**Economic and Environmental Feasibility of Re-routing the Indo-Sri Lankan Shipping Channel: A Green Initiative of Sustainable Development**

***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 advocates the significance of this route to the maritime industry in meeting SDGs.

***Keywords:*** Energy efficiency; operational index; Carbon footprint; Sethusamudram canal project; Green supply chain; 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 m, 10.7 m 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 (>20m) 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 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 (Cormier and Elliott, 2017; Recuero Virto, 2018; Allen *et al.,* 2021).

The research is structured in 5 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.

* 1. **Sethu Samudram Canal Project (SSCP)**

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 kilometre stretch for a width of 300 meters and a depth of 12 meters for ships less than 30000 Dead Weight Tonnage (DWT) with draft restricted to 10m. 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 50000-100000 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; David 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 1998-2005, 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 40m. 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 Fig. 1(a) and the proposed Sethusamudram canal route is shown in Fig. 1(b). Though it has been proven to be a shorter route for marine vessels than by circumnavigating Sri Lanka, there is more to its statistical side of environmental and economic benefits.



**Fig. 1(a)** Existing route circumnavigating Sri Lanka



**Fig. 1(b)** Proposed Sethusamudram canal route

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 Organization (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 and Seuring, 2011; Krozer *et al.*, 2003; Mickwitz *et al.*, 2008; Nanaki and Koroneos, 2012; Ziegler and Hansson, 2003; cQorri *et al.,* 2021). To overcome these environmental issues the IMO provides several measures such as EEDI/EVDI, EEOI, CO2 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 and Van Duin, 2011; Halog *et al.*, 2001; Krozer *et al.*, 2003; Mickwitz *et al.*, 2008; Saengsupavanich *et al.*, 2009; Utne, 2009). Moroever the impact of sustianbale operations is not limited to enviornment 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 emphasize 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 and 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.

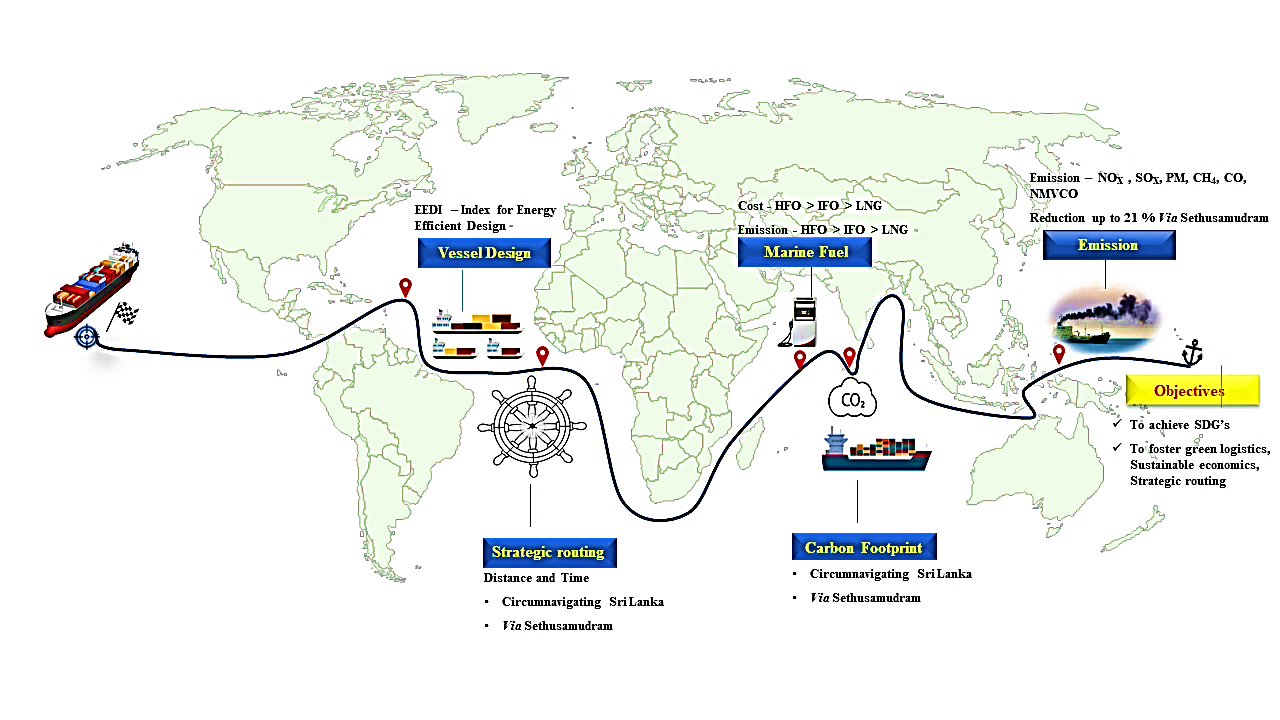
Secondly, it is difficult to understand and analyse the entire scenario based on background studies and factual information on related events. A clear understanding and in-depth study of marine engineering, emissions, and the study of fuels are equally necessary. The basic design and working of ships 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, CO2 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 and 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 and 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 etc. 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 and Danao, 2017).

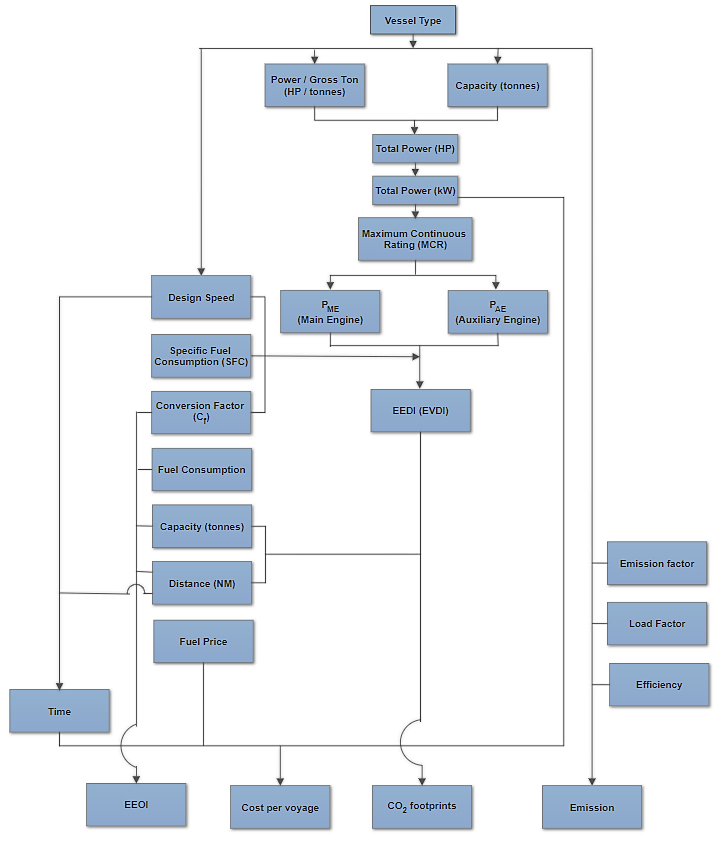
The literature survey presents a variety of studies ranging from addressing the possible problems faced while constructing SSCP to the methodology of assessment of environmental and economic impacts. However, the lack of a report collectively addressing environmental and economic issues and their influence 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 Fig. 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.

**Fig. 2** Categories to quantify the environmental and economic factors

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. Fig. 3 shows the numerical formulation and methodology adopted in this study.



**Fig. 3** Flowchart depicting the method of calculation of findings discussed in the study, namely-Time, EEOI, Cost per voyage, CO2 footprint and Emission.

*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 CO2 possible through CO2 footprint analysis. Eq. (1) represents the formula for the calculation of EEDI using dependent factors.

(1) (Kedzierski and O’Leary, 2012)

The IMO introduced the EEDI to determine the amount of CO2 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 CO2.
* 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 to be 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 ‘***fi***’ 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.

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 Table 1 to Table 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 and 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 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 its pillars. This will set standards for emissions and will help organisations manage their fleets in a better way (Kedzierski and 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 emissions rating is vessel specific and requires 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 CO2 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 CO2 per year can borrow a carbon loan from a country producing lesser CO2 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’. Eq. (2) represents the formulation of specific power

*P = PMain Engine(ME) + PAuxiliary Engine(AE)* (2)

Where P is the specific power and PME and PAE are powers of the main and auxiliary engine respectively. The purpose of splitting the Specific 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. Table 2 and Table 3 shows the calculation of PAE and SFC values based on Maximum Continuous rating MCRAE values considered. Eqs. (3) and (4) represent the formulation of power for the auxiliary engine and main engine respectively

*PAE = (0.025MCRME) + 250, if MCRME > 10000 kW*

*= 0.05 MCRME, if MCRME < 10000 kW* (3)

*PME = 0.75 MCRME* (4)

As specific power is known, it can be used to calculate *MCRME*.

The MCRME calculated earlier can be used to select the SFCME value from Table 1. The calculations are considered for the three engine ages ranging from Pre-1983, 1984-2000, and 2001-2007.

**Table 1.** Values of MCR and SFC at various engine ages for the main engine

|  |  |  |
| --- | --- | --- |
| **Engine Age** | **MCRME (kW)** | **SFCME(g/kWh)** |
| **Pre-1983** | >15000  5000 to 15000  <5000 | 205  215  225 |
| **1984-2000** | >15000  5000 to 15000  <5000 | 185  195  205 |
| **2001-2007** | >15000  5000 to 15000  <5000 | 175  185  195 |

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

**Table 2.** Calculation of PAE for two different MCRME values

|  |  |
| --- | --- |
| **MCRME (kW)** | **PAE (kW)** |
| **>10000** | (0.025MCR ME) + 250 |
| **<10000** | 0.05MCRME |

The SFCAE values can be considered from the PAE or MCRME values calculated using Table 2.

**Table 3**. Values of SFC according to MCRAE values

|  |  |  |
| --- | --- | --- |
| **Engine age** | **MCRAE>800kW** | **MCRAE<800kW** |
| **Any** | 220 g/kWh | 230 g/kWh |

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.

**Table 4.** Carbon conversion factor (CF) values for different marine fuels

|  |  |  |
| --- | --- | --- |
| **Fuel type** | **Carbon content** | **CF**  **(t-CO2/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 |
| IFO |  | 3.1 |
| Propane | 0.819 | 3.000 |
| Butane | 0.827 | 3.030 |
| Liquified Natural Gas – LNG | 0.75 | 2.750 |

**Table 5.** SFC values at different engine ages

|  |  |
| --- | --- |
| Engine Age | SFC (g/kWh) |
| Pre 1983 | 225 |
| 1984 – 2000 | 205 |
| 2000 – 2007 | 195 |
| Auxiliary Engine | 220 |

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.

**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  Tanker  Tanker | 7656.73  11318.66  23968.92 | 14.5  14.5  14.5 | 50000  100000  300000 |
| Cargo | 5992.23 | 17.5 | 15000 |
| Bulk Carrier | 16370 | 14.7 | 75000 |
| Container (Feeder)  Container (Panamax) | 18302.85  23226.43 | 21  22 | 31000  37000 |

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

*EEDI or EVDI =*  (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, HFO, LNG and 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 were 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 CO2 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 Organization, (2009), and the International Maritime Organization, (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) i.e. HFO has a lesser polluting index and is less expensive than MGO and LFO. However, this claim was later proven to be 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 Organization, (2014), International shipping emitted 796 million tonnes of CO2 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 CO2, which represented 2.8% of the global emissions of CO2 for that year. The statistics of emissions suggest that ships were responsible for approximately 85% of CO2 emissions from international shipping and together they represent the first-ever mandatory global regime for CO2 emission reduction in an entire industry sector.

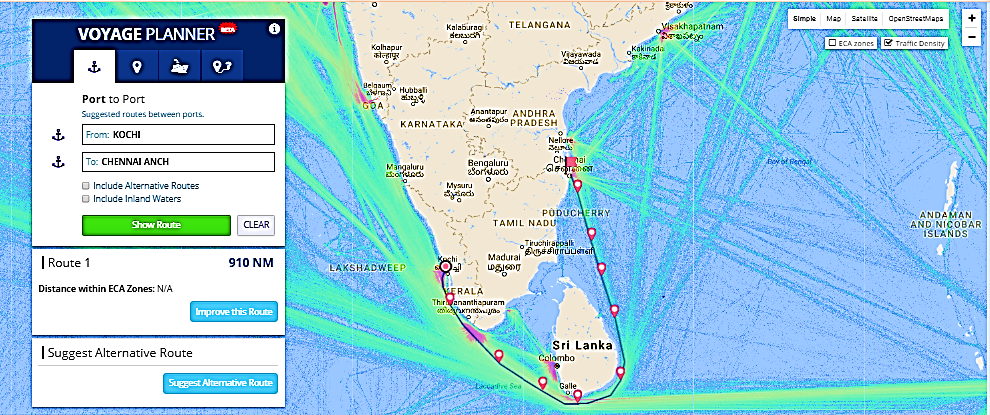
At present, sustainable development has received a lot of attention and after reflecting on the principles of sustainable and responsible development, the countries started a system of keeping the number of emissions low, specifically CO2 and CO resulting in the birth of Carbon economies and the study 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, CO2 footprint and fuel consumption*

According to RIGHTSHIP EVDI is an estimate of CO2 emitted per tonne nautical mile travelled. Eq. (6) represents formulation for CO2 footprint.

*2 footprint =*  (6)

The sea distances in nautical miles required to compute CO2 footprint and EEOI were obtained using an online platform {http://www.marinevesseltraffic.com/2013/07/distance-calculator.html}.



**Fig. 4** Marine Traffic tool

The Marine Traffic tool represents the sea routes (as shown in Fig. 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.

Though 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.

**Table 8.** 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) | - |

The change in routing plans between the ports mentioned above can function as a CO2 emissions reduction strategy ( Wang *et al.,* 2013; Cariou, 2011; Liao *et al.*, 2010). Therefore, the analytical approach of calculating CO2 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 Organization, (2009) report, the EEOI is used as an indicator for measuring CO2 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 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. Eq. (7) represents the generalised form of EEOI.

EE OI = (7)

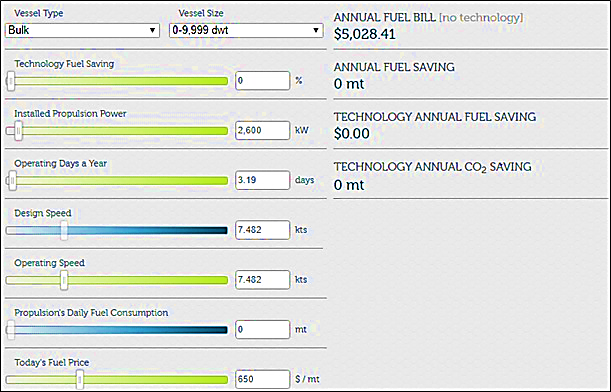
(International Maritime Organization, 2009)

Where,

* J is the type of fuel considered
* FCj is the mass of fuel ‘f’ consumed
* CFj is the fuel mass to CO2 mass conversion factor for fuel j
* mcargo is the mass of cargo carried for a voyage
* D is the distance of voyage sailed

According to RIGHTSHIP, (2013) in Eq. (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).



**Fig. 5** Better fleet Annual fuel costing and CO2 and Fuel Savings Calculator

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 Fig. 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 etc. 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 14th 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 (CFj) have been considered from IMO 8217 standards as mentioned in the report by International Maritime Organization, (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 has 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, etc. 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 guidelines of MARPOL and IMO as a temporary solution till 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 CO2 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 i.e. 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, etc. 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 also 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, etc. 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 Eq. (8). The time taken for a voyage is calculated by dividing the total distance by the vessel speed which is assumed to be 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 to be 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.

(8)

Secondly, the time calculation from Eq. (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 Section 3.1 and Section 3.2 generates the total fuel cost titled ‘Annual Fuel Bill’ in the same window visible in Fig. 5.

*4.2 Algebra of Emissions*

International Maritime Organization, (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 NOx, Particulate Matter (PM) etc. 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 Eq. (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 5.6.

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

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

Total CO2 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)*

CO2 per tonne-km: *3.17[F + (p/s)G]/wWv* (9)

(Psaraftis and Kontovas, 2009)

The total number of nautical miles travelled by vessel in a year are obtained by *sDV* in which *sD* is the number of sea days in a year and *V* is the vessel speed. In Eq. (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, Eq. (9). precisely represents the CO2 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, the sulphur content in the fuel affect the emissions of undesirable substances during a voyage (European Comission, 2002). However, all parameters in Eq. (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 Eq. (10). to simulate ideal conditions.

*EFijk* (10)

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

Where,

* *Eijk* are emissions of type i from vessel j on route k in gram [g]
* *EFij* is the emissions factor for emissions of type i on vessel j in [g/kWh]
* *LFjk* 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;
* *KWj* is the rated main engine power in kilowatts [kW] for vessel *j*, is the engine efficiency
* *Tjk* is the duration of the voyage for vessel *j* on route *k* in hours

The values of *Eijk* 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 Organization, (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 CO2 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 i.e. 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 were 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 were performed for the two routes considered in this study i.e. by SSCP and the other by circumnavigating Sri Lanka are tabulated in Table 9 and Table 10 respectively.

**Table 8.** EEDI and EVDI (in gm CO2/ tonne Nautical Miles (NM)) varying with tonnes carried

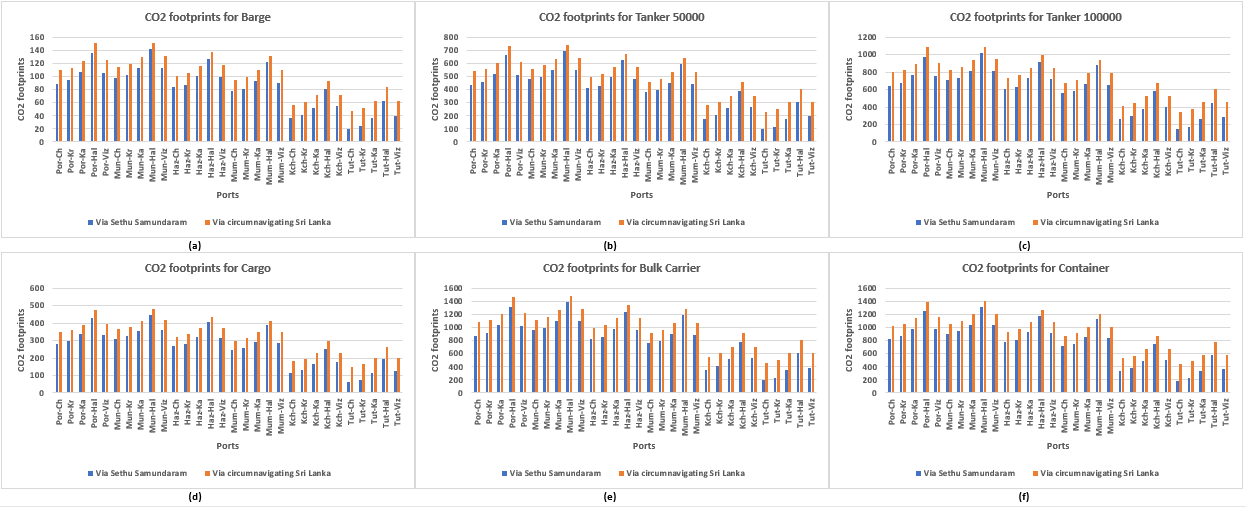
|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Engine Age | Ships  Fuels | Lighter  (Barge) | Tanker  (50000 DWT) | Tanker  (100000 DWT) | Tanker  (300000 DWT) | Cargo | Bulk Carrier | Container (Feeder) | Container (Panamax) |
| Pre 2000 | Diesel | 13.46 | 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.** CO2 footprints (in Million gm CO2) for voyages to a combination of ports via Sethu Samundaram

| Ports | Distances | Barge | | Tanker 50000 | | Tanker 100000 | | Cargo | | Bulk Carrier | | Container | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 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 CO2) for voyages to a combination of ports via circumnavigating Sri Lanka

| Ports | Distances | Barge | | Tanker 50000 | | Tanker 100000 | | Cargo | | Bulk Carrier | | Container | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 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 |



**Fig. 6** CO2 footprints (in Million gm CO2) comparison for voyages between a combination of ports (a) Barge (b) Tanker of 50000 dwt (c) Tanker 100000 dwt (d) Cargo (e) Bulk Carrier (f) Container

*5.3 EEOI*

**Table 11.** EEOI values for voyages by different vessels to a combination of ports

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Barge | | | | | | | | | | |
| 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 |  |  |  |  |
| 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 (50000 DWT) | | | | | | | | | | |
| 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 |  |  |  |  |
| 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 (100000 DWT) | | | | | | | | | | |
| 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 |  |  |  |  |
| 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 | | | | | | | | | | |
| 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 |  |  |  |  |
| 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 | | | | | | | | | | |
| 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 |  |  |  |  |
| 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 | | | | | | | | | | |
| 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 |  |  |  |  |
| 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 |

It can be observed from Table 9 and Table 10 that an increase in distances and vessel capacity results in a higher CO2 footprint. In certain routes, a difference of 107-108 grams of CO2 or multiples of 108 grams of CO2 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, CO2 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. Fig. 6 show the drastic reduction in CO2 footprint via SSCP for Barge, Bulk carrier, Container and Tanker of capacities 50000 dwt and 100000 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 CO2 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 CO2 conversion factor changes i.e. 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 and Cristian, 2014).

*5.4 Time and Distance*

**Table 12** Time and Distance data for voyages for a combination of ports

|  |  | | | Time | | | | | | | | | | | | | | | | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ports | Distance | | | Barge | | | | Tanker 50000 DWT | | | | Tanker 100000 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 |
| 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 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.

* 1. *Fuel costs*

Table 13 provides the fuel cost calculation for voyages for a combination of ports by different vessels. 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 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 14th 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 14th 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.

**Table 13.** Fuel cost calculation for voyages for a combination of ports by different vessels

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ports | Barge | | Tanker 50000 dwt | | Tanker 100000 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 | 45919.40 | 57061.60 | 74454.60 | 92520.81 | 49927.70 | 62040.40 | 102903.90 | 127989.90 | 99465.30 | 123499.70 |
| Por-Kr | 1762.50 | 2131.44 | 48620.50 | 58637.30 | 78834.30 | 95075.63 | 52882.00 | 63812.90 | 108791.40 | 131573.60 | 105011.69 | 127197.30 |
| Por-Ka | 1992.30 | 2310.64 | 54810.60 | 63701.90 | 88871.10 | 103287.50 | 59677.00 | 69278.40 | 123126.30 | 142836.70 | 118692.79 | 137920.30 |
| Por-Hal | 2534.10 | 2818.73 | 69779.50 | 77657.80 | 113141.82 | 125915.90 | 75925.60 | 84493.00 | 156659.70 | 174066.30 | 151231.62 | 168240.60 |
| Por-Viz | 1975.40 | 2348.59 | 54360.40 | 64714.80 | 88141.10 | 104929.90 | 59086.00 | 70312.40 | 122102.40 | 145652.50 | 117583.51 | 140138.80 |
| Mun-Ch | 1812.20 | 2125.00 | 46756.70 | 54897.40 | 76529.30 | 89853.56 | 54207.30 | 63704.50 | 111914.60 | 131157.80 | 107894.69 | 126547.70 |
| Mun-Kr | 1895.60 | 2214.65 | 52211.70 | 61006.40 | 84657.00 | 98917.00 | 56691.20 | 66334.50 | 116978.60 | 136728.20 | 113015.11 | 132033.80 |
| Mun-Ka | 2081.20 | 2410.68 | 57332.60 | 66350.00 | 92960.30 | 107581.20 | 62389.50 | 72179.00 | 128625.80 | 148881.90 | 123987.45 | 143737.70 |
| Mun-Hal | 2623.40 | 2802.72 | 67734.60 | 72326.70 | 110865.00 | 118381.20 | 78607.90 | 83867.90 | 162048.30 | 173189.10 | 156538.73 | 167145.30 |
| Mun-Viz | 2089.50 | 2425.27 | 57555.30 | 66795.30 | 93321.30 | 108303.30 | 62535.60 | 72617.30 | 129132.20 | 149894.70 | 124718.94 | 144469.20 |
| Haz-Ch | 1569.90 | 1878.68 | 43241.70 | 51711.70 | 70113.00 | 83846.45 | 47099.50 | 56314.60 | 97082.20 | 116093.00 | 93733.40 | 112040.70 |
| Haz-Kr | 1626.30 | 1966.57 | 44802.00 | 54163.60 | 72642.80 | 87821.93 | 48708.50 | 58947.50 | 100630.90 | 121416.20 | 97028.70 | 117166.80 |
| Haz-Ka | 1870.50 | 2164.89 | 51488.80 | 59624.50 | 83485.00 | 96676.40 | 56022.00 | 64798.30 | 115586.10 | 133836.60 | 111674.58 | 129249.60 |
| Haz-Hal | 2363.20 | 2557.37 | 65085.50 | 70434.90 | 105530.87 | 114204.60 | 70795.50 | 76500.10 | 146003.60 | 157917.00 | 140966.28 | 152316.80 |
| Haz-Viz | 1839.20 | 2185.77 | 50708.70 | 60181.80 | 82220.10 | 97579.92 | 55144.40 | 65529.70 | 113558.30 | 135104.00 | 109843.85 | 130348.00 |
| Mum-Ch | 1325.20 | 1607.50 | 34218.40 | 41523.40 | 56007.10 | 67963.68 | 39696.20 | 48173.70 | 81849.30 | 99338.50 | 79157.00 | 95662.10 |
| Mum-Kr | 1377.00 | 1688.16 | 37935.00 | 46547.30 | 61508.60 | 75472.66 | 41176.40 | 50595.90 | 85114.00 | 104235.50 | 82188.60 | 100714.70 |
| Mum-Ka | 1582.50 | 1870.61 | 43574.00 | 51468.60 | 70651.70 | 83452.15 | 47366.40 | 55978.40 | 97706.20 | 115661.70 | 94314.80 | 111493.50 |
| Mum-Hal | 2080.00 | 2231.67 | 53730.50 | 57575.30 | 92927.80 | 99577.37 | 62302.90 | 66878.10 | 128487.10 | 137814.70 | 123956.50 | 133051.20 |
| Mum-Viz | 1548.00 | 1872.53 | 42651.20 | 51571.10 | 69155.60 | 83618.39 | 46424.40 | 56113.00 | 95607.49 | 115661.74 | 92293.70 | 111830.40 |
| Kch-Ch | 615.60 | 978.40 | 16997.60 | 26887.10 | 27560.30 | 43595.33 | 18387.90 | 29339.50 | 37956.72 | 60449.59 | 36552.00 | 58212.40 |
| Kch-Kr | 715.90 | 1059.41 | 19676.00 | 29153.50 | 31903.10 | 47270.00 | 21362.40 | 31773.20 | 44282.84 | 65369.91 | 42644.00 | 63289.10 |
| Kch-Ka | 903.10 | 1242.73 | 24826.80 | 34201.20 | 40254.70 | 55454.59 | 27041.00 | 37181.40 | 55763.58 | 76850.64 | 53812.70 | 74119.31 |
| Kch-Hal | 1375.90 | 1603.58 | 37909.80 | 44193.80 | 61647.70 | 71656.69 | 41237.50 | 47997.80 | 85051.17 | 99109.22 | 81903.50 | 95779.70 |
| Kch-Viz | 945.60 | 1242.73 | 26063.00 | 34201.20 | 42259.10 | 55454.59 | 28257.90 | 37181.40 | 58340.89 | 76850.64 | 56181.80 | 74119.31 |

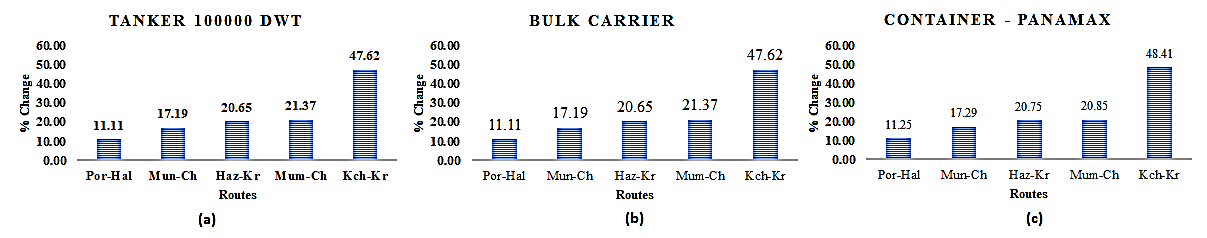
**Table 14.** Percentage savings on fuel costs via SSCP

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ports | Tanker 100000 dwt | | | Bulk Carrier | | | Container-Panamax | | |
| Via Sethu | Via SL | % Change | Via Sethu | Via SL | % Change | Via Sethu | Via SL | % Change |
| Por-Hal | 113141.8 | 125915.9 | 11.29 | 156659.7 | 174066.3 | 11.11 | 151231.6 | 168240.6 | 11.25 |
| Mun-Ch | 76529.3 | 89853.6 | 17.41 | 111914.6 | 131157.8 | 17.19 | 107894.7 | 126547.7 | 17.29 |
| Haz-Kr | 72642.8 | 87821.9 | 20.90 | 100630.9 | 121416.2 | 20.65 | 97028.7 | 117166.8 | 20.75 |
| Mum-Ch | 56007.1 | 67963.7 | 21.35 | 81849.3 | 99338.5 | 21.37 | 79157.0 | 95662.1 | 20.85 |
| Kch-Kr | 31903.1 | 47270.0 | 48.17 | 44282.8 | 65369.9 | 47.62 | 42644.0 | 63289.1 | 48.41 |



**Fig. 7.** Fuel cost comparison for voyages to a combination of ports (a) Barge **(b)** Tanker 50000 dwt (c) Tanker 100000 dwt (d) Cargo (e) Bulk Carrier (f) Container Panamax

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 Fig.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. Fig. 8 show the percentage reduction in fuel costs via SSCP for Tanker, Bulk carrier, and Container respectively.



**Fig. 8** Percentage reduction in Fuel cost for voyages between different ports via SSCP (a) Tanker of capacity 100000 dwt (b) Bulk Carrier (c) Container Panamax

* 1. *Emissions*

The seven different types of effluents namely CO2, NOx, SOx, PM, CO, NMVOC and CH4 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. Fig. 9 represents the reduction in emissions for Bulk carriers via SSCP.

**Fig. 9** Percentage reduction in emissions for voyages via SSCP for a Bulk Carrier

**6. Implications**

The EEDI/EVDI and CO2 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 Betterfleet 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 CO2 footprint and the contribution of India and Sri Lanka towards green logistics.

**Table 15**. Percentage reduction in emissions via SSCP of different vessels

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Emission Type | Emission Factor | Lighter (Barge) | | Tanker - 50000 DWT | | Tanker - 100000 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 |
| CO2 | 670 | 106651047.72 | 129375989.71 | 547935938.01 | 664688461.46 | 817654418.47 | 991877735.55 | 355308922.08 | 431017826.01 | 1174609696.00 | 1424886320.00 | 1118672029.82 | 1357033909.82 |
| NOX | 13 | 2069348.69 | 2510280.40 | 10631592.83 | 12896940.30 | 15864936.48 | 19245388.90 | 6894053.71 | 8363032.45 | 22790934.40 | 27647048.00 | 21705576.70 | 26330508.70 |
| SOX | 11.35 | 1806700.58 | 2191667.89 | 9282198.35 | 11260020.95 | 13851309.92 | 16802704.92 | 6019039.20 | 7301570.63 | 19898238.88 | 24137999.60 | 18950638.12 | 22988559.52 |
| PM | 1.43 | 227628.36 | 276130.84 | 1169475.21 | 1418663.43 | 1745143.01 | 2116992.78 | 758345.91 | 919933.57 | 2507002.78 | 3041175.28 | 2387613.44 | 2896355.96 |
| CO | 0.54 | 85957.56 | 104273.19 | 441620.01 | 535719.06 | 659005.05 | 799423.85 | 286368.38 | 347387.50 | 946700.35 | 1148415.84 | 901616.26 | 1093728.82 |
| NMVOC | 0.5 | 79590.33 | 96549.25 | 408907.42 | 496036.17 | 610189.86 | 740207.27 | 265155.91 | 321655.09 | 876574.40 | 1063348.00 | 834829.87 | 1012711.87 |
| CH4 | 0.01 | 1591.81 | 1930.98 | 8178.15 | 9920.72 | 12203.80 | 14804.15 | 5303.12 | 6433.10 | 17531.49 | 21266.96 | 16696.60 | 20254.24 |
| % Change | | 21.3078 | | 21.3077 | | 21.3077 | | 21.3079 | | 21.3072 | | 21.3076 | |

**Table 16.** Variation of CO2 footprint (in Million gm CO2) along the two routes from Chennai to Muscat

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ports | Distances | Barge | | Tanker 50000 | | Tanker 100000 | | 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 |

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

*CO2 footprint via SSCP = 246.06 tonnes taxed at 1.6USD per tonne*

*CO2 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 = 39696.23 USD*

*Cost of Fuel via Sri Lanka = 48173.73USD*

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 over Sri Lanka is 8561.62USD which amounts to 555813.51INR 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 CO2 footprint would yield would only be realised in the long run in the form of weather and climate normalisation, biodiversity, etc. 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 etc 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 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 has 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 and 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.

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**Abbreviations**

|  |  |
| --- | --- |
| EEDI | Energy Efficiency Design Index |
| EVDI | Existing Vessel Design Index |
| EEOI | Energy Efficiency Operational Index |
| MCR | Maximum Continuous rating |
| SSCP | Sethusamudram canal project |
| ME | Main Engine |
| AE | Auxiliary engine |
| SEEMP | Ship Energy Efficiency Management Plan |
| NM | Nautical Mile |
| DWT | Dead Weight Tonnage |
| IMO | International Maritime Organization |
| EIA | Environmental Impact Assessment |
| HSVA | Hamburgische Schiffbau-Versuchsanstalt GmbH |
| TFR | Technical Feasibility Report |