	6.81	98.09	4.09	109.14	4.55
Por-Viz	1682	2000	224.81	9.37	267.31	11.14	116.00	4.83	137.93	5.75	116.00	4.83	137.93	5.75	96.11	4.00	114.29	4.76	114.42	4.77	136.05	5.67	76.45	3.19	90.91	3.79
Mun-Ch	1560	1830	208.50	8.69	244.59	10.19	107.59	4.48	126.21	5.26	107.59	4.48	126.21	5.26	89.14	3.71	104.57	4.36	106.12	4.42	124.49	5.19	70.91	2.95	83.18	3.47
Mun-Kr	1632	1907	218.12	9.09	254.88	10.62	112.55	4.69	131.52	5.48	112.55	4.69	131.52	5.48	93.26	3.89	108.97	4.54	111.02	4.63	129.73	5.41	74.18	3.09	86.68	3.61
Mun-Ka	1793	2076	239.64	9.99	277.47	11.56	123.66	5.15	143.17	5.97	123.66	5.15	143.17	5.97	102.46	4.27	118.63	4.94	121.97	5.08	141.22	5.88	81.50	3.40	94.36	3.93
Mun-Hal	2259	2413	301.92	12.58	322.51	13.44	155.79	6.49	166.41	6.93	155.79	6.49	166.41	6.93	129.09	5.38	137.89	5.75	153.67	6.40	164.15	6.84	102.68	4.28	109.68	4.57
Mun-Viz	1800	2088	240.58	10.02	279.07	11.63	124.14	5.17	144.00	6.00	124.14	5.17	144.00	6.00	102.86	4.29	119.31	4.97	122.45	5.10	142.04	5.92	81.82	3.41	94.91	3.95
Haz-Ch	1351	1616	180.57	7.52	215.99	9.00	93.17	3.88	111.45	4.64	93.17	3.88	111.45	4.64	77.20	3.22	92.34	3.85	91.90	3.83	109.93	4.58	61.41	2.56	73.45	3.06
Haz-Kr	1400	1692	187.12	7.80	226.14	9.42	96.55	4.02	116.69	4.86	96.55	4.02	116.69	4.86	80.00	3.33	96.69	4.03	95.24	3.97	115.10	4.80	63.64	2.65	76.91	3.20
Haz-Ka	1609	1862	215.05	8.96	248.86	10.37	110.97	4.62	128.41	5.35	110.97	4.62	128.41	5.35	91.94	3.83	106.40	4.43	109.46	4.56	126.67	5.28	73.14	3.05	84.64	3.53
Haz-Hal	2032	2199	271.59	11.32	293.91	12.25	140.14	5.84	151.66	6.32	140.14	5.84	151.66	6.32	116.11	4.84	125.66	5.24	138.23	5.76	149.59	6.23	92.36	3.85	99.95	4.16
Haz-Viz	1582	1880	211.44	8.81	251.27	10.47	109.10	4.55	129.66	5.40	109.10	4.55	129.66	5.40	90.40	3.77	107.43	4.48	107.62	4.48	127.89	5.33	71.91	3.00	85.45	3.56
Mum-Ch	1239	1503	165.60	6.90	200.88	8.37	85.45	3.56	103.66	4.32	85.45	3.56	103.66	4.32	70.80	2.95	85.89	3.58	84.29	3.51	102.24	4.26	56.32	2.35	68.32	2.85
Mum-Kr	1287	1579	172.01	7.17	211.04	8.79	88.76	3.70	108.90	4.54	88.76	3.70	108.90	4.54	73.54	3.06	90.23	3.76	87.55	3.65	107.41	4.48	58.50	2.44	71.77	2.99
Mum-Ka	1480	1749	197.81	8.24	233.76	9.74	102.07	4.25	120.62	5.03	102.07	4.25	120.62	5.03	84.57	3.52	99.94	4.16	100.68	4.20	118.98	4.96	67.27	2.80	79.50	3.31

(Continues)

TABLE 12 (Continued)

Ports	Distance		Time																							
			Barge				Tanker 50,000 DWT				Tanker 100,000 DWT				Cargo				Bulk carrier				Container Panamax			
			Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating		Via Sethu		Circumnavigating	
	Via Sethu	Via SL	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days	Hrs	Days
Mum-Hal	1945	2086	259.96	10.83	278.80	11.62	134.14	5.59	143.86	5.99	134.14	5.59	143.86	5.99	111.14	4.63	119.20	4.97	132.31	5.51	141.90	5.91	88.41	3.68	94.82	3.95
Mum-Viz	1448	1751	193.53	8.06	234.03	9.75	99.86	4.16	120.76	5.03	99.86	4.16	120.76	5.03	82.74	3.45	100.06	4.17	98.50	4.10	119.12	4.96	65.82	2.74	79.59	3.32
Kch-Ch	573	910	76.58	3.19	121.63	5.07	39.52	1.65	62.76	2.61	39.52	1.65	62.76	2.61	32.74	1.36	52.00	2.17	38.98	1.62	61.90	2.58	26.05	1.09	41.36	1.72
Kch-Kr	666	986	89.01	3.71	131.78	5.49	45.93	1.91	68.00	2.83	45.93	1.91	68.00	2.83	38.06	1.59	56.34	2.35	45.31	1.89	67.07	2.79	30.27	1.26	44.82	1.87
Kch-Ka	840	1156	112.27	4.68	154.50	6.44	57.93	2.41	79.72	3.32	57.93	2.41	79.72	3.32	48.00	2.00	66.06	2.75	57.14	2.38	78.64	3.28	38.18	1.59	52.55	2.19
Kch-Hal	1281	1493	171.21	7.13	199.55	8.31	88.34	3.68	102.97	4.29	88.34	3.68	102.97	4.29	73.20	3.05	85.31	3.55	87.14	3.63	101.56	4.23	58.23	2.43	67.86	2.83
Kch-Viz	880	1156	117.62	4.90	154.50	6.44	60.69	2.53	79.72	3.32	60.69	2.53	79.72	3.32	50.29	2.10	66.06	2.75	59.86	2.49	78.64	3.28	40.00	1.67	52.55	2.19
Tut-Ch	320	753	42.77	1.78	100.64	4.19	22.07	0.92	51.93	2.16	22.07	0.92	51.93	2.16	18.29	0.76	43.03	1.79	21.77	0.91	51.22	2.13	14.55	0.61	34.23	1.43
Tut-Kr	386	830	51.59	2.15	110.93	4.62	26.62	1.11	57.24	2.39	26.62	1.11	57.24	2.39	22.06	0.92	47.43	1.98	26.26	1.09	56.46	2.35	17.55	0.73	37.73	1.57
Tut-Ka	580	1000	77.52	3.23	133.65	5.57	40.00	1.67	68.97	2.87	40.00	1.67	68.97	2.87	33.14	1.38	57.14	2.38	39.46	1.64	68.03	2.83	26.36	1.10	45.45	1.89
Tut-Hal	992	1333	132.58	5.52	178.16	7.42	68.41	2.85	91.93	3.83	68.41	2.85	91.93	3.83	56.69	2.36	76.17	3.17	67.48	2.81	90.68	3.78	45.09	1.88	60.59	2.52
Tut-Viz	636	1008	85.00	3.54	134.72	5.61	43.86	1.83	69.52	2.90	43.86	1.83	69.52	2.90	36.34	1.51	57.60	2.40	43.27	1.80	68.57	2.86	28.91	1.20	45.82	1.91

TABLE 13 Fuel cost calculation for voyages for a combination of ports by different vessels

Ports	Barge		Tanker 50,000 DWT		Tanker 100,000 DWT		Cargo		Bulk carrier		Container-Panamax	
	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL
Por-Ch	1667.60	2072.41	45,919.40	57,061.60	74,454.60	92,520.81	49,927.70	62,040.40	10,2903.90	12,7989.90	99,465.30	12,3499.70
Por-Kr	1762.50	2131.44	48,620.50	58,637.30	78,834.30	95,075.63	52,882.00	63,812.90	108,791.40	131,573.60	105,011.69	127,197.30
Por-Ka	1992.30	2310.64	54,810.60	63,701.90	88,871.10	103,287.50	59,677.00	69,278.40	123,126.30	142,836.70	118,692.79	137,920.30
Por-Hal	2534.10	2818.73	69,779.50	77,657.80	113,141.82	125,915.90	75,925.60	84,493.00	156,659.70	174,066.30	151,231.62	168,240.60
Por-Viz	1975.40	2348.59	54,360.40	64,714.80	88,141.10	104,929.90	59,086.00	70,312.40	122,102.40	145,652.50	117,583.51	140,138.80
Mun-Ch	1812.20	2125.00	46,756.70	54,897.40	76,529.30	89,853.56	54,207.30	63,704.50	111,914.60	131,157.80	107,894.69	126,547.70
Mun-Kr	1895.60	2214.65	52,211.70	61,006.40	84,657.00	98,917.00	56,691.20	66,334.50	116,978.60	136,728.20	113,015.11	132,033.80
Mun-Ka	2081.20	2410.68	57,332.60	66,350.00	92,960.30	107,581.20	62,389.50	72,179.00	128,625.80	148,881.90	123,987.45	143,737.70
Mun-Hal	2623.40	2802.72	67,734.60	72,326.70	110,865.00	118,381.20	78,607.90	83,867.90	162,048.30	173,189.10	156,538.73	167,145.30
Mun-Viz	2089.50	2425.27	57,555.30	66,795.30	93,321.30	108,303.30	62,535.60	72,617.30	129,132.20	149,894.70	124,718.94	144,469.20
Haz-Ch	1569.90	1878.68	43,241.70	51,711.70	70,113.00	83,846.45	47,099.50	56,314.60	97,082.20	116,093.00	93,733.40	112,040.70
Haz-Kr	1626.30	1966.57	44,802.00	54,163.60	72,642.80	87,821.93	48,708.50	58,947.50	100,630.90	121,416.20	97,028.70	117,166.80
Haz-Ka	1870.50	2164.89	51,488.80	59,624.50	83,485.00	96,676.40	56,022.00	64,798.30	115,586.10	133,836.60	111,674.58	129,249.60
Haz-Hal	2363.20	2557.37	65,085.50	70,434.90	105,530.87	114,204.60	70,795.50	76,500.10	146,003.60	157,917.00	140,966.28	152,316.80
Haz-Viz	1839.20	2185.77	50,708.70	60,181.80	82,220.10	97,579.92	55,144.40	65,529.70	113,558.30	135,104.00	109,843.85	130,348.00
Mum-Ch	1325.20	1607.50	34,218.40	41,523.40	56,007.10	67,963.68	39,696.20	48,173.70	81,849.30	99,338.50	79,157.00	95,662.10
Mum-Kr	1377.00	1688.16	37,935.00	46,547.30	61,508.60	75,472.66	41,176.40	50,595.90	85,114.00	104,235.50	82,188.60	100,714.70
Mum-Ka	1582.50	1870.61	43,574.00	51,468.60	70,651.70	83,452.15	47,366.40	55,978.40	97,706.20	115,661.70	94,314.80	111,493.50
Mum-Hal	2080.00	2231.67	53,730.50	57,575.30	92,927.80	99,577.37	62,302.90	66,878.10	128,487.10	137,814.70	123,956.50	133,051.20
Mum-Viz	1548.00	1872.53	42,651.20	51,571.10	69,155.60	83,618.39	46,424.40	56,113.00	95,607.49	115,661.74	92,293.70	111,830.40
Kch-Ch	615.60	978.40	16,997.60	26,887.10	27,560.30	43,595.33	18,387.90	29,339.50	37,956.72	60,449.59	36,552.00	58,212.40
Kch-Kr	715.90	1059.41	19,676.00	29,153.50	31,903.10	47,270.00	21,362.40	31,773.20	44,282.84	65,369.91	42,644.00	63,289.10
Kch-Ka	903.10	1242.73	24,826.80	34,201.20	40,254.70	55,454.59	27,041.00	37,181.40	55,763.58	76,850.64	53,812.70	74,119.31
Kch-Hal	1375.90	1603.58	37,909.80	44,193.80	61,647.70	71,656.69	41,237.50	47,997.80	85,051.17	99,109.22	81,903.50	95,779.70
Kch-Viz	945.60	1242.73	26,063.00	34,201.20	42,259.10	55,454.59	28,257.90	37,181.40	58,340.89	76,850.64	56,181.80	74,119.31

FIGURE 7 Fuel cost comparison for voyages to a combination of ports (a) barge (b) tanker 50,000 DWT (c) tanker 100,000 DWT (d) cargo (e) bulk carrier (f) container Panamax [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 14 Percentage savings on fuel costs via SSCP

	Tanker 100,000 DWT			Bulk carrier			Container-Panamax		
Ports	Via Sethu	Via SL	% change	Via Sethu	Via SL	% change	Via Sethu	Via SL	% change
Por-Hal	113,141.8	125,915.9	11.29	156,659.7	174,066.3	11.11	151,231.6	168,240.6	11.25
Mun-Ch	76,529.3	89,853.6	17.41	111,914.6	131,157.8	17.19	107,894.7	126,547.7	17.29
Haz-Kr	72,642.8	87,821.9	20.90	100,630.9	121,416.2	20.65	97,028.7	117,166.8	20.75
Mum-Ch	56,007.1	67,963.7	21.35	81,849.3	99,338.5	21.37	79,157.0	95,662.1	20.85
Kch-Kr	31,903.1	47,270.0	48.17	44,282.8	65,369.9	47.62	42,644.0	63,289.1	48.41

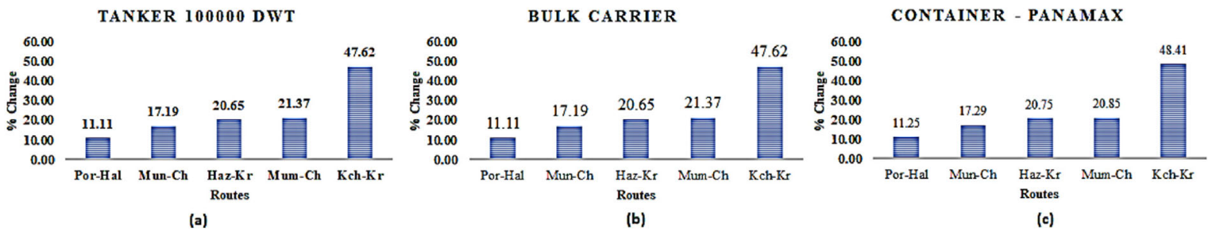

FIGURE 8 Percentage reduction in fuel cost for voyages between different ports via SSCP (a) tanker of capacity 100,000 DWT (b) bulk carrier (c) container Panamax [Colour figure can be viewed at wileyonlinelibrary.com]

5.5 | Emissions

The seven different types of effluents namely CO_2, NO_x, SO_x, PM, CO, NMVOC and CH_4 form the major portion of emissions from marine fuels and are represented in Table 15. The variation of emissions can be noted with respect to the different vessels for either route taken between Mumbai and Chennai and a difference of 10 tonnes or more on either route can be observed from Table 16. It can be noted that taking the SSCP route can cut down emissions by 21% per voyage, which can hugely benefit the environment in the long run if weighed against the setbacks such as sedimentation dredging costs incurred in the short term by implementing norms as reported in Section 6 of this study. Figure 9 represents the reduction in emissions for Bulk carriers via SSCP.

6 | IMPLICATIONS

The EEDI/EVDI and CO_2 footprint values observed were drastically reduced via SSCP than the route involving the circumnavigation of Sri Lanka making it a favourable route. The reason behind the huge difference was mainly due to the difference between distances travelled as factors such as Power installed; Carbon conversion, speed and capacity were common to a type of vessel for both the routes. However, the EEOI remained unaffected by routes as it is mainly an indication of the working condition of vessels and has environmental or economic implications only when the vessel is not performing up to the required limits also depending on the product life. A similar trend of decrement was observed in voyage duration obtained from voyage distance and vessel speed (design speed). The decrease in fuel consumption via the SSCP route also caused a reduction in costs calculated by the Better fleet fuel savings calculator. A huge reduction in the amount of emissions via SSCP can be majorly credited to a reduction in the voyage duration via SSCP as other factors such as power, efficiency, load factor and emissions factor remained common for a vessel type. The findings have differentiated the two routes based on environmental and economic or monetary factors and have validated the merits of the Sethusamudram Canal Project. The data from the research findings numerically supports the entire idea of the existence of a canal for navigation at a controversial location such as that of the Adams Bridge or through the Palk Strait and Gulf of Mannar. It proves that the existence of the same could prove to be an advantage not only to the domestic marine traffic of India but also to international maritime traffic as less time and capital is wasted while travelling through this shorter route evident from this study. Moreover, it also suggests a way in which maritime emissions and their impact could be reduced around the Indian subcontinent. Besides these, the SSCP has many more advantages to offer. Firstly, the reduction of CO_2 footprint and the contribution of India and Sri Lanka towards green logistics.

For example, the voyage of a cargo vessel from Mumbai to Chennai is considered.

CO_2 footprint via SSCP = 246.06 tonnes taxed at 1.6USD per tonne.

CO_2 footprint via Sri Lanka = 298.49 tonnes taxed at 1.6USD per tonne.

Tax via SSCP = 393.696 USD.

Tax via Sri Lanka = 477.584 USD.

Considering the fuel costs from Table 12.

Cost of Fuel via SSCP = 39,696.23 USD.

TABLE 15 Percentage reduction in emissions via SSCP of different vessels

Emission type	Emission factor	Lighter (barge)		Tanker 50,000 DWT		Tanker 100,000 DWT		Cargo		Bulk carrier		Container (Panamax)	
		Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL	Via Sethu	Via SL
CO_2	670	106,651,047.72	129,375,989.71	547,935,938.01	664,688,461.46	817,654,418.47	991,877,735.55	355,308,922.08	431,017,826.01	1,174,609,696.00	1,424,886,320.00	1,118,672,029.82	1,357,033,909.82
NO_X	13	2,069,348.69	2,510,280.40	10,631,592.83	12,896,940.30	15,864,936.48	19,245,388.90	6,894,053.71	8,363,032.45	22,790,934.40	27,647,048.00	21,705,576.70	26,330,508.70
SO_X	11.35	1,806,700.58	2,191,667.89	9,282,198.35	11,260,020.95	13,851,309.92	16,802,704.92	6,019,039.20	7,301,570.63	19,898,238.88	24,137,999.60	18,950,638.12	22,988,559.52
PM	1.43	227,628.36	276,130.84	1,169,475.21	1,418,663.43	1,745,143.01	2,116,992.78	758,345.91	919,933.57	2,507,002.78	3,041,175.28	2,387,613.44	2,896,355.96
CO	0.54	85,957.56	104,273.19	441,620.01	535,719.06	659,005.05	799,423.85	286,368.38	347,387.50	946,700.35	1,148,415.84	901,616.26	1,093,728.82
NMVOC	0.5	79,590.33	96,549.25	408,907.42	496,036.17	610,189.86	740,207.27	265,155.91	321,655.09	876,574.40	1,063,348.00	834,829.87	1,012,711.87
CH_4	0.01	1591.81	1930.98	8178.15	9920.72	12,203.80	14,804.15	5303.12	6433.10	17,531.49	21,266.96	16,696.60	20,254.24
% Change		21.3078		21.3077		21.3077		21.3079		21.3072		21.3076	

Cost of Fuel via Sri Lanka = 48,173.73USD.

Therefore, carbon taxes via SSCP are 83.88USD less than the taxes paid via Sri Lanka. Similarly, the total money saved on fuel and tax by preferring SSCP to Sri Lanka is 8561.62USD, which amounts to 555,813.51INR a significant sum in the Indian currency. The environmental, economic, socio-political and socio-economic benefits are discussed in the following subsections.

6.1 | Environmental and economic benefits

The reduction in fuel costs and taxes on emissions outweigh the challenges faced initially as both the Indian and Sri Lankan governments can levy dredging Cess to recover the capital lost on dredging the bed covered by sediments. Moreover, the route can be planned efficiently to properly offset the Mannar Marine Park to ensure minimal damage. A staggering 21% saved on emissions by sailing through the SSCP will have a greater impact on the environment than what is currently experienced by reluctantly holding the project claiming to protect the biodiversity in this region. The results that the reduced CO_2 footprint would yield would only be realised in the long run in the form of weather and climate normalisation, biodiversity, and so forth. Also, the benefits are not only for the private businesses but also can be mutually enjoyed by the respective governments by levying taxes, which would support further economic growth.

6.2 | Socio-political and socio-economic benefits

The idea of a canal affects fishing activities in the region as it provides occupation to people living in nearby villages as a workforce to run the entire project. This results in the overall upliftment of places that were drought-stricken with agricultural limitations or otherwise neglected. Lastly, India is a country with a vast coastline and the idea of a canal improves the chances of connectivity between both coasts creating an entirely different trade route and fostering maritime trade with neighbouring countries. The increased security concerns due to the project can provide India and Sri Lanka with the chance to hold joint defence programs for combat specific to the area for which the budget could be shared creating a win-win situation. The increased employment in either country will drastically change the GDP and living conditions of the population. The deserted and tsunami struck villages could be brought back to life thereby providing an opportunity to utilise space which in the otherwise population-wise dense cities is difficult due to the presence of high rises and civilization which leave small open corridors. The construction of facilities and utilities such as Shore protection works, Breakwater, dredging equipment facilities and so forth, which are required to keep the canal operational, may be constructed in the deserted villages after proper geological survey to ensure efficient open-space utilisation. The revival of these villages would also provide an incentive to engineer and construct disaster-resistant structures for the project similar to those

TABLE 16 Variation of CO_2 footprint (in million gm CO_2) along the two routes from Chennai to Muscat

Ports	Distances	Barge		Tanker 50,000		Tanker 100,000		Cargo		Bulk carrier	
		Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000	Pre 2000	Post 2000
Via Sethu	1850	652	566	962	836	423	367	1314	1131	1245	1071
Via SL	2233	787	683	1161	1009	510	443	1586	1365	1503	1293

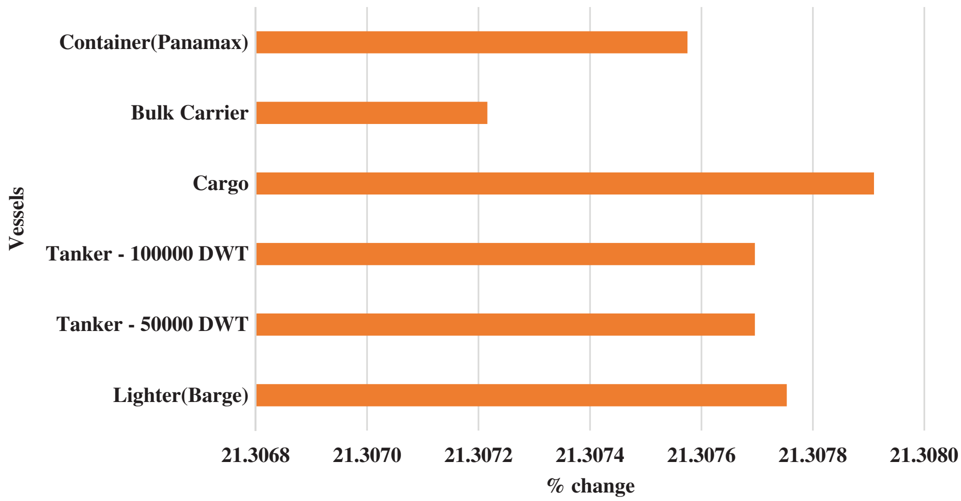

FIGURE 9 Percentage reduction in emissions for voyages via SSCP for a bulk carrier [Colour figure can be viewed at wileyonlinelibrary.com]

seen in disaster-prone zones in countries such as Japan. A new international zone open to all for trade could be commissioned having benefits for all entities in the economics of the region. The project will serve as a joyous occasion for the Indian and Sri Lankan governments to join hands by forgetting the differences of the past and embark on a journey of mutual benefit to a more prosperous future.

6.3 | Limitations of the study and scope for future research

One of the major limitations of the study is the presence of the Gulf of Mannar Marine Wildlife Reserve, which serves as a dwelling place for several rare marine species, which could be endangered by threats due to oil spills. Secondly, the region has been deeply affected by cyclones in the recent past and life near the coast was nearly devastated by the constant changes in weather conditions. The ocean shelf in the region is shallow due to sedimentation and requires annual dredging activities for maintaining a sufficient depth for the vessels to safely pass through the canal. Moreover, the canal could become a notorious place for anti-social activities such as terrorism if not monitored carefully as a significant amount of marine traffic would be diverted through the route. Nonetheless, the religious and sentimental values associated with the region have also played a significant role in the rejection of proposals by various committees earlier. The mythological background of the region has prevented the governments from further indulgences in the development of any such project. Therefore, it is important to address these limitations and carry out further research to mitigate problems in the process of making this strategic route viable for transport and logistics in the future. Another point that should be emphasised is security and continuous coastal patrolling to ensure safe trade in the region. The involvement of the government in educating the masses about the merits of the project could influence the possibility of its sanctioning soon. The implementation of better construction methods for a robust structure should be researched for the construction of a canal resistant to changes in the weather and the sea and one that makes it possible for heavier maritime traffic to pass through the same. Besides these changes, it is extremely important to plan the construction, such that the marine traffic does not disturb the wildlife reserve in any manner. Altogether, these factors give rise to economic uncertainty (Nocera & Cavallaro, 2014). This uncertainty needs to be addressed in a manner such that the implementation of SSCP delivers the expected advantages discussed in this study. The queuing and management of traffic at various points provides a vast scope of study in the future to ensure the operations at required standards without any major difficulties intervening in its normal operation and as a new start for the development of green maritime supply chains in the Indian subcontinent. The study takes into consideration voyages involving an international port whilst not covering many other international regions because the benefits provided by the SSCP are only over a limited geographical area covering mainly the Indian subcontinent and its neighbours along with the Middle East. The SSCP may not impact other international voyages drastically due to the geography of the region. Lastly, studying the real impact of the construction of SSCP on the environment and surroundings could be an extension of the study. However, attempts to investigate the real impact of the construction of SSCP would be very difficult mainly due to the lack of resources. The presence of further literature or reports on practically conducted investigations based on the real impact of the construction would also be interesting and bolster this study.

7 | CONCLUSION

The methodology highlighted in Section 3 provides a well-organised blueprint for carrying out this comparative study and lays the foundation for the timely execution of important milestones such as the Quantification of Economic and Environmental Metrics with the illustrations of Quantified factors to enable better interpretation and inference of data. Section 4 assesses maritime routing based on environmental and economic factors. The calculation of vessel design and operational indices makes it easier to understand the impact of marine vessels on the environment for a given route. The findings in Section 5 credit the project with the inferred benefits and check the feasibility of SSCP simultaneously from not only an environmental but also a financial viewpoint to affirm that its existence would deliver the expected financial benefits. The merits required to justify the actual existence of SSCP can be inferred from this study. The objective of assessing an economic and environmentally beneficial maritime route in the Indian subcontinent is a promising step towards sustainability, which is collectively demonstrated through the course of the aforementioned sections and findings.

ACKNOWLEDGEMENT

The authors like to thank all officials at Port Trust of India, Thoothukudi who supported this work with their valuable ideas and data collection.

ORCID

Jayakrishna Kandasamy https://orcid.org/0000-0002-5225-7620
Anil Kumar https://orcid.org/0000-0002-1691-0098

REFERENCES

Acomi, N., & Cristian, O. (2014). The influence of different types of marine fuel over the energy efficiency operational index. *Energy Procedia*, *59*, 243–248.

Allen, C., Metternicht, G., & Wiedmann, T. (2021). Priorities for science to support national implementation of the sustainable development goals: A review of progress and gaps. *Sustainable Development*, *29*(4), 635–652.

Arctic Climate Change Economy and Society (ACCESS). (2014). Calculation of fuel consumption per mile for various ship types and ice conditions in past, present and in future.

Basurko, O. C., Gabiña, G., & Uriondo, Z. (2013). Energy performance of fishing vessels and potential savings. *Journal of Cleaner Production*, *54*, 30–40.

Bonilla, S. H., Almeida, C. M. V. B., Giannetti, B. F., & Huisingh, D. (2010). The roles of cleaner production in the sustainable development of modern societies: An introduction to this special issue. *Journal of Cleaner Production*, *18*(1), 1–5.

Bouman, E. A., Lindstad, E., Rialland, A. I., & Strømman, A. H. (2017). State-of-the-art technologies, measures, and potential for reducing GHG emissions from shipping – A review. *Transportation Research Part D: Transport and Environment*, *52*, 408–421.

Brynolf, S., Fridell, E., & Andersson, K. (2014). Environmental assessment of marine fuels: Liquefied natural gas, liquefied biogas, methanol and bio-methanol. *Journal of Cleaner Production*, *74*, 86–95.

Cariou, P. (2011). Is slow steaming a sustainable means of reducing CO2 emissions from container shipping? *Transportation Research Part D: Transport and Environment*, *16*(3), 260–264.

Carse, A. (2012). Nature as infrastructure: Making and managing the Panama Canal watershed. *Social Studies of Science*, *42*(4), 539–563.

Chang, Y.-T., & Danao, D. (2017). Green shipping practices of shipping firms. *Sustainability*, *9*(5), 829.

Chuah, L. F., Klemeš, J. J., Yusup, S., Bokhari, A., & Akbar, M. M. (2017). A review of cleaner intensification technologies in biodiesel production. *Journal of Cleaner Production*, *146*, 181–193.

Cormier, R., & Elliott, M. (2017). SMART marine goals, targets and management – Is SDG 14 operational or aspirational, is 'life below water' sinking or swimming? *Marine Pollution Bulletin*, *123*(1–2), 28–33.

European Comission. (2002). Market survey of marine distillates with 0.2% sulphur content. https://ec.europa.eu/environment/archives/air/pdf/chapter3_end_ship_emissions.pdf

Geerlings, H., & Van Duin, R. (2011). A new method for assessing CO2-emissions from container terminals: A promising approach applied in Rotterdam. *Journal of Cleaner Production*, *19*(6–7), 657–666.

Giorgiutti, Y., Rezende, F., Van, S., Monteiro, C., & Preterote, G. (2014), Impact of fouling on Vessel's energy efficiency. 25° Congresso Nacional de Transporte Aquaviário, Construção Naval e Offshore, Rio de Janeiro, pp. 1–8.

Godil, D. I., Yu, Z., Sharif, A., Usman, R., & Khan, S. A. R. (2021). Investigate the role of technology innovation and renewable energy in reducing transport sector CO2 emission in China: A path toward sustainable development. *Sustainable Development*, *29*(4), 694–707.

Gold, S., & Seuring, S. (2011). Supply chain and logistics issues of bio-energy production. *Journal of Cleaner Production*, *19*(1), 32–42.

Govindan, K., & Soleimani, H. (2017). A review of reverse logistics and closed-loop supply chains: A journal of cleaner production focus. *Journal of Cleaner Production*, *142*, 371–384.

Griffith, R. T. H. (2008). *The RÁMÁYAN of VÁLMÍKI translated into English verse*. Forgotten Books.

Halog, A., Schultmann, F., & Rentz, O. (2001). Using quality function deployment for technique selection for optimum environmental performance improvement. *Journal of Cleaner Production*, *9*(5), 387–394.

Harrington, R. L. (1992). *Marine engineering*. Society of Naval Architects and Marine Engineers.

Hermeling, C., Klement, J. H., Koesler, S., Köhler, J., & Klement, D. (2015). Sailing into a dilemma: An economic and legal analysis of an EU trading scheme for maritime emissions. *Transportation Research Part A: Policy and Practice*, *78*, 34–53.

Hindustan Petroleum Corporation Ltd. (2009). Marine fuels & lubricants - Product Digest, India.

Hon, G., Smith, T., & Hauerhof, E. (2016). BetterFleet: Data and method.

International Maritime Organization. (2009), Guidlines for voluntary use of the ship energy efficiency operation indicator (EEOI). London.

International Maritime Organization. (2012). Annex 19 - guidance for the development of a ship energy efficiency management plan (SEEMP).

International Maritime Organization. (2014) Third IMO greenhouse gas study 2014, Suffolk, UK.

Kalli, J., Karvonen, T., & Makkonen, T. (2009). Sulphur content in ships bunker fuel in 2015. A study on the impacts of the new IMO regulations and transportation costs, Ministry of Transport and Communications, Finland.

Kedzierski, A., & O'Leary, A. (2012). Energy efficiency of ships: What are we talking about? Transport and Environment.

Khan, S. A. R., Zhang, Y., Kumar, A., Zavadskas, E., & Streimikiene, D. (2020). Measuring the impact of renewable energy, public health expenditure, logistics, and environmental performance on sustainable economic growth. *Sustainable Development*, *28*(4), 833–843.

Krozer, J., Mass, K., & Kothuis, B. (2003). Demonstration of environmentally sound and cost-effective shipping. *Journal of Cleaner Production*, *11*(7), 767–777.

Liao, C. H., Tseng, P. H., Cullinane, K., & Lu, C. S. (2010). The impact of an emerging port on the carbon dioxide emissions of inland container transport: An empirical study of Taipei port. *Energy Policy*, *38*(9), 5251–5257.

MAN Diesel & Turbo. (2012). Basic principles of ship propulsion. Copenhagen, pp. 1–45.

Masante, D., McCormick, N., Vogt, J., Carmona-Moreno, C., Cordano, E., & Ameztoy, I. (2018), Drought and water crisis in Southern Africa. https://doi.org/10.2760/81873.

McCullough, D. (1977). *The path between the seas: The creation of the Panama Canal, 1870–1914*. Simon & Schuster.

Mickwitz, P., Hyvättinen, H., & Kivimaa, P. (2008). The role of policy instruments in the innovation and diffusion of environmentally friendlier technologies: Popular claims versus case study experiences. *Journal of Cleaner Production*, *16*(1 SUPPL. 1), 162–170.

Nanaki, E. A., & Koroneos, C. J. (2012). Comparative LCA of the use of biodiesel, diesel and gasoline for transportation. *Journal of Cleaner Production*, *20*(1), 14–19.

Nocera, S., & Cavallaro, F. (2014). A methodological framework for the economic evaluation of CO2 emissions from transport. *Journal of Advanced Transportation*, *48*(2), 138–164.

Novo-Corti, I., González-Laxe, F., & Pociovalisteanu, D. M. (2015). The economic analysis of maritime catastrophes in sensitive areas: The assessment and calculation of damages in the environment and population's way of life. *Journal of Cleaner Production*, *107*, 267–278.

Psaraftis, H. N., & Kontovas, C. A. (2009). CO 2 emission statistics for the world commercial fleet. *WMU Journal of Maritime Affairs*, *8*, 1–25.

Qorri, A., Gashi, S., & Kraslawski, A. (2021). Performance outcomes of supply chain practices for sustainable development: A meta-analysis of moderators. *Sustainable Development*, *29*(1), 194–216.

Rajendran, C. P. (2005). Sethusamudram shipping canal project and the eternal silence of the Indian earth scientists [10]. *Current Science*, *89*(2), 246–247.

Ramesh, R. (2004). Sethusamudram shipping canal project and the unconsidered high risk factors: Can it withstand them? https://www.elaw.org/system/files/Sethusamudram_Shipping_Canal_Project_Final.pdf

Recuero Virto, L. (2018). A preliminary assessment of the indicators for sustainable development goal (SDG) 14 'conserve and sustainably use the oceans, seas and marine resources for sustainable development'. *Marine Policy*, *98*, 47–57.

RIGHTSHIP. (2013). Calculating and comparing CO2 emissions from the global maritime fleet, London. https://www.safety4sea.com/wp-content/uploads/2014/09/pdf/Rightship_GHG_Emission_Rating.pdf

Rodriguez, S. (2007). Review of the environmental impacts of the Sethusamudram Ship Canal project (SSCP). Indian Ocean Turtle Newsletter, No. 6, pp. 16–20.

Rodriguez, S., John, J., Arthur, R., Shanker, K., & Sridhar, A. (2007). Review of Environmental and Economic Aspects of the Sethusamudram Ship Canal Project (SSCP). https://www.dakshin.org/wp-content/uploads/2017/06/SSCP_Review_Full_25Oct07.pdf

Saengsupavanich, C., Coowanitwong, N., Gallardo, W. G., & Lertsuchatavanich, C. (2009). Environmental performance evaluation of an industrial port and estate: ISO14001, port state control-derived indicators. *Journal of Cleaner Production*, *17*(2), 154–161.

Sarkis, J. (2003). A strategic decision framework for green supply chain management. *Journal of Cleaner Production*, *11*(4), 397–409.

Suki, N. M., Suki, N. M., Sharif, A., & Afshan, S. (2021). The role of logistics performance for sustainable development in top Asian countries: Evidence from advance panel estimations. *Sustainable Development*, *29*(4), 595–606.

Tichavska, M., & Tovar, B. (2015). Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port. *Transportation Research Part A: Policy and Practice*, *78*, 347–360.

Trozzi, C. (2010). Emission estimate methodology for maritime navigation. 19th Annual International Emission Inventory Conference Emissions Inventories - Informing Emerging Issues, US EPA, Rome, pp. 1–12.

Utne, I. B. (2009). Improving the environmental performance of the fishing fleet by use of quality function deployment (QFD). *Journal of Cleaner Production*, *17*(8), 724–731.

Wang, P., Wu, W., Zhu, B., & Wei, Y. (2013). Examining the impact factors of energy-related CO2 emissions using the STIRPAT model in Guangdong Province, China. *Applied Energy*, *106*, 65–71.

Wang, X., Yuen, K. F., Wong, Y. D., & Li, K. X. (2020). How can the maritime industry meet sustainable development goals? An analysis of sustainability reports from the social entrepreneurship perspective. *Transportation Research Part D: Transport and Environment*, *78*, 102173.

Winnes, H., Fridell, E., & Moldanová, J. (2020). Effects of marine exhaust gas scrubbers on gas and particle emissions. *Journal of Marine Science and Engineering*, *8*(4), 299.

Ziegler, F., & Hansson, P. A. (2003). Emissions from fuel combustion in Swedish cod fishery. *Journal of Cleaner Production*, *11*(3), 303–314.

How to cite this article: Kandasamy, J., Nadeem, S. P., Kumar, A., K.E.K, V., Nikhil, H. B., & Solanki, N. H. (2021). Economic and environmental feasibility of re-routing the Indo-Sri Lankan shipping channel: A green initiative of sustainable development. *Sustainable Development*, 1–25. https://doi.org/10.1002/sd.2269