Fit for 55 legislation package, and its impact on the Cypriot economy: A case study for liquid and liquified cargo

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Abstract:

The recent adoption of directives and regulations as part of the Fit for 55 legislation package and the inclusion of shipping to the decarbonisation sphere will affect the Cypriot economy and the consumers. The Cypriot energy system is heavily dependent on fossil fuels, thus the effect on the commodities of liquid and liquified petroleum products has been investigated. The thesis presents an enhanced top-down methodology, which estimates the new Operational Expenditure (OPEX) of these vessels and the new Unit Cost of the transported goods.

The characteristics of the island and expert opinions have resulted in four scenarios for the projected bunkering fuel mix until 2030. The scenarios incorporated the recent provisions of the Fit for 55 legislative package. Key findings of the scenarios are 1) the uptake of LNG as a primary source of bunkering fuel will always be vulnerable to

global market price fluctuations, 2) for island nations like Cyprus, implementing the legislative framework is expected to have a greater impact on their economies.

The methodology estimates the additional OPEX and the new Unit Cost. This allows the investigation of the financial feasibility of alternative solutions or the estimation of their pricing policy.

Keywords:

Fit for 55, shipping decarbonisation, liquid and liquified cargo, Cypriot Economy, legislative impact.

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Finally, I would like to thank all the stakeholders (in the public and private sectors) who shared their experience and expertise, contributed to the proper analysation of the data, and assisted in the formulation of the selected scenarios.

[1] Cyprus Marine and Maritime Institute, Marine & Offshore Science, Technology & Engineering Centre https://www.cmmi.blue/marine-offshore-science-technology-engineering-centre/

[2] Methodology to Assess the Technoeconomic Impacts of the EU Fit for 55 Legislation Package in Relation to Shipping, https://www.mdpi.com/2077-1312/10/8/1006

Summary

For island nations like Cyprus, which are heavily dependent on fossil fuels to cover their energy needs the implementation of the framework is expected to have more pronounced effects. Yet the investigation of the impacts of the Fit for 55 must be performed on a case-by-case basis. This thesis focuses on the impact of the Fit for 55 legislative package on the Cypriot economy. More specifically, the impact on the commodities of liquid and liquified cargo for the road, shipping, aviation transportation, production of electricity, and heating have been assessed. The study investigates four selected scenarios, namely: a) Business as Usual, b) ramp up of LNG and use of biofuels, c) manipulation of the EU-ETS intra-extra EU factor, and d) Best-case scenario formulated by the state of play on the island and experts' opinion. Scenarios b and c have sub-scenarios for good and bad cases.

The recently adopted legislative framework aims to decarbonise the maritime transport industry. The measures will try to expedite the research and development on alternative green fuels and innovative new technology solutions to mitigate the cost arising from the regulations.

The construction of new facilities on the island is expected to facilitate the uptake of LNG as a primary fuel for vessels carrying liquid and liquified cargo. The characteristics of the fleet trading in Cyprus and its projected composition are not promising due to the low possibility of adopting new technologies and using alternative fuels. This landscape affected the projected fuel matrix distributed horizontally in the selected scenarios for the period 2024 to 2030.

The study concludes that the additional operating expenses of vessels trading in Cyprus will be enough to affect the unit cost of the transported goods. The expected additional unit cost will be vulnerable to fluctuations in the LNG market prices, since LNG is

considered an alternative source of energy (a bridging fuel) that will be used by the industry in the years to come to aid its decarbonisation efforts. The use of biofuels (liquid and gaseous) needs to be considered. When preparing the thesis, these were expected to be the renewable green options for the maritime transport sector at least until 2030. The shipping industry will compete with other industries (i.e., aviation) where alternative solutions are more limited.

To meet the targets of 2030 and 2050 as set by the European Union and the International Maritime Organisation (IMO) significant investments should be considered at the global, EU, and national levels. Investments when developing alternative options will create opportunities for entrepreneurs, tackling the imminent reduction of the environmental footprint of maritime transportation.

The future version of the MSF455 model can act as an assessment tool for new technologies setting price limits considering the legislative levy that will arise with the adoption of the new regulations and the addition of future ones.

1. Introduction

Throughout recorded history, people and goods were transported by shipping. Shipping transformed civilizations into empires. Nowadays is the most widely used and most efficient mode of transportation (see Table 1). At the global level, 80 percent of trade is carried out by vessels, (UNCTAD, 2022), while at the European Union (EU) level, 90 percent of the external freight trade is seaborne (European Commission, 2023). For island nations like Cyprus, this percentage increases due to the lack of road and rail transportation and on the productivity capacity of the country. Even if shipping ranks first in fuel efficiency for freight transportation (see Table 1), it still contributes significantly to the worldwide production of greenhouse gas (GHG) emissions. According to (CE Delft, 2018), the largest ships of the global fleet contribute equal levels of CO_2 and more sulphur compared with the world's cars. In addition, maritime transport would rank as the 6th biggest emitter if it were a nation (DNV-GL, 2019).

Table 1: Specific fuel consumption for break cargo transport (Koehler, 1985), reproduced (Papanikolaou, 2014). Translated to CO_2 assuming diesel as a fuel (Faber, et al., 2021).

Ship	0.4 kg/ (ton 100 km)	1.24 kg of CO_2
Truck	1.1 ÷ 1.6 kg/ (ton 100 km)	3.42 ÷ 4.98 kg of CO_2
Rail	0.7 ÷ 1.6 kg/ (ton 100 km)	2.18 ÷ 4.98 kg of CO_2
Airplane	6 ÷ 8 kg/ (ton 100 km)	18. 66 ÷ 24.88 kg of CO_2
	It refers to tons payload and includes the weight of fuel.	
	11 ÷ 14 kg/ (ton 100 km)	34. 21 ÷ 43.53 kg of CO_2
	It refers to tons payload and includes the weight of fuel for transatlantic flights	

For this reason, at the global level, the International Maritime Organization (IMO), during the 72nd session of the Marine Environment Protection Committee (MEPC), adopted a strategy for shipping on climate change. The strategy set by the IMO targets to reduce the total GHG emissions at annual level by at least 50 percent by 2050 compared to 2008 (MEPC 72, 2018). At EU level on 11th December 2019, the European Commission (EC) presented the European Green Deal (European Commission, 2019), which is the key strategy for climate neutrality, aiming for Europe to become the first climate-neutral continent by 2050. In order to achieve this target, the Fit for 55 package was submitted to the European Council in July 2021, with the aim to bring EU legislation in line with the 2030 goal of reducing net greenhouse gas emissions by at least 55% compared to 1990 (EC, 2021). The package was proposed in line with the Paris Agreement (COP21) however not all of its provisions have been adopted. Cyprus as a Member State will comply with the package when adopted by the Commission.

This thesis seeks to evaluate the impact of the implementation of the package on the Cypriot economy at the end-user level. More specifically it will focus on liquid and liquified petroleum products of category 27: Mineral fuels, mineral oils and products of their distillation of the Harmonized Commodity Description and Coding System (HS code) (European Customs Portal, 2023). These are the main products used to produce electricity, goods (agriculture, industry), and used as road, shipping, and aviation bunkering fuel. The additional cost for transporting the products in the country will be estimated in this thesis.

Having in mind the country's energy dependence to a large extent on fossil fuels the research objectives were developed into the following three categories with set specific objectives:

(A) Analysing the state of play in Cyprus:

A1) To quantify the distribution of liquid and liquified cargo carriers and port calls.

A2) To investigate how the legislation package and the characteristics of the island affect the contribution of the future fuel mix.

(B) Enhancing the already developed methodology (Mallouppas G. , Yfantis, Ktoris, & Ioannou, 2022):

B1) To enhance the methodology developed assessing the impacts of the Fit for 55 on the Operating Expenses (OPEX) of shipping vessels.

(C) Estimating the additional cost based on selected scenarios:

C1) To develop representative scenarios.

C2) To investigate the effect of the Fit for 55 up to 2030 with projections implementing four selected scenarios.

C3) To investigate how the additional transportation cost will affect the unit costs of the products transported.

The thesis, with appropriate evidence, will propose guidance to policymakers, fuel providers, and end-users of Cyprus, applicable to other EU nations with similar characteristics (i.e., Malta).

The thesis is divided into a literature review, which presents how the percentage of the fuel cost on the OPEX of a vessel carrying liquid and liquified cargo is affected by the package, and how this additional cost is affecting the unit cost of the transported cargo. This is followed by a section on the theoretical and operational framework and how it is linked to our study. The thesis analyses the Cyprus landscape, and the adopted and proposed legislative package. In the empirical and analytical methodology, an enhanced model will be introduced to estimate the additional cost based on selected scenarios. In the following section, the results will be presented, together with a discussion on the selected scenarios. The final section includes the conclusions of the study and proposals on future work.

2. Literature Review

This section will be divided into two parts. The first part will provide insights regarding the formation of the policy framework. The second part presents the technical and methodological approach to set the base on how the model will assess the additional Operating Expenditure (OPEX) and how this extra cost is transferred to the end user by calculating the new Unit Cost.

2.1. Policy Framework

Market based measures (MBMs) is a concept under debate since 2006, when it was first introduced at the MEPC56 (IMO, 2006).

"Lagouvardou et al. describes the evolution of the MBMs in a comprehensive manner" (Lagouvardou, Psaraftis, & Zis, 2020). In 2010 ten proposals have been introduced to the IMO for discussion (Psaraftis, Zis, & Lagouvardou, 2021).The proposals have been submitted by the biggest flag and ownership registries (i.e., Japan, the Marshall Islands, Bahamas, United Kingdom, Cyprus, etc.). Proposals included the establishment of an International Fund for GHG emissions from ships, incentives to improve energy efficiency, indexes, and systems to record the efficiency, a global Emissions Trading System, etc. Until 2019, little progression has been recorded (Tanaka & Okada, 2019; Mallouppas, George; Yfantis, Elias, 2021) with the exception of the inclusion of the MBMs in the Initial IMO Strategy (Psaraftis, Zis, & Lagouvardou, 2021). In the strategy, the MBMs have been considered as medium-term measures.

At the EU level, the announcement of the European Green Deal (European Commission, 2019) acted as an MBM-related measure mainly through the provision to include shipping in the EU Emission Trading System (EU ETS). This development was in line with the IMO strategy of 2018 since the EU was committed to be in line with the developments at the global level. In April 2023, the measure was finally improved by the European Parliament and is expected to be implemented by the 1st of January 2024.

Further analysis of all the provisions of the directives and plans included in the Fit for 55 package is discussed in the next section. Measures that are already adopted or are in discussion like the MBMs, focus on economic indicators and or tax levies (Mallouppas, George; Yfantis, Elias, 2021).

Even if the thesis is assessing the impacts of an EU legislative package, maritime transport, is regulated by the IMO. Hence, the inclusion of measure and regulations (like the designation of the Mediterranean Sea as SECA (MEPC 79, 2022)) will be considered in the analysis. The designation implies that all vessels travelling through the Mediterranean Sea must use Ultra-low sulphur fuel oil as a primary fuel or be equipped with exhaust gas cleaning systems. This development is expected to affect the fuel composition compared to today's imported volumes. Cyprus mainly imports liquid and liquified cargo from the Mediterranean and the Black Sea. Thus gradually, ULSFO is expected to become the dominant primary fuel in one of the global busiest shipping transportation areas. The scarcity of the ULSFO will add voyage cost to the already incurred cost that will result from the implementation of the legislation.

As discussed, the maritime sector is under pressure to reduce its environmental footprint. The challenges are not limited to optimising the logistic chain but expanding to technological innovations. Speed reduction and digitalisation (to optimise the berthing/ unloading of cargo) were the first reaction to reduce the carbon footprint of the industry. The solution was more applicable to ships moving at higher speeds, like container ships and cruise vessels. Speed reduction was introduced to a case study to evaluate the impacts of a bunker levy on tanker vessels (Lagouvardou, Psaraftis, & Zis, Impacts of a bunker levy on decarbonizing shipping: A tanker case study, 2022). The findings of the study indicated that a significant bunker levy is expected to result in speed reduction for the sector. Even if the tanker sector adopted these short-term measures implementing Fit for 55 will further pressurise the industry.

Short and medium-term measures (incremental innovations) are expected to be adopted by the industry to achieve, even partially, the targets of 2030. Radical innovations are needed to reach the targets of 2050. The enhanced model introduced in this thesis can be used to evaluate the financial feasibility of solutions claiming to achieve the decarbonisation of the maritime sector.

2.2. Methodological approach

Stopford describes the cost of running ships in great detail (Stopford, 2008). He distinguishes five main categories namely operating, maintenance, voyage, cargo-handling, and capital costs. Undoubtably, the fuel cost has the highest valued sub-category, accounting to more than 25% of the total cost of the vessel. This percentage varies depending on the vessel category, size classification, age[3], trading routes, etc... In addition, based on the type of the chartering contract different stakeholders undertake to pay the cost.

Voyage and operating expenses are linked to the day-to-day management of the vessel and are also referenced as one (Mallouppas, George; Yfantis, Elias, 2021). This categorisation includes labour and their consumables, fuel and lube oil costs, periodic maintenance, insurance, spares, and canal dues. Like the fuel cost the rest of the vessel Operating Expenditure (OPEX) vary based on the vessel category, size classification, age, and trading routes. An example is the crew of a 10-year-old ship, which requires 24 seafarers to undertake the maintenance workload whereas a 20-year-old ship might

[3] With the term age, we refer to new-building, second-hand, etc. vessels.

require 28 (Stopford, 2008).

The additional cost of the vessel following the adoption of the Fit for 55 legislative package will be attributed to the OPEX. Ceteris paribus[4], the Unit Cost of the transferred cargo is expected to be affected by the additional cost since:

$$Unit\ Cost = \frac{LC + OPEX + CH}{PS} \tag{1}$$

Where LC: is the sum of the capital cost, CH: is the cost of handling the cargo, and PS: is the parcel size of the vessel.

Another aggravating factor for Cyprus, is that the expected imports for the liquid cargo will be handled by the smallest category of product, and chemical tanker vessels (lower parcel size higher unit cost). The same applies for the LPG carriers and the portion of the fleet that will continue to trade liquid fuel to produce electricity (analysis is conducted in the following section).

Literature states that models estimating the emissions follow either a macro-economic scope or an engineering scope approach (Toscano & Murena, 2019). The 4th IMO GHG study suggests using yearly fuel sales statistics to estimate the emissions (Faber, et al., 2021; Yfantis, Ioannou, Paradeisiotis, Mallouppas, & Ktoris, 2022). Typically, a macro-economic approach focuses on market interactions within the economy and has little technological detail. On the other hand, the engineering, bottom-up approach, focuses on the sustainability of individual energy technologies and their relative costs. The bottom-up approach estimates emissions generated from vessels using real-data as provided by the Autonomous Identification System (AIS) of the vessel. Data include operational characteristics of the voyage, geometrical characteristics of the vessel and weather conditions. The data are collected by satellite communication or terrestrial

[4] All other parameters being unchanged or constant.

stations and are considered of Very High Frequency (VHF) (Faber, et al., 2021; Tichavska & Tovar, 2015; Jalkanen, et al., 2009). Additional methodological insights for this approach are provided in the 4th IMO GHG study.

On the other hand, the macro-economic approach is combining data on bunkering fuel sales (quantities and types) or cargo statistics (Schrooten, Vlieger, Panis, Chiffi, & Pastori, 2009), and fuel-related emission factors (Song & Shon, 2014; Nunes, Alvim-Ferraz, Martins, & Sousa, 2017). Literature shows that the main limitation of top-down approaches is the inability to track ship movements in real time, which can lead to uncertainties and inconsistencies in the emissions calculation (Song & Shon, 2014; Woo & Im, 2021). The 2nd challenge of the shipping industry for the next decades, the digitalisation, can support the enhancement of these approaches/ models. The establishment of international and domestic inventories are the common application for these approaches (European Environmental Agency, 2013). Finally, this approach can be used when obtaining refined data and traffic information is not possible. Nonetheless, to estimate GHG emissions an energy-based approach can be used (Faber, et al., 2021). Figure 1 presents the methodology of the top-down approach.

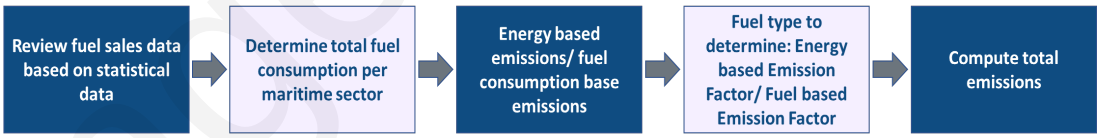

Figure 1: Flowchart describing the top-down methodology.

Hybrid methodologies is a combination of the two approaches. Usually, the bottom-up approach estimates the total emissions while the macro-economic estimates the geographic characterisation. Vice versa AIS data are used to determine the geographic characterization followed by the determination of the total emissions by the top-down approach.

The initial methodology proposed by (Mallouppas G. , Yfantis, Ktoris, & Ioannou,

2022) uses a top-down approach. Through an innovative process, the bunkering fuel sales statistics are replaced by *OPEX* to estimate the consumption of a vessel. The proposed enhanced methodology of this thesis includes additional vessel types, size classifications and fuels based on the Cypriot landscape and estimate the unit cost based on the apportionment of the fleet. In summary, the inclusion of these vessels was based on the fleet trading liquid and liquified cargo in Cyprus, and on expected LNG vessels due to the operation of a Floating Storage Regasification Unit (FSRU). *OPEX* values are depicted in Table 2 together as well as the percentage of the fuel cost corresponding to each size classification. The data have been extracted by available literature and market research (Bernacki, 2021; European Commission DG Environment, 2010; Bilen, et al., 2018; Rogers, 2018; Grose, Flaherty, & Shell, 2007; Wood Mackenzie, 2021; TIMERA ENERGY, 2018; Dorian LPG Ltd, 2022; BW Epic Kosan, 2022; Gupta & Prasad, 2006).

Table 2: OPEX and fuel cost as percentage to OPEX.[5]

Ship Type	Size Classification (DWT or m^3)	OPEX (€/day)	% fuel cost to OPEX
LPG (in m^3)	Handy Gas Carriers[6] ~7,000 - 25,000	14,785	28%
LNG (in m^3)	Q-FLEX 165,000 - 216,000	58,287	35%
Tanker (in DWT)	Extra small tanker[7] ~5,000 - 10,000	20,485[8]	28%
	Small tanker 10,000 - 24,999	22,355[8]	30%
	Intermediate tanker 25,000 - 34,999 Medium Range 1 (MR1) 35,000 - 44,999	25,628	30%
	Medium Range 2 (MR2) 45,000 - 54,999	30,333	30%

[5] OPEX and % of fuel cost to OPEX may vary based on theoretical approaches, actual market values, trading routes, the energy efficiency of each vessel, fuel prices, speed, propulsion system, specific size of each classification, etc. This thesis estimates the additional cost based on values provided by literature as an additional percentage to the initial input.

[6] The lowest value is approximately 7,000m^3 based on the vessels trading Cyprus above 5,000 GT threshold for the implementation of the Fit for 55

[7] The lowest value is approximately 5,000DWT based on the vessels trading Cyprus above 5,000 GT threshold for the implementation of the Fit for 55

[8] Interpolated data by assuming a linear relationship

Following the inclusion of maritime transport to the EU ETS the Carbon Border Adjustment Mechanism (CBAM) sets a factor γ = 0.5 for extra-EU imports/ exports and γ = 1.0 for intra-EU imports/ exports. Expected auctioning EU Allowances (EUAs) (CO_2 €/tonne tariff) for Cyprus are shown in Table 3. CBAM considers extra-EU imports/ exports of less than 300NM as transit voyages with a factor γ = 1.0.

Table 3: Expected Auctioning EUAs for Cyprus.

Year	Total allowances EUAs	Price (€/EUA)	Expected net revenues (€)
2024	1,500,000	100	148,952,250
2025	1,500,000	100	148,952,250
2026	1,500,000	100	148,952,250
2027	1,500,000	110	163,892,250
2028	1,500,000	120	178,832,250
2029	1,500,000	130	193,772,250
2030	1,500,000	140	208,712,250

Table 5 and Table 6 present the fleet characteristics for vessels trading liquid and liquified cargo in Cyprus. The two tables include statistics based on imported goods' port of origin and port of destination. The two ports have been identified to assess the chartering options on the island. It is worth mentioning that most of the Cypriot oil companies own and manage their fleet (liquid fuels for road transportation, LPG, liquid fuels for ship-to-ship bunkering). Average travelling time was also calculated to facilitate optimization of strategic reallocation of traded cargo for selected scenarios (see next section) and unit cost calculation. Smaller size product and chemical tankers are used to import liquid cargo to cover the main energy demands of the island (road transportation, aviation, shipping, road construction and heating). Fuels to produce electricity, are carried out by medium size tankers. The majority of medium and especially large size product tanker vessels are berthing at VTTV oil terminal used for storage purposes (transit cargo), thus will be exempted from our analysis. Another factor is low sample size for the specific categories (LR1 and LR2, see Table 4).

Table 4: Fleet statistics based on carrying capacity.

Cargo type	Size classification[9]	Carrying Capacity	Port calls[10]	No. Vessels[11]	Ratio port calls / vessel[12]	Total Capacity (tonne)[13]	% of total capacity[14]	Avg. Age (years)[15]
Liquid	Extra small tanker[16]	<5,000 GT[17]	677	88	7.69	4,308,162	11.2%	10.42
	Extra small tanker	5,000 GT - 10,000 DWT[18]	852	77	11.06	6,266,741	16.3%	10.33
	Small tanker	10,000 - 24,999 DWT	109	49	2.22	1,610,409	4.2%	15.02
	Intermediate tanker[19]	25,000 - 34,999 DWT	106	27	3.93	3,429,880	8.9%	14.37
	Medium Range 1[19] (MR1)	35,000 - 44,999 DWT	372	182	2.04	14,475,947	37.7%	17.88
	Medium Range 2[19] (MR2)	45,000 - 54,999 DWT	139	97	1.43	6,809,499	17.7%	10.78
	Long Range 1[19] (LR1)	55,000 - 79,999 DWT	9	8	1.13	665,211	1.7%	13.22
	Long Range 2[19] (LR2)	80,000 - 159,999 DWT	8	7	1.14	815,073	2.1%	7.75
Liquified	Handy Gas Carriers[16]	<5,000 GT	252	10	25.2	1,050,907	89.9%	29.89
	Handy Gas Carriers	>5,000 GT	11	10	1.1	91,118	7.8%	10.27
	Mid-Sizes[20]	25,000 - 50,000 m3	1	1	1.00	26,798	2.3%	1

[9] For vessels carrying liquid cargo size classification was based on Average Freight Rate Assessment (AFRA)
[10] Port calls refers to how many times vessels berthed at an oil terminal to load or unload cargo in the period 2017 to 2022.
[11] No. Vessels refers to unique numbers of vessels traded in Cyprus in the period 2017 to 2022.
[12] Ratio port calls / vessel refers to the ration between port call and number of vessels of each size classification.
[13] Total Capacity is the sum of the DWT capacity of each size classification of all vessels traded in Cyprus in the period 2017 to 2022.
[14] % of total capacity is the percentage of the DWT capacity of each size classification of the total.
[15] Avg. Age is the average age of each size classification of all vessels traded in Cyprus in the period 2017 to 2022.
[16] Extra small tankers and handy gas carries of lower than 5,000 GT will not be affected by the legislation since it applies to vessels above that threshold. The storage capacity for gas cargo at Vasilikos Energy and Industrial Area and the renewal of the fleet might increase the liquified cargo carries affected by the legislation.
[17] Gross Tonnage (GT) refers to the volume of all enclosed spaces on a vessel.
[18] Deadweight tonnage (DWT) refers to the weight (or displacement) that a ship can carry.
[19] Larger vessels of classifications Intermediate to LR2 are mainly berthing at VTTV's Oil Terminal (61.2%), followed by EAC's Oil Terminals (19.7% for Vasiliko and 11.2% for Dekelia), UK military base at Akrotiri (7.4%), Larnaca Oil Terminal (0.16%), and Larnaca Port (0.32%).
[20] Due to small sample size Mid-Sizes LPG carries will not be analysed in this thesis.

Table 5: Fleet statistics based on carrying capacity and Port of Origin 2017-2022.

Cargo type	Size classification	Carrying Capacity	Average traveling time (h)[21]	Non-EU more than 300NM	Non-EU less than 300NM	EU	Unknown/ Open Sea[22]	EU Med and Black Sea	Non-EU Med and Black Sea
Liquid	Extra small tanker	<5,000 GT	49.1	10.3%	7.4%	82%	0.30%	81.7%	17%
	Extra small tanker[23]	5,000 GT - 10,000 DWT	27.64	7.4%	80.8%	11.2%	0.70%	11.2%	85%
	Small tanker	10,000 - 24,999 DWT	74.32	28.4%	11%	58.7%	1.8%	57.8%	31.2%
	Intermediate tanker	25,000T - 34,999 DWT	71.17	65.1%	3.8%	30.2%	0.94%	25.5%	66%
	Medium Range 1 (MR1)	35,000 - 44,999 DWT	78.39	13.4%	17.2%	67.7%	1.6%	60.2%	28.8%
	Medium Range 2 (MR2)	45,000 - 54,999 DWT	119.72	30.2%	10.8%	56.8%	2.2%	36%	33.1%
	Long Range 1 (LR1)	55,000 - 79,999 DWT	126.63	30.0%	10%	40%	20%	10%	30%
	Long Range 2 (LR2)	80,000 - 159,999 DWT	192.33	14.3%	14.3%	57.1%	143%	0%	0%
Liquified	Handy Gas Carriers	<5,000 GT	39.58	19.8%	1.2%	69.8%	9.1%	69.8%	21%
	Handy Gas Carriers	>5,000 GT	66.7	0%	9.1%	81.8%	9.1%	72.7%	9.1%
	Mid-Sizes	25,000 - 50,000 m3	79	100%	0%	0%	0%	0%	100%

The transition from oil to LNG to produce electricity and the regions selected for trading can avoid an additional penalty by EU ETS if trading occurs from non-EU Mediterranean and or Black Sea countries of more than 300NM. Depending on the distance (daily fair) and the additional penalty optimisation process will need to be performed.

[21] The average traveling time (h) for each size classification was estimated to indicate that the trading destinations of the imported cargo are relatively close, providing limited alternatives to reduce the unit cost when considering the travelling distance.
[22] Unknown/ Open Sea refers to a not known previous or next port of a vessel. This classification must be avoided in the future to allow the calculation of the additional cost based on the provisions of the legislation.
[23] Extra small tankers greater than 5,000 GT will be the most affected classification as they trade in non-EU regions with near proximity to Cyprus (less than 300NM), still based on the provision of the EU ETS legislation will be considered as transit voyages with 100% penalty.

Table 6: Fleet statistics based on carrying capacity and Port of Destination 2017-2022.

Cargo type	Size classification	Carrying Capacity	Average traveling time (h)	Non-EU more than 300NM	Non-EU less than 300NM	EU	Unknown/ Open Sea[24]	EU Med and Black Sea	Non-EU Med and Black Sea
Liquid	Extra small tanker	<5,000 GT	41.74	5.3%	22.9%	67.5%	4.3%	67.5%	27.9%
	Extra small tanker	5,000 GT - 10,000 DWT	23.89	6.1%	81%	9.6%	3.3%	9.6%	86.9%
	Small tanker	10,000 - 24,999 DWT	45.8	7.2%	19.3%	52.2%	19.3%	52.3%	26.6%
	Intermediate tanker	25,000 - 34,999 DWT	76.84	67%	6.6%	10.4%	16%	9.4%	69.8%
	Medium Range 1 (MR1)	35,000 - 44,999 DWT	52.7	22.6%	25%	25.5%	26.9%	24.7%	41.1%
	Medium Range 2 (MR2)	45,000 - 54,999 DWT	77.1	25.9%	16.6%	23.7%	33.8%	23%	30.2%
	Long Range 1 (LR1)	55,000 - 79,999 DWT	164.86	50%	0%	30%	20%	20%	20%
	Long Range 2 (LR2)	80,000 - 159,999 DWT	152.4	42.8%	0%	28.6%	28.6%	28.6%	0%
Liquified	Handy Gas Carriers	<5,000 GT	38.33	13.1%	0.40%	71.8%	14.7%	71.8%	13.5%
	Handy Gas Carriers	>5,000 GT	20.00	9.1%	45.4%	18.2%	27.3%	18.2%	54.56%
	Mid-Sizes	25,000 - 50,000 m3	N/A	0%	0%	0%	0%	0%	0%

Combined trading (EU and non-EU) in the Mediterranean and the Black Sea for Origin and Destination ports remains identical in absolute numbers and are prominent for Cyprus. There is a margin of shifting trade from non-EU regions of less than 300NM to more than 300NM to avoid a 100% penalty from EU ETS.

[24] Unknown/ Open Sea categorisation is increased for the port of destination ports. To fully implement the provisions of EU ETS all ports of Origin and Destination must be properly reported.

3. The landscape in 2023

The purpose of this section is to describe the Cypriot state of play and how it is linked to the variables used to produce our research hypotheses. The policy framework will also be analysed, which acted as an enabler for this thesis. The proposed and already adopted legislations by the EU and the IMO are expected to affect the fuel mix supplied in Cyprus for bunkering the shipping industry. These developments drove the Cypriot government to plan the construction of infrastructures to facilitate the transition to a greener future. Will this be sufficient to reach the targets of 2030? What about 2050? In addition, the rationale for using case study scenarios will be described and how these are linked to future infrastructure and adoption of new technologies to achieve the so-called shipping decarbonisation.

3.1. Cypriot Landscape

3.1.1. Cyprus a shipping nation

Cyprus is considered a shipping nation. Cyprus ranks 4th in Europe and 12th globally in gross tonnage capacity of the vessels sailing under the Cypriot flag (Cyprus Smart Specialisation Strategy 2030, 2023). In addition, about 20 percent of the world's third ship management fleet, is managed by more than 300 ship-related (Shipping Deputy Ministry, 2022) companies located on the island with the support of approximately 9,000 employees on shore and approximately 55,000 seafarers onboard the vessels. According to the Ship Management Report of 2022 of the Central Bank of Cyprus (Ship Management Report, 2022) revenues from ship management increased to €648 million during the second half of 2022. An amount corresponding to 4.6% of the islands 6-month Gross domestic product (GDP). The contribution only from ship management to the GDP since 2017 varies approximately from 4 to 5%, and the estimated total amount for shipping corresponds to around 7% (Cyprus Smart Specialisation Strategy 2030, 2023). The developments described below allowed the creation of a favourable ecosystem to support the shipping industry of Cyprus:

- Establishment of the Department of Merchant Shipping in 1977
- Cyprus joined IMO in 1987
- Full member of the EU since 2004
- Approved by the EU of an "Open Registry" endorsing a competitive Tonnage Tax System, introduced with the Merchant Shipping Law in 2010
- Commercialisation of Cyprus's main port in 2017
- Establishment of the Shipping Deputy Ministry of Cyprus in 2018
- Provision of high-quality services (legal, accounting, and tax advisory)
- 28 Merchant Shipping Bilateral Agreements
- Treaties for the avoidance of Double Taxation with over 60 countries

Due to its geographic position and its intersection with one of the busiest shipping canals in the world, the Suez Canal, Cyprus offers services not only to vessels berthing at Cypriot port but also to transit voyages. These services include ship-to-ship bunkering and the provision of other consumables. The lack of interconnection with any nation increases this percentage for Cyprus. Shipping trade in Cyprus is conducted mainly through Limassol's port, the main port of Cyprus since 1974. The international port calls for liquid and liquified cargo of category 27: mineral fuels, mineral oils, and products of their distillation are conducted through 8 oil terminals. Figure 2 illustrates statistics and characteristics of the tanker vessels fleet calling those ports.

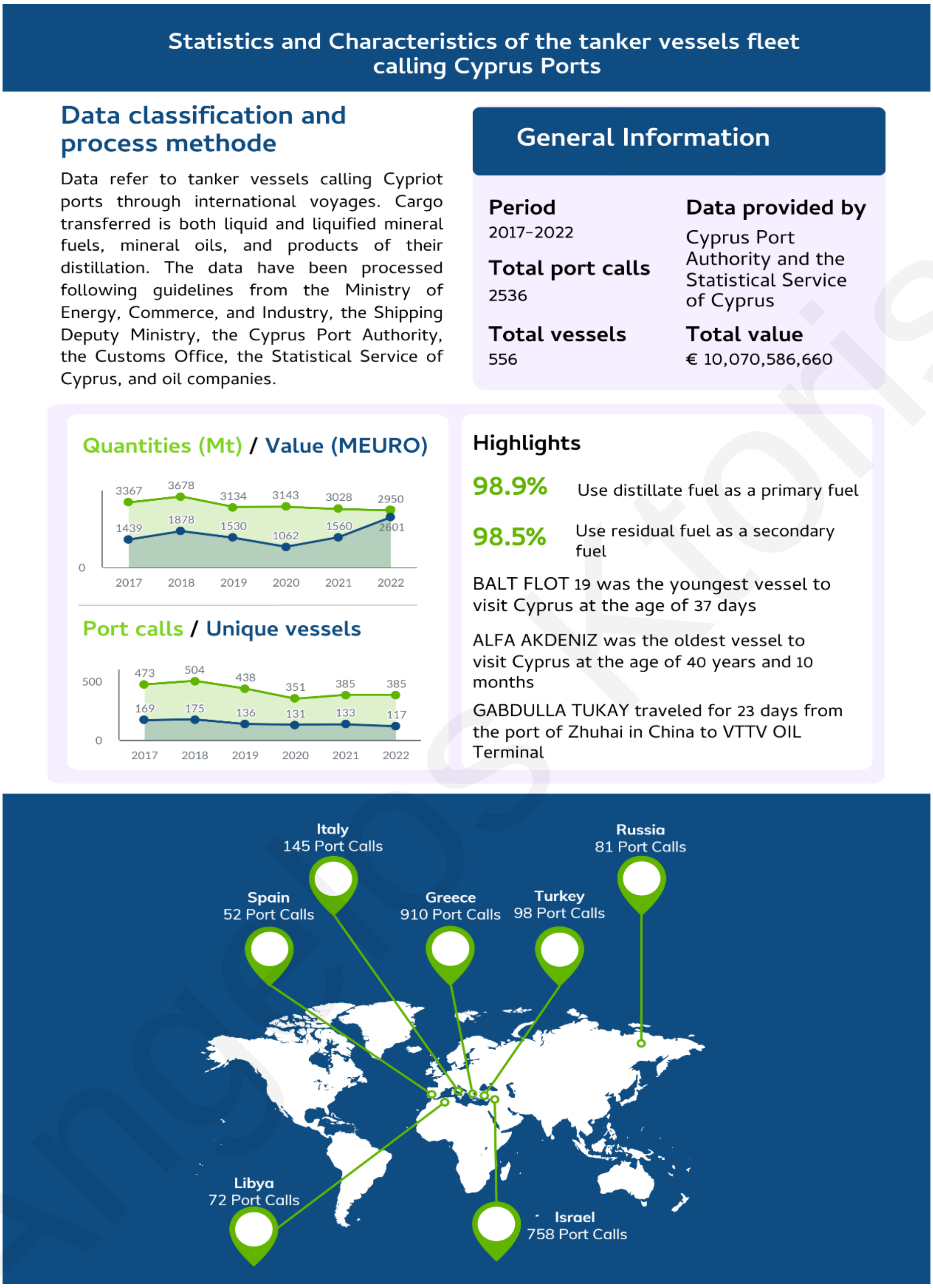

Figure 2: Cypriot Landscape Infographic.

3.1.2. Analysing the characteristics of the vessels trading in Cyprus

To set the scene on the characteristics of the Cypriot landscape data from the Cyprus Port Authority (CPA) and the Statistical Service of Cyprus (CYSTAT) have been processed. The period of the survey spanned from 2017 to 2022. CPA since 2017 publishes details on vessels calling Cyprus ports including basic characteristics for each call. The data are available through the Vessel Traffic Services (VTS) (PCS portal, n.d.). Table 7 lists all tankers vessels calling Cyprus ports and anchorage areas.

Table 7: Liquid and Liquified carriers calling Cypriot ports 2017-2022.

District	**Port Name/ Anchorage point**	**Year**					
		2017	**2018**	**2019**	**2020**	**2021**	**2022**
Limassol	Akrotiri Oil Terminal	12	10	10	11	8	11
	CPA Terminal	13	1	4	2	6	1
	DP WORLD Terminal	0	2	0	1	4	3
	EUROGATE Terminal	1	0	0	0	0	0
	Limassol Anchorage	317	298	274	301	229	229
	Moni Oil Terminal	1	0	0	1	0	0
	Moni Anchorage	38	1	1	32	2	3
Larnaca	Larnaca Anchorage CPA	27	38	24	39	20	10
	Larnaca Anchorage KITION	0	0	0	0	0	2
	Larnaca Oil Terminal	206	201	191	76	41	39
	Larnaca Port	66	44	36	22	16	10
Dekelia	Dekelia Oil Terminal	20	15	13	12	13	14
Zigi	EAC Oil Terminal	28	22	20	19	20	25
	Vasilikos Port Cement Facilities	54	38	37	68	73	109
	VTTV Oil Terminal	152	162	107	123	175	147
	Zigi Anchorage	12	31	25	17	13	14
	Total	947	863	742	724	620	617

In Table 8 calls have been further processed to correspond to only one berth for the whole voyage, berthing at loading and or unloading terminal or areas to exclude vessels not importing goods. In addition, bunkering vessels (CYLAW: List of Regulatory Administrative Acts, 2017; CYLAW: List of Regulatory Administrative Acts, 2018; CYLAW: List of Regulatory Administrative Acts, 2022) have been excluded as well. Finally, according to a source from the Electricity Authority of Cyprus (EAC) unloading oil from the EAC's facilities at Moni Oil Terminal terminated in 2012. As mentioned, Cyprus attracts international calls for the provision of services due to its geographical positioning, this is clearly illustrated when comparing the two tables.

Table 8: Tanker vessels port calls at loading/ unloading facilities.

District	**Port Name/ Anchorage point**	**Year**					
		2017	**2018**	**2019**	**2020**	**2021**	**2022**
Limassol	Akrotiri Oil Terminal	11	10	10	11	8	11
	Limassol Anchorage	34	54	53	52	50	54
Larnaca	Larnaca Oil Terminal	203	200	190	73	41	39
	Larnaca Port	15	14	13	11	11	9
Dekelia	Dekelia Oil Terminal	10	14	13	12	13	11
Zigi	EAC Oil Terminal	23	20	20	19	20	23
	Vasilikos Port Cement Facilities	29	33	32	59	69	96
	VTTV Oil Terminal	147	160	106	113	172	136
	Total	472	505	437	350	384	379

The decision by the Council of Ministers, Republic of Cyprus, in November 2014 to relocate the oil and gas facilities from the Larnaca seafront to the Vasilikos Energy and Industrial Area was implemented in late 2019 for the liquid cargo and is due to completion for the liquified. VTTV Oil Terminal began operations in 2014, and until 2019 it was mainly used as a storage facility with a capacity of 545,000 m^3. After the reallocation of the oil facilities to the Vasilikos Energy and Industrial Area company's jetties are used to facilitate unloading cargo to oil companies for domestic use. Due to its storage capacity, the facility is used to accommodate larger size tanker vessels compared with the ones importing products for local consumption.

To allow further analysis of the fleet trading in Cyprus, the data have been further enhanced with IHS Markit data (IHS Markit, 2023). In addition, ports of origin have been processed to estimate the transportation time of each port call based on the service speed of each vessel. Additional categorisation was made based on EU and non-EU ports of origin and destination, characteristics that will allow the development of additional scenarios. Table 4 to Table 6 present the analysed data. Additional notes to support our hypothesis have been added.

3.1.3. Data on imported goods

CYSTAT publishes annual reports for Intra & Extra EU trade. Reports are available through the CYSTAT website (CYSTAT, n.d.). The categorisation of the commodities is based on the Harmonized Commodity Description and Coding System (HS code). Commodities for mineral fuels, mineral oils and products of their distillation are listed under category 27. The category includes solid, liquid and liquified products. Table 9 illustrates the mass (in million tonnes) and value (in €'M) of commodities imported in Cyprus for the period 2017-2022.

Table 9: Imported commodities of category 27, 2017-2022.

Form of the commodity	2017		2018		2019	
	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M
Solid	141.3	14.2	77.4	9.0	116.3	10.8
Liquid	3311.8	1407.6	3624.1	1848.3	3071.5	1498.2
Liquified	55.4	31.3	53.5	30.1	62.3	31.8
Form of the commodity	2020		2021		2022	
	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M
Solid	80.6	7.2	96.5	11.3	109.5	25.9
Liquid	3089.5	1036.6	2975.2	1525.8	2889.8	2546.3
Liquified	53.7	25.7	52.7	34.7	62.2	54.3

The main use of the imported quantities is transportation fuels and oils (road transportation, aviation, shipping), electricity production, road construction and heating. Cypriot industry and economy are heavily dependent on fossil fuels. Tourism seasonality, not only in energy demand, affects even further the distribution, thus the demand of the island. Island's unique features in power generation and electricity demands as it relies on oil-fired power generation limits the reduction of CO_2 emissions. Cyprus' Integrated National Energy and Climate Plan (NECP) (Cyprus' Integrated National Energy and Climate Plan, 2020) envisaged that two projects the EuroAsia Interconnector and the EastMed Pipeline would end Cyprus energy dependency from shipping. The Final Investment Decision (FID) for the EastMed Pipeline is expected to take place by the end of the year (Landini, 2023). A no go decision will make Cyprus's reliance on imports of fossil fuels even higher. On the other hand, the EuroAsia Interconnector a Project of Common Interest (PCI) has been approved for €657 million funding.

3.1.4. Electricity generation

The gross electricity production by fuel, is shown in Figure 3 while the energy consumption by fuel is shown in Figure 4. The figures have been reproduced from EuroStat (EuroStat, 2022). Both figures show that the main source for electricity production Figure 3 and the overall energy consumption in Cyprus Figure 4 are fossil-based fuels. Some production of electricity is generated via Renewable Energy Sources (RES) from 2008 and onwards, however, the power generated is relatively low. Cyprus energy consumption from fossil fuels accounts to more than 90 percent of and the rest is from renewables.

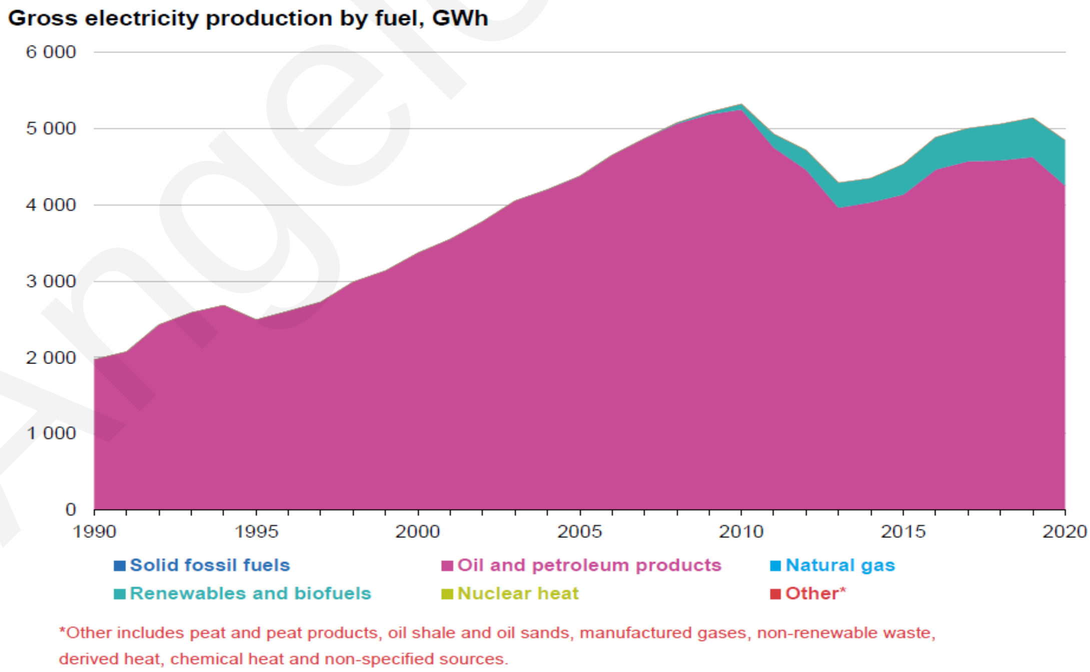

Figure 3: Gross electricity production by fuel. Figure reproduced from EuroStat (2022).

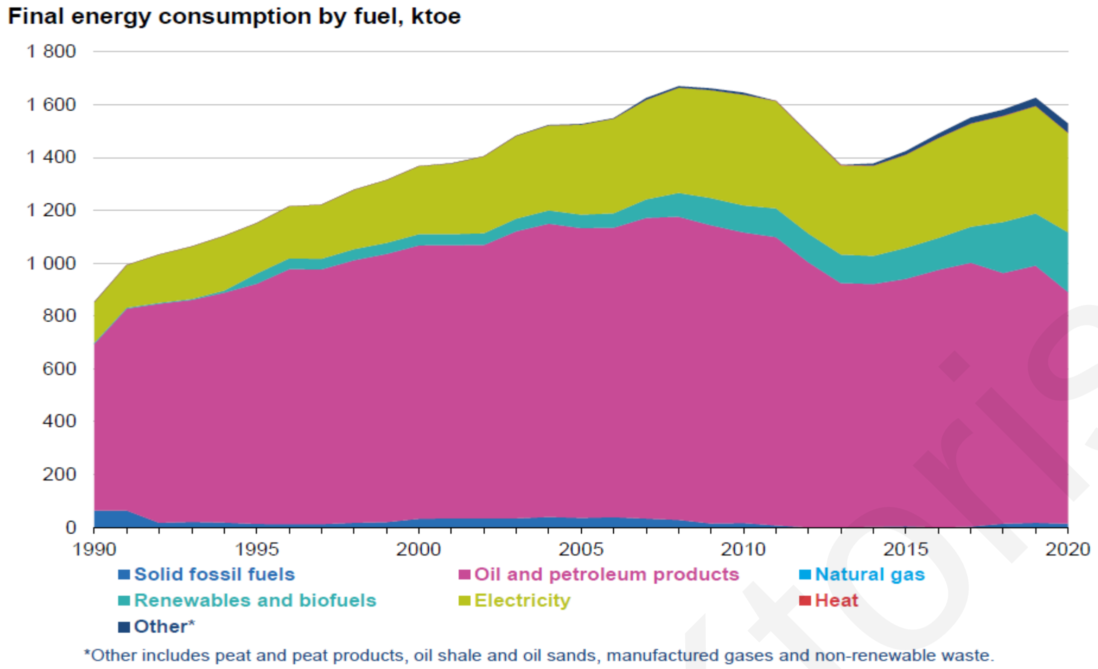

Figure 4: Final energy consumption by fuel. Figure reproduced from EuroStat (2022).

Note that as per the NECP, the key objective in terms of renewable energy sources is by 2030 to achieve at least 23% in final energy consumption, in accordance with the relevant recommendation by the European Commission.

3.1.5. The option of Liquified Natural Gas

Liquefied Natural Gas (LNG) is considered the bridging fuel to decarbonise many industries, including shipping. LNG has been labelled as a transition fuel to aid the decarbonisation of the shipping industry. This is because LNG can reduce the GHG emissions by up to 23 percent and can significantly reduce harmful emissions (CO, PM due to improved combustion efficiencies and SO_x emissions) compared to heavy fuel oil. NO_x emissions are still rather high due to the improved combustion efficiencies (since higher temperatures are achieved). On the other hand, after-treatment technologies for Internal Combustion Engine can reduce NO_x emissions. The positive LNG effects, however, can be reviewed due to methane slip (Balcombe, et al., 2019). Current engines show a methane slip of 2-5% (Jafarzadeh, Paltrinieri, Utne, & Ellingsen, 2017; Schuller, Reuter, Hengstler, Whitehouse, & Zeitzen, 2017). Methane is a much more potent GHG than CO_2, with 28-36 higher global warming potential at hundred years (EPA, n.d.).

Overall, the proposed legislation package would have a positive impact in the uptake of LNG in the maritime industry, however issues such as methane slip and the required infrastructure that affect the supply chain and relative costs will need to resolve. Note that the Russia-Ukraine war and the sanctions imposed on Russia dramatically affected the prices of LNG. Following a year of high record values, at the beginning of 2023, the prices were normalized at 2020 price levels (TRADING ECONOMICS, 2023). It is anticipated for the next years, EU nations and private sector to compete on their Best Alternative to a Negotiated Agreement (BATNA) for options in importing destinations and prices.

In this landscape Cyprus plans to develop a Floating Storage and Regasification Unit (FSRU) at Vasilikos Energy and Industrial Area (Michael, 2019). The FSRU is an essential investment to provide cleaner energy not only to produce electricity, but for bunkering vessels as well. The project will be operational within 2023 (LNGPrime, 2023; The Maritime Executive, 2023; KNEWS, 2023).

Table 10 presents the composition of the newly-build and expected new building fleet that will trade liquid and liquified cargo worldwide for the next decades. Tankers carrying liquid mineral fuels, mineral oils, and products of their distillation are struggling to adopt other forms of primary fuels. Tankers with primary fuel other than distillate fuel are either trading is regions with LNG bunkering infrastructure or have the ability (LNG ready) to use with minor retrofits (Kokolinakis, 2020).

Table 10: Newly-build and expected new building tanker vessels 2015-2027.

Year of build or expected	**Type of Cargo**	**Primary Fuel**	**No. Vessels**	**Percentage of total**	**Secondary Fuel**	**Percentage of primary fuel**
2015-2018	Liquid	Distillate Fuel	1599	91.4%	Residual Fuel (Not Applicable)	92.7% (7.3%)
		LNG	15	0.86%	Distillate Fuel	100%
		Methanol	8	0.46%	Distillate Fuel	100%
		Not known	128	7.3%	Not Applicable	---
	Total		1750			
2015-2018	Liquified	Distillate Fuel	276	64.5%	Residual Fuel (Not Applicable)	96.4% (3.6%)
		Ethane	2	0.47%	Distillate Fuel	100%
		Gas Boil Off	8	1.9%	Distillate Fuel	100%
		LNG	127	29.7%	Distillate Fuel	100%
		LPG	15	3.5%	Distillate Fuel	100%
	Total		428			
2019-2023	Liquid	Distillate Fuel	1565	92.1%	Residual Fuel	100%
		LNG	76	4.5%	Distillate Fuel (LBG)	97.4% (2.6%)
		Methanol	16	0.94%	Distillate Fuel	100%
		Not known	42	2.5%	Not Applicable	---
	Total		1699			
2019-2023	Liquified	Distillate Fuel	168	41.3%	Residual Fuel	100%
		Ethane	19	4.7%	Distillate Fuel	100%
		LNG	164	40.3%	Distillate Fuel	100%
		LPG	56	13.8%	Distillate Fuel	100%
	Total		407			
2023-2027	Liquid	Distillate Fuel	352	77%	Residual Fuel	100%
		LNG	72	15.8%	Distillate Fuel	100%
		Methanol	2	0.44%	Distillate Fuel	100%
		Not known	31	6.8%	Not Applicable	---
	Total		457			
2023-2027	Liquified	Distillate Fuel	41	9.7%	Residual Fuel	100%
		Ethane	14	3.3%	Distillate Fuel	100%
		LNG	284	67%	Distillate Fuel	100%
		LPG	81	19.1%	Distillate Fuel	100%
		Not known	4	0.94%	Not Applicable	---
	Total		424			

Based on the findings, it is expected that until 2030 tanker vessels carrying liquid cargo, trading in Cyprus, will use Distillate Fuel as a primary fuel. The FSRU make the LNG a potential bunkering fuel if more LNG dual-fuelled tankers penetrate the industry and relevant infrastructures are built in neighbouring trading destinations.

The enhanced MSF455 model will be updated to include the lowest size classification.

On the other hand, tankers carrying liquified cargo (LNG and LPG) are shifting towards the cargo they are carrying. More specifically, for the size classification (Q-FLEX) of LNG carriers that will be bunkering Cyprus' FSRU (Michael, 2019) for the period 2015-2018, 74.2% uses LNG as primary fuel, followed by 7% using distillate fuel and 6.3% using the gas boil off process[25]. For the period 2019-2023, and 2023-2027, LNG carriers of that size uses 100% LNG as primary fuel.

Based on the findings, it is expected that LNG carriers to trade in Cyprus will use LNG as a primary fuel. The capability of the FSRU to bunker vessels with LNG will facilitate the replacement of distillate fuel currently used by tanker vessels transferring oil for electricity production with LNG carriers using LNG as fuel. This process is expected to make the transportation and production of electricity on the island greener.

The enhanced MSF455 model will be updated to include LNG carriers.

[25] LNG carrier cargo tanks are insulated; however, a small amount of warming occurs continuously during the transferring of the cargo. This causes the LNG cargo to evaporate as it reaches its boiling point. Through a system this gas is collected and used as fuel. When vessels are on ballast mode (returning to refuelling destination) they use distillate fuel.

3.1.6. The use of Liquified Petroleum Gas

Cyprus, considering its size, imports significant volumes of Liquified Petroleum Gas (LPG). The main areas of use of LPG on the island are industrial, commercial, and domestic. The use of LPG as liquid gas for propulsion in road transportation was exploited, but it seems to be pulled on hold (Vasiliou, 2022). The creation of the Vasilikos Energy and Industrial Area allowed the construction of a new LPG unit (CNA, 2023). The facility is expected to expedite the development in the use of LPG as liquid gas for propulsion in road transportation. The project was approved in 2018 (Nicolaou, 2018) by the Commission for the Protection of Competition (C.P.C.) of the Republic of Cyprus. The facility is capable for storage, bottling, management of LPG and control and maintenance of LPG cylinders. LPG demand shows strong seasonality with the daily supply to end users of LPG varying from 90 MT per day during the summer months to 200 MT respectively during the winter months. The design of the facility nevertheless allows covering all needs of the country, which amount to approximately 50,000 MT (see Table 9). The facility will be used by all LPG providers/ operators of the island, namely Petrolina (Holdings) Public Ltd, EKO Logistics Ltd, Intergaz Ltd και Synergas Ltd. This strategic alliance made the project feasible. Analysing the characteristics of the fleet trading LPG on the island (gas capacity and age of the fleet), the capabilities of the new VLPG unit and the characteristics of the newly build or expected newbuilding vessels the bunkering fuel for this type of vessels is expected to be distillate fuel. More specifically, all vessels build between 2015-2018, uses distillate fuel as primary fuel (fleet of 46 vessels). For the period 2019-2023, 84.6% use distillate fuel followed by 15.4% using LPG (fleet of 11) and finally for 2023-2027, LPG carriers of that size uses 57.1% LNG as primary fuel while 42.9% use distillate fuel.

Based on the findings, it is expected that LPG carriers to trade in Cyprus will use distillate fuel as a primary fuel. The FSRU provides the option of bunkering LNG, 2nd preferred option in the specific size classification. The ratio of port calls/vessel and the average age is the highest for this type of vessel. When the fleet is to be renewed, LNG can be investigated for use as a primary fuel, considering the construction of relevant infrastructures in neighbouring trading destinations.

The enhanced MSF455 model will be updated to include LPG carriers.

3.1.7. The option of liquid and gaseous biofuels

Waste-to-Energy (WtE) is the process of utilising solid or liquid waste to produce electricity, heat, or fuels. When organic waste (biomass) is used as the feedstock, the WtE process is considered renewable. The production of biogas is positioned as energy which can not only generate a source of green energy but also turns the cost of waste management into a revenue opportunity. This green form of energy can be produced by municipal solid and organic, animal, and sewage sludge wastes.

Even if Cyprus is classified among countries with small scale decentralised biogas production and non-existing gas grid, biogas is currently used to produce electricity (Figure 5). As reported by (Kythreotou, Tassou, & Florides, 2012) the theoretical biogas that could be produced from all biodegradable waste streams in Cyprus annually, corresponds to 11,4000,000m^3. The considered biodegradable waste streams predominately consist of solid and liquid agricultural residues, sewage sludge, solid and liquid wastes, and the biodegradable portion of municipal solid waste.

In addition, the potential of upgrading biogas to biomethane to address the needs of the local shipping market is under research and development (Maritime Cyprus, 2023; BioCH4-to-Market, 2022; bioCNG-to-Cold Ironing, 2023). The challenges, benefits and state of the art regarding the uptake of biomethane in the maritime industry is discussed by (Mallouppas G. , Yfantis, Ioannou, Paradeisiotis, & Ktoris, 2023).

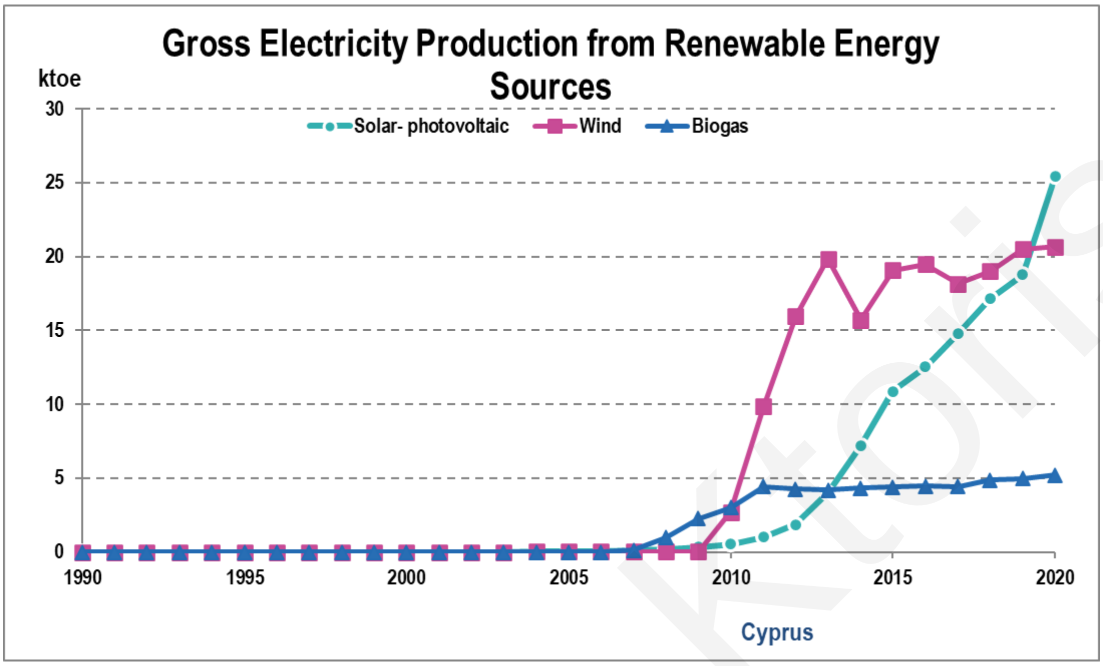

Figure 5: Gross electricity production from solar (photovoltaics), wind and biogas. Data from EuroStat (2022).

The biomethane can be used as a biofuel directly or in blends for marine auxiliary engines or main propulsion engines. However, the liquefaction or compression process will hinder the overall efficiency. Coupled with the huge volumes needed to support marine operations, the current local production alone is not expected to penetrate shipping by 2030. A more efficient solution will be to blend the fuel with the natural gas of the FSRU following the provisions of the relevant ISO standard (ISO 20675:2018, 2018) to produce even greener electricity. Considering the theoretical potential to produce biofuels in Cyprus, investing in such facilities has to be exploited. Biofuels without purities can be directly blended with fossil fuels with the existing technology. The shipping industry will claim its share in the use of biofuels as bunkering fuels to achieve its targets for 2030 and 2050. Regardless of the final mix per industry by 2030 and 2050, the outcome, will benefit the overall decarbonisation efforts for a less dependent economy on fossil fuels.

Biofuels, liquid and gaseous, must penetrate the bunkering fuel mix of Cyprus to medicate the impact of the Fit for 55 on the Cypriot economy by 2030. The proposed quantities, based on selected scenarios will need to be enriched to achieve the relevant targets for 2050. The maritime sector, though, will compete with other industries (i.e., aviation) where decarbonisation options are even more limited.

The inclusion of biofuels in the bunkering fuel mix for shipping will be considered in selected scenarios.

3.1.8. The option of alternative green fuels

Decarbonisation options for the maritime sector exist but are limited. There has been a large activity in promoting alternative fuels like green hydrogen, methanol, and ammonia. Green implies that the fuels' process of production uses Renewable Energy Sources (RES). Short sea routes can potential be electrified with the use of batteries. The use of batteries tough, is limited to due to weight and capacity restrictions since in order to have enough power for open ocean applications, a large number of batteries are needed making the overall weight restrictive. The key barriers in the production and distribution of green fuels are: 1) cost of renewable energy in the production process, 2) storage facilities, 3) additional storage demand onboard the vessel, 4) low technology maturity levels, 5) lack of global bunkering infrastructure, 6) lack of safety protocols and training, and 7) lack of regulations. The low maturity and the time needed for the development of infrastructures and global network high-risk investment cost, thus will not be investigates in this thesis. These alternative options are expected to be viable after 2030 following proper investigation, extensive testing, and validation.

The use of alternative green fuels will not be an option in 2030, thus will not be included in the selected scenarios of this thesis. However, when these technologies reach technological maturity, address legal and regulatory aspects, and are adopted by the shipping industry (through new-building orders) government will need to evaluate the development of relevant infrastructures to achieve 2050 targets.

3.1.9. Mediterranean Sea to become Emission Control Area

In December 2021, during the Conference of the Parties (COP 22), of the United Nations, it was agreed to establish the Mediterranean Sea as a sulphur emission control area (SECA). During the MEPC 79 (MEPC 79, 2022), IMO designate the Mediterranean as SECA, marking a significant step towards cleaner air in the whole region. The decision will be enforced from 1st January 2025. The intention of IMO for desulphurisation the shipping industry was initiated with the adoption of IMO 2020 (IMO, 2020; IMO, 2021) regulation, that limited the content of sulphur in ships' fuel oil to 0.5% (from 3.5% previously) globally. IMO 2020 envisages that most ships would switch to quality, low sulphur, fuel oils to comply with the limit. The Very Low Sulphur Fuel Oil (VLSFO) and marine gas oil (MGO) are considered compliant fuels.

The enforcement of this regulation introduced a new technology, for the shipping industry, the exhaust gas cleaning systems (scrubbers). Scrubbers are used to absorb the excess sulphur when lower quality fuels are used. A scrubber filters the exhaust gases by spraying seawater into the exhaust gas stream. Open-loop system, discharged back into the sea the resulting wash water while close-loop systems store the outcome of the process and discharge it when at berth. The long-term effect of the discharges in open-loop systems is debatable thus researchers are estimating the long run effects of the discharges (EMERGE project, 2020). In addition, the EU Sulphur Directive limits the emission of sulphur content not to exceed 0.1% when ships are at berth in EU ports (Directive (EU) 2016/802, 2016). The bunkering quantities for all vessels trading in Cyprus ports are depicted in Table 11 and Table 12.

Switching to higher quality fuels is evident. Cyprus conditionally (Regulations of CA 373/2016 Part II – CPA) allows the use of open-loop scrubbers (NorthStandard Limited, 2023) in Cypriot ports and anchorage areas.

Table 11: Imported bunkering fuels based on sulphur content 2017-2019.

Product	2017		2018		2019	
	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M
Fuel oils (sulphur concentration of <= 0,1%)	0	0	0	0	0	0
Fuel oils (sulphur concentration of > 0,1% but <= 1%)	825	246	849	301	651	240
Fuel oils (sulphur concentration of > 0,1% but <= 0,5%)	0	0	0	0	0	0
Fuel oils (sulphur concentration of > 0,5%)	0	0	0	0	0	0
Fuel oils (sulphur concentration of > 1%)	155	44	167	60	152	49

Table 12: Imported bunkering fuels based on sulphur content 2020-2022.

Product	2020		2021		2022	
	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M	Mass (Mt)	Value €'M
Fuel oils (sulphur concentration of <= 0,1%)	0	0	~0	~0	0.001	0.005
Fuel oils (sulphur concentration of > 0,1% but <= 1%)	0	0	0	0	0	0
Fuel oils (sulphur concentration of > 0,1% but <= 0,5%)	160	49	134	60	195	136
Fuel oils (sulphur concentration of > 0,5%)	176	45	150	62	213	126
Fuel oils (sulphur concentration of > 1%)	0	0	0	0	0	0

The adoption of scrubber systems was endorsed by the vessels trading in Cyprus based on the findings, on the contrary with the industry norm (Grainger, 2021; Placek, 2022). Since the IMO 2020 was enforced globally, the supply and demand curves of the specific fuel (VLSHO) shifted dramatically forming a new equilibrium point (Peter, 2020). Even if the Mediterranean region is among the busiest in trade volumes and attracts all types and classifications of vessels (Khodjet, Klarwein, & Tode, 2021) the demand and supply (availability and low prices) in Ultra-Low Sulphur Heating Oil (ULSHO) is not expected to be shifted as in the case of VLSHO in 2020.

Even if Cypriot ports allow scrubber systems, the designation of the Mediterranean as SECA will affect the bunkering fuel mix after 2025.

The enhanced MSF455 model will be updated to include VLSHO and ULSHO.

3.1.10. Carbon Capture Utilisation and Storage

A promising technology to assist in the reduction of the carbon footprint of the maritime sector is carbon capture utilisation and storage. Unlike land-based applications this technology face limitations when implemented onboard a vessel. The combustion of 1 kilogram of fuel in an engine produces approximately 3 kilograms of carbon dioxide (CO_2). The additional mass when stored onboard the vessel, implies the reduction of the transferred cargo. These limitations are currently under investigation by the research community (Green Marine, 2023) and the industry (The Maritime Executive, 2023).

The optimisation process between having less transferred cargo or paying the emission levy imposed by the legislation can be a future enhancement module of the model used in this thesis.

The future model can be used by a technology provider, to estimate the pricing policy of the proposed solution.

3.2. Fit for 55 legislation package

The EU has committed to becoming the first climate-neutral continent by 2050. The establishment of the European Green Deal and the adoption of the European Climate Law initiated this path in 2019 to be in line with the Paris Agreement. The implementation of the legislative framework arose from this process will facilitate the target of keeping the global temperature increase to 1.5°C, below 2°C legally binding. In the pursuit of this target, a new EU target for 2030 is set to reduce the GHG emissions by at least 55% compared to 1990 levels. To achieve those targets contributions from all sectors of the economy (including the maritime sector) will be required.

The European Commission plans to transform the transport system with the introduction of the sustainable and smart mobility strategy in December 2020. The “Fit for 55” package was presented in July 2021 with a set of 13 legislative proposals.

It is worth mentioning that currently, shipping vessels use almost entirely fossil fuels as primary fuels, mainly VLSHO. The implementation of a mix of new technologies, alternative fuels in the fuel mix, and operational measures, such as slow steaming[26] and just in time arrival[27] can achieve the reduction target of 2030 as set by the IMO.

In addition, improvements in the operational efficiency of the vessel through data gathering and processing, limited use of low-quality fuels and the use of energy efficient indexes (introduction of the Energy Efficiency Existing Ship Index (EEXI), the Carbon Intensity Indicator (CII), and the Energy Efficiency Design Index (EEDI), and) can further facilitate this process.

For the maritime sector to reach its 2050 goals, a global transition to alternative green fuels and other energy sources is required. As discussed in this section all alternative fuels have limitations, and through research and development solutions are exploited for the solutions to reach sufficient maturity. Today, it is evident that no obvious fuel choice for the global fleet is winning the race.

Fit for 55 main objectives are summarised as (KPMG, 2022): (1) Guarantee environmental integrity and solidarity, (2) inclusion of shipping to the EU Emissions Trading System (ETS), to strengthen its capacity, (3) adoption of policies to facilitate carbon taxation and to ensure the building of carbon prices, and (4) influencing end consumers with the introduction of carbon pricing and respective taxation. The directives and regulations that directly affect shipping are: (1) EU ETS, (2) Carbon

[26] a process of intentional reduction of the speed of cargo vessels to cut down fuel consumption and thus carbon emissions.

[27] a process developed to ensure that the vessel arrives at its destination when all facilities and services are available

Border Adjustment Mechanism (CBAM), (3) FuelEU Maritime, (4) REPowerEU, (5) the revised Renewable Energy Directive (RED) II, (6) the revised EU Monitoring, Reporting, and Verification (MRV) Regulation, (7) Alternative Fuel Instructive Directive (AFID), and (8) the revised Energy Taxation Directive (ETD).

3.2.1. EU ETS

EU ETS (EU ETS (final text), 2023) is the latest measure adopted by the European Parliament on 18th of April 2023. The text will be implemented from the 1st of January 2024 (European Parliament, 2023). The directive aims to involve the maritime sector in the EU carbon trading scheme. It targets vessels calling EU ports, of at least 5,000 gross tonnes, regardless of their flag of registration. It is considered a market-based tool designed to reduce greenhouse gas emissions. In principle a cap on the total amount of carbon emissions is set by the EU. Companies receive allowances to emit a certain amount, if they exceed their allowance, they must buy additional allowances on the market, while companies that emit less can sell their unused allowances. It was recorded that ETS has been successful in reducing emissions in other sectors, thus the need to expand its application to the maritime sector. The adoption of the EU MRV regulation (see below) will facilitate the implementation of EU ETS. The MRV regulation developed a framework to better understand the consumption of fuel and the emission of CO_2 from the shipping industry.

EU ETS includes emissions in all EU ports, all intra-EU voyages are associated with 100% emission, while extra-EU voyages are associated with 50% of emissions. The approach considers only the emissions generated on board the vessel ('tank-to-wake').

The Innovation Fund will allocate at least €20 million of ETS allowances to maritime projects, an amount that corresponds to approximately €2 billion considering the current ETS carbon price. Eligible research projects will include the production of alternative fuels, exploitation of new technologies like Carbon Capture, Utilisation and Storage (CCUS), and the overall effective energy transition of the shipping industry. Figure 6 presents the phase-in timeline for the implementation of EU ETS.

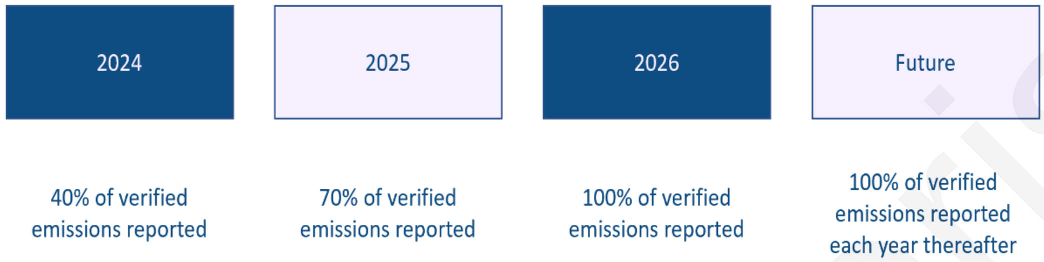

Figure 6: EU ETS implementation timeline.

Table 3 depict the expected auctioning EU Allowances (EUAs) for Cyprus as presented by the Department of Environment, Ministry of Agriculture, Rural Development and Environment, Republic of Cyprus during the Cyprus Shipping Chamber's (CSC) Members meeting (March 2023).

3.2.2. Carbon Border Adjustment Mechanism (CBAM)

CBAM is considered an alternative measure to address the risk of carbon leakage. The maritime sector will be included in the measure making shipping will not receive a free allocation. To allow importers, traders, and producers to adjust to the new norm a transitional phasing-out period of free allowances will be used. The relevant delegated acts on free allocation should be adjusted accordingly for the sectors and subsectors covered by the CBAM. The reduction of free allocation should be implemented by applying a factor for the CBAM sectors. Revenues that occurred by auction will be allocated to the Innovation Fund.

To respect the proportion of the free allocation available for the non-CBAM sectors, the final amount to deduct from the free allocation and to be auctioned should be calculated based on the proportion that the CBAM demand represents in respect of the free allocation needs of all sectors receiving a free allocation. The allocation of allowances has been presented in the previous sub-section (see Figure 6 and Table 4).

3.2.3. FuelEU Maritime

FuelEU Maritime (FuelEU Maritime proposal, 2021) is a new regulation that seeks to drive the shift towards low carbon alternative maritime fuels. The regulation will consider GHG emissions from the whole value chain ('well-to-wake') in contrast to the approach of EU ETS. FuelEU Maritime also reached, recently, an initial agreement between the European Council and the European Parliament (EC, 2023). Same as EU ETS this regulation will be applied to all ships regardless of their flag of registration, with a gross tonnage above 5,000 in a non-discriminatory manner.

Default or actual and certified emission factors will be established to measure the performance on a well-to-wake basis for renewable and low-carbon maritime fuels. This process will estimate the well-to-tank and the tank-to-wake emissions generation. The limit on the GHG intensity of the energy used onboard a vessel arriving at, staying within, or departing from an EU port is illustrated in Table 13.

Table 13: FuelEU Maritime reduction factor.

Year	Reduction of the reference value of [Y grams of CO_2 equivalent per MJ]
2025	-2%
2030	-6%
2035	-13%
2040	-26%
2045	-59%
2050	-75%

3.2.4. REpowerEU

The aim of the REpowerEU proposal is to facilitate the ramp up biomethane production. The aim for 2030 is set at 35 billion cubic meters (bcm) of biomethane production on an annual bases (Mallouppas G. , Yfantis, Ioannou, Paradeisiotis, & Ktoris, 2023). In Cyprus 11 biogas plant units are operational contributing to the renewable energy mix for electricity production (see Figure 5) (FinancialMirror, 2019). On the other hand, the potential of domestic production of biomethane is yet to be exploited (Maritime Cyprus, 2023). At EU level, the production of biomethane and biogas is estimated at 3 bcm and 15 bcm, respectively (Mallouppas G. , Yfantis, Ioannou, Paradeisiotis, & Ktoris, 2023). Gas for Climate estimations for 2030 is for biomethane to produce 41 bcm above REPowerEU target of 35 bcm (Alberici, Grimme, & Toop, 2022). These developments are encouraging, thus the scenarios formulated took into consideration the projected uptake of biomethane.

3.2.5. Renewable Energy Directive (RED) II

RED II envisages that the share of energy from renewable sources in 2030 will be at least 32% (based on NECP for Cyprus this percentage drops to 23%) and at least 14% in the transport sector. Based on the existing scenario, fuels used in the shipping and the aviation industries can opt-in to contribute to the 14% transport target (EU Science Hub, 2018) but are not obliged to do so.

3.2.6. EU Monitoring, Reporting and Verification (MRV) Regulation

Vessels above 5,000 gross tonnages arriving at, staying within, or departing from an EU port are obliged to monitor, report, and verify their CO_2 emissions since 2018 (Regulation (EU) 2015/757, 2015). At the global level, similar measures have been adopted recently on energy efficiency for existing and newly build ships.

To facilitate the implementation of the EU ETS the EU MRV will be updated to include CO_2, CH_4 and N_2O emissions to be align with the ETS scope. In addition, additional ship types and size classification will be included in.

3.2.7. Alternative Fuel Instructive Directive (AFID)

The new proposed directive seeks to ramp up the availability of LNG by 2025 in EU ports. In addition, shore-side electricity facilities for passenger and containership vessels in the core EU ports (based on the port calls made each year) by 2030 will need to be available. For Cyprus only Limassol port is considered as a core port (European Commission, 2014), in addition shore side electrification, as in FuelEU Maritime, applies to container and passenger vessels (out of scope for this thesis). As regards the provisions to rump up the LNG availability as a bunkering fuel, the construction of the FSRU, which will be operational as of 1st January 2024, will achieve the set targets.

3.2.8. Energy Taxation Directive (ETD)

The proposed revised directive aims to give an end to tax exemptions for conventional fossil fuels currently used by the shipping industry and incentivise the uptake of alternative green fuels. When adopted, the bunker fuels traded in the EU would no longer be tax-exempt if voyages are within the EU. More specifically, fuels will be taxed based on their environmental performance and energy content (Baert, 2023). Conventional fossil fuels, used by the maritime sector are expected to be taxed at the highest rate while electricity to be taxed at the lowest rate. Figure 7 presents the proposed minimum tax rates (KPMG, 2021).

As the new ETD is a revision of an existing directive, its unanimous acceptance is required, by all members states. Following the adoption domestic legislation will need to be amended.

Fuel types	Example fuels	Minimum Tax Rate
Conventional fossil fuels and non-sustainable biofuels	Gas oil, petroleum	10.75 euros/GGJ
Fossil-based fuels supportive of decarbonisation in the short term	Natural gas, LPG	For the first 10 years 7.17 euros/GGJ for motor fuel and 0.6 euros/GGJ for heating
Sustainable but not advanced biofuels	Food crop derived biofuels, wood mass derived biofuels	5.38 euros/GGJ for motor fuel and 0.45 euros/GGJ for heating
Electricity, advanced sustainable biofuels, biogas and renewable non-biological fuels	Renewable hydrogen	0.15 euros/GGJ

Figure 7: Proposed minimum tax rates under ETD. Figure reproduced from (KPMG, 2021).

The “Fit for 55” legislative package, is the most comprehensive building block to achieve the ambitious 2030 climate target. Maritime transport is expected to make its contribution in that way, even if is one of the least carbon-intensive modes to transport people and goods with 3.5% of all GHG emissions in 2018, while road transportation accounts for 71% and aviation for 14.4% will pay its share towards EU carbon neutrality by 2050.

3.3. Why use case studies

The research methodology that builds the foundation of the overall approach for this thesis was formulated from the gathering of data and their analysis up to the research design (N, Haigh, & Amaratunga, 2006; Collis & R., 2003). The data used to form our hypothesis are market based, provisions/ factors based on adopted/ proposed legislative frameworks and historical trends (of the past decades) of the specific shipping sector. The research objectives are defined in the Introduction section.

A combination of quantitative and qualitative approaches has been used to provide an in-depth analysis of the current and future landscape. These approaches are currently considered as alternative strategies for research (Yilmaz, 2013). The contribution of experts in analysing the status quo and the foreseen future towards decarbonisation assist in the development of the proposed case studies (scenarios). The quadruple helix approach was followed to gather industry insights from: 1) Public Sector (Ministry of Energy, Commerce and Industry, Shipping Deputy Ministry, Cyprus Ports Authority, Department of Customs and Excise, Statistical Service of Cyprus), and semi-public bodies (Electricity Authority of Cyprus), 2) Academia & Research (Cyprus Marine and Maritime Institute, University of Cyprus), 3) Private Sector (Petronav Ship Management Limited, FP Marine), 4) Civic Society (Cyprus Shipping Chamber). The information provided by the experts benefited this thesis in conjunction with an extended literature review from academic journals, market research, conference papers and reports specific to the vessel carrying liquid and liquified cargo.

Scenarios are used because predicting complex alternatives for extended periods is challenging. Covid-19 and the Russia-Ukraine war are recent examples that heavily affected oil prices and trade trends, as the gulf war and the 2007–2008 financial crisis did in the past. Fossil fuels (especially oil) prices are formulating trends, alliances, economies, even currencies and are direct and indirect affect the prices of nearly all goods and services prices globally. The decarbonisation is challenging from all perspectives, and it is expected to be of grade research and technological development interest for the decades to come.

Figure 8 illustrates the approach conducted in this thesis. Step 1 is the Literature Review to identify the provisions of the Fit for 55 legislative package. Step 2 refers to the gathering of data for the fleet carrying liquid and liquified cargo, trading in Cyprus. The period began in 2017, as this is the year that such data were publicly available. Based on a 1st analysis of the data, at that time, the proposed provision of the legislation the scenarios have been formulated. Further analysis of the data and modification of the factors from the adopted legislation followed with consultation with the experts. This open loop process continued until the scenarios were finalised. The scenarios than acted as inputs to the enhanced model and finally the results were analysed, and important takeaways were discussed.

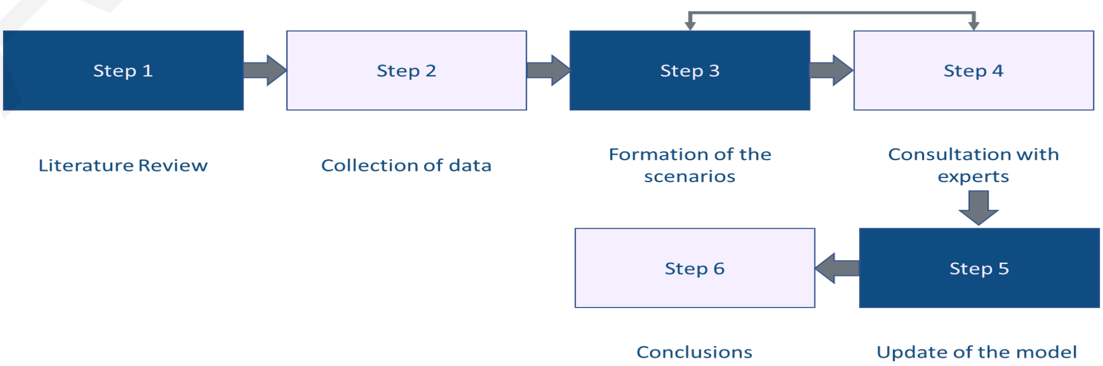

Figure 8: Flowchart outlining methodology used in this thesis.

3.4. Selected Scenarios

A set of parameters will be identical for all scenarios. These are: the FSRU will serve as a bunkering station, by the 1st of January of 2024 the FSRU will begin operations, the demand for liquid and liquified products will remain the same (calculated on average based on imports and port calls of the period 2017-2022). The projected price of each fuel used in the scenarios will be presented in the next section. In the next section, we will also present the fuel mix matrix for each scenario.

3.4.1. Scenario A: Business as Usual (BAU)

In the BAU scenario, most of the fleet trading in Cyprus will continue to use distillate fuel as a primary fuel. Due to the seasonality on demand in electricity generation and the type of contracts used in the trading of LNG (70%-90% contracts based on long-term charters (Wood Mackenzie, 2021)), and for buffering/ energy security purposes it is anticipated that portion of the liquid fuels used in the production of electricity will continue to be traded in Cyprus. LNG carries are expected to use LNG as a primary fuel, LPG and liquid cargo carriers are expected to use distillate fuel, as a primary fuel. Percentage in the use of HFO, VLSHO, ULSHO will change from the 1st of January 2025 due to the designation of the Mediterranean Sea as SECA.

3.4.2. Scenario B: ramp up of LNG and use of biofuels

Two sub-scenarios will be projected. “Good” (B1) scenario where the EuroAsia Interconnector will begin operations by the 1st of January of 2027. Based on that the, LNG will be used entirely to produce electricity. EuroAsia Interconnector will be used for buffering/ energy security purposes. LNG, as a primary fuel, will penetrate the local liquid carrier tankers and LPG carriers, starting from 1st of January 2027. Significant percentages of biofuels will also be in use by the industry, starting from 1st of January 2025.

"Bad" (B2) scenario where the construction of the EuroAsia Interconnector is delayed and begins operation after 2030. LNG, as a primary fuel, penetrate the local liquid carrier tankers and LPG carriers (like scenario B1), starting from 1st of January 2027, but with lower percentages. Lower percentages of biofuels (compared with B1) will also be in use by the industry, starting from 1st of January 2026.

The thesis evaluates two scenarios since the EuroAsia Interconnector, a significant infrastructure, is still under debate. The construction of this infrastructure will impact the fuel mix to be imported onto the island. This was reflected in the produced fuel matrix. In addition, incentivising measures for adopting greener solutions (fuels, technologies) will facilitate the achievement of the mid-term targets of 2030 and long-ran targets of 2050.

3.4.3. Scenario C: manipulation of the EU-ETS intra-extra-EU factor

Two sub-scenarios will be projected. "Good" (C1) scenario where Cyprus gets exempted from transit calls from non-EU port calls of less than 300NM, regards the provisions of EU ETS emission allowances. All other parameters are kept equal to the scenario A. The hypothesis is based on recent, similar exceptions Cyprus managed to achieve for the aviation industry (Stockwatch, 2022).

"Bad" (C2) scenario where a liquid cargo importer, strategically switches trading destination from non-EU neighbouring countries of less than 300NM, to non-EU neighbouring countries of more than 300NM. Size classification to be investigated is extra small tankers of carrying capacity less than 10,000 DWT, but above 5,000 GT legislative threshold. All other parameters are kept equal to the scenario A.

Even if scenario C1 will heavily affect competitiveness, it was evaluated to prove that this provision of the legislation is not equally affecting economies across the EU member states. The geographical position of Cyprus and the main trading destinations will negatively affect the new unit cost of the transported cargo. On the other hand, the strategic reallocation of a trading route could give a comparative advantage to an oil-importing company.

3.4.4. Scenario D: Best-case scenario

The Best-case scenario will be a combination of the scenarios B1 and C1.

4. Methodology

Figure 9 illustrates the enhanced processes flowchart of the MSF455 model. The improved methodology was tailored to the characteristic of Cyprus and to evaluate the scenarios and their sub-scenarios resulting from the consultation with the expert. The algorithm estimates the new Unit Cost, by estimating the new OPEX based on CO_2 penalties (adopted or proposed), fuel mixture (specific scenarios), percentage of taxation on bunkering fuels (not used in the current case study), consideration of intra-EU imports of liquid and liquified cargo in Cyprus.

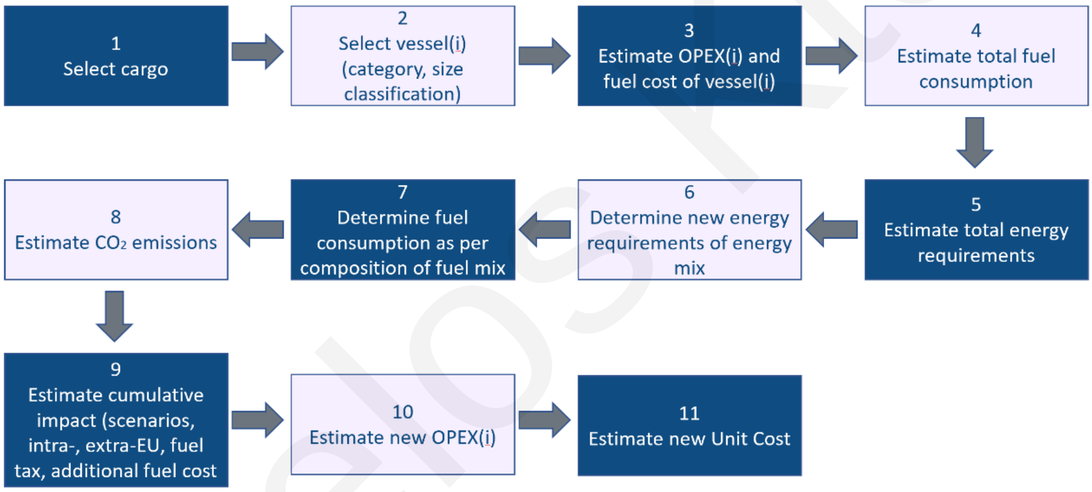

Figure 9: Enhanced MSF455 assesses new Unit Cost

Step 1: Selection of the cargo to be imported (liquid or liquified), based on value *i*, where subscript *i* indicates ship type.

Step 2: Based on the selected cargo, identify the appropriate ship (product/ chemical tanker, LNG or LPG carrier) based on $ship_i$.

Step 3: Estimate the $OPEX_i$ of $ship_i$. Values selected based on literature, but the algorithm can be adjusted to actual market values.

Step 4: Estimate fuel consumption:

$$FC_i = \frac{OPEX_i * f}{C_{2024-2030}} \quad (2)$$

where FC_i is the fuel consumption of the fuel mix in kg per $ship_i$. f is the % of fuel cost to $OPEX_i$, and $C_{2024\text{-}2030}$ is the projected fuel cost for the respective period and fuel mix. Table 14 depicts the fuel prices in Euro/ megajoule (MJ) for the fuels that will be used in our scenarios (European Commission, 2020; IRENA, 2021; Placek, 2023a; Placek, 2023b; Ship & Bunker, 2023; CAPEX, 2023).

Table 14: Fuel prices of the selected scenarios. Values are linearly interpolated on a year-by-year basis.

Fuel time	2024	2025	2026	2027	2028	2029	2030
HFO	0.008	0.009	0.010	0.010	0.011	0.012	0.012
Biogas	0.0126	0.0110	0.0094	0.0078	0.0063	0.0047	0.0031
Biofuel	0.026	0.026	0.026	0.026	0.026	0.026	0.026
VLSFO	0.0120	0.0121	0.0121	0.0121	0.0122	0.0122	0.0123
ULSFO	0.0143	0.0143	0.0144	0.0144	0.0144	0.0145	0.0145
LNG	0.0239	0.0204	0.0169	0.0133	0.0098	0.0063	0.0042

<u>Step 5</u>: Estimate the total energy requirements of $ship_i$:

$$FE_i = FC_i * LHV_{FUEL} \tag{3}$$

Where FE_i are the combined energy requirements per ship and LHV_{FUEL} is the Lower Heating Value of each fuel in MJ/kg. LHV values for the selected fuels are shown in Table 15 (Faber, et al., 2021).

Table 15: Lower Heating Value of the selected fuels MJ/kg.

Fuel	HFO	Biogas	Biofuel	VLSFO	ULSFO	LNG
LHV	40	50	38	41.7	42.4	50

<u>Step 6</u>: The new energy requirements are determined based on the new energy composition; these are user input requirements.

$$FE_{ij} = FE_i \eta_{ij} \alpha_{ij} \tag{4}$$

where η_{ij} is the change in the combined energy requirements due to switching to a different fuel (change in combustion efficiency). In this thesis alternative fuels (Biogas, Biofuel, and LNG) are assumed to improve combustion efficiencies, at the value of 98%, as opposed to their fossil fuel counterparts (HFO, VLSFO, and ULSFO). It is worth mentioning that the change in improvement depends on several factors such as fuel composition, type of engine, and type of injection to name a few. a_{ij} is the percentage of $fuel_j$ of $ship_i$.

Step 7: Determine fuel $mass_i$ of fuel mix based on new energy requirements of the $ship_i$:

$$FC_{ij} = FE_{ij}/LHV_j \tag{5}$$

Where FC_{ij} is the fuel consumption of $ship_i$ and fuel $type_j$. LHV_j is the latent heat value of fuel $type_j$.

Step 8: Estimate total CO_2 emissions of new fuel mix of $ship_i$.

$$CO_{2,i} = \sum_j \left(FC_{ij} * EF_j\right) \tag{6}$$

Where EF_j is the fuel-based emission factor of $fuel_j$. Values used HFO, VLSFO, and ULSFO = 3.114, LNG = 2.755, Biogas, and Biofuel = 0 (Faber, et al., 2021).

Step 9: Estimate cumulative impact based on scenarios for CO_2 tax, intra- and extra-EU imports, and additional fuel cost up to 2030:

$$taxplus_{ik} = CO2tax_{ik} + additionalfuelcost_{ik} \tag{7}$$

Where $taxplus_{ik}$ is added tax per $year_k$ on $vessel_i$. It is composed of CO_2tax_{ik} which is the CO_2 penalty defined as:

$$CO2tax_{ik} = \gamma \delta_k \varepsilon_k CO_{2,i} \tag{8}$$

Where $\gamma = 1.0$ for intra-EU imports, $\gamma = 0.5$ for extra-EU imports, δ_k is the CO_2 penalty in EUR/tonne for $year_k$ and ε_k is the carbon penalty allowance as per CBAM until 2026. The $additionalfuelcost_{ik}$ is the additional fuel cost of $fuel_j$ based on projections and reference year (2022).

$$additionalfuelcost_{ik} = \sum_j FE_{ij}\left(C_{jk} - C_{j2022}\right) \tag{9}$$

Step 10: Estimate cumulative impact based on scenarios for CO_2 tax, intra- and extra-EU, and additional fuel cost up to 2030:

$$\pi_{ik} = taxplus_{ik}/OPEX_i \quad (10)$$

Step 11: Estimate the additional Unit Cost for the year 2030:

$$Unit\ Cost = \frac{LC + OPEX + CH}{PS} \quad (1)$$

OPEX$_i'$ estimated based on characteristics of each size classification (intra/ extra EU distribution, average traveling time, total average capacity) of the fleet trading in Cyprus. Based on allocation of expenses (Stopford, 2008)

$$Unit\ Cost = \frac{0.4 * LC + 0.55 * OPEXi + 0.05 * CH}{PS} \quad (1a)$$

$$OPEXi' = OPEXi + taxplus_{ik} \quad (1a)$$

$$Unit\ Cost' = \frac{0.4 * LC + 0.55 * OPEXi + 0.05 * CH + OPEX'}{PS} \quad (1b)$$

$$Unit\ Cost' = Unit\ Cost + \frac{OPEX'}{PS} \quad (1c)$$

Table 16 depicts the average carrying capacity of the fleet traded in Cyprus for the period 2017-2022 per size classification (extracted from Table 4).

Table 16: Unit Cost and Carrying Capacity

Ship Type	Size Classification (DWT or m^3)	PS (DTW or m^3)
LPG (in m^3)	Handy Gas Carriers ~7,000 - 25,000	8,283
LNG (in m^3)	Q-FLEX 165,000 - 216,000	190,500
Tanker (in DWT)	Extra small tanker ~5,000 - 10,000	7,355
	Small tanker 10,000 - 24,999	14,774
	Intermediate tanker 25,000 - 34,999	32,357
	Medium Range 1 (MR1) 35,000 - 44,999	38,314
	Medium Range 2 (MR2) 45,000 - 54,999	48,989

4.1. Scenarios fuel matrix

Table 17 introduces the fuel mix matrix based on the selected scenarios. The fuel mix for each scenario was estimated taking into account the imported cargo (see Table 9), the fleet characteristics importing liquid and liquified cargo (see Table 4 and Table 5) the implementation of the adopted EU and IMO legislative framework (Fit for 55, SECA), the operation of the FSRU, the planned ramp up of liquid and gaseous biofuels, and the potential connection of Cyprus with the EuroAsia Interconnector. The fuel percentages have been spread horizontally over the projected period. Fuel composition can be accepted as a temporal function by the model.

Table 17: Fuel mix matrix for the selected scenarios.

Fuel Mix	HFO	Biogas	Biofuel	VLSFO	ULSFO	LNG
Scenario A						
Liquid cargo	30%	0%	0%	30%	40%	0%
Liquified cargo LNG	0%	0%	0%	0%	0%	100%
Liquified cargo LPG	30%	0%	0%	30%	40%	0%
Scenario B1						
Liquid cargo	20%	0%	10%	25%	35%	10%
Liquified cargo LNG	0%	15%	0%	0%	0%	85%
Liquified cargo LPG	10%	10%	0%	10%	20%	50%
Scenario B2						
Liquid cargo	25%	0%	5%	25%	40%	5%
Liquified cargo LNG	0%	5%	0%	0%	0%	95%
Liquified cargo LPG	20%	5%	0%	20%	30%	25%
Scenario C1						
Liquid cargo	30%	0%	0%	30%	40%	0%
Liquified cargo LNG	0%	0%	0%	0%	0%	100%
Liquified cargo LPG	30%	0%	0%	30%	40%	0%
Scenario C2						
Liquid cargo	30%	0%	0%	30%	40%	0%
Liquified cargo LNG	0%	0%	0%	0%	0%	100%
Liquified cargo LPG	30%	0%	0%	30%	40%	0%
Scenario D						
Liquid cargo	20%	0%	10%	25%	35%	10%
Liquified cargo LNG	0%	15%	0%	0%	0%	85%
Liquified cargo LPG	10%	10%	0%	10%	20%	50%

5. Results and Discussion

In this section the results of the research objectives will be presented and discussed.

5.1. Quantification of the liquid and liquefied vessels trading in Cyprus

Publicly available data from the Vessel Traffic Services (VTS) of the Cyprus Port Authority (CPA) have been obtained. The data have been analysed following extensive consultation with industry experts. The main characteristics of the vessels trading in Cyprus are depicted in Table 7 to Table 6. The average age of all types and size classifications of the fleet exceeds ten years, but the majority of the fleet is expected to continue to trade until 2030, Liquified Petroleum Gas (LPG) carriers are an exception. The newly build and the expected new building vessels are presented in Table 10. Even if a percentage of that vessels is anticipated to penetrate Mediterranean trading routes, the adoption of alternative green fuels for primary fuelling is not observed. Exception are the Liquified Natural Gas (LNG) carriers. The imported products come mainly from Mediterranean and Black Sea nations; larger size vessels berthing at VTTV storage facilities present lower percentages. Trade occurs with EU and non-EU nations, a parameter used by the Carbon Border Adjustment Mechanism (CBAM). A disadvantage is the lack of historical trading data for LNG carriers, vessels expected to import natural gas to produce energy due to the construction of a Floating Storage and Regasification Unit (FSRU). The quantities imported on the island are shown in Table 9. Compared with the maximum capacity that could have been transferred (see Table 4) it seems that an optimisation process can be conducted to minimise, to the possible extent, the unit cost of the transferred cargo.

5.2. How the particularities of Cyprus affect the fuel mix

The construction of the FSRU is expected to switch the fuel used to produce electricity from fuel oil to natural gas. LNG as a bridge fuel towards decarbonisation will assist in the reduction of the overall emissions generated in Cyprus. Fuel oil will continue to be used for buffering, security, and seasonality reasons, until the construction of the EuroAsia Interconnector. The newly built LPG plant at Vasilikos Energy and Industrial Area can facilitate the further uptake of LPG on the island. Local production of biofuels (liquid and gaseous) is an option that can be exploited based on the theoretical capacity of the produced waste. Biofuels, if compared with other green fuels, have less technical issues. The drawback is the low global production. The FSRU will have bunkering jetties, thus assisting in the penetration of LNG as a primary fuel for the future fleet trading in Cyprus. Hydrogen, ammonia, and methanol are future green options. The construction of appropriate bunkering facilities, when technical and regulatory issues are resolved, should be investigated. Lastly, the designation of the Mediterranean Sea as a sulphur emission control area (SECA) is expected to rump up the use of Ultra-Low Sulphur Heating Oil (ULSHO).

5.3. Enhancement of the MSF455 methodology

The methodology presented and the model have been enhanced. New fuels have been included, namely the Very Low Sulphur Fuel Oil (VLSFO), and the ULSHO. Updated provisions of the recently adopted EU ETS, have been incorporated. Provisions include expected auctioning allowances for Cyprus and percentages of verified emissions per year. Additional, size classifications for tanker vessels carrying liquid cargo as well as ship types of vessels carrying liquified cargo have been added. Updated current and projected fuel prices have been used. The Unit Cost of the transported work has been introduced to estimate the additional cost arising from the legislative framework.

5.4. Scenarios formulated by the local landscape and legislation.

The selected scenarios have been formulated considering the vessels' characteristics, the constructed and planned facilities, and the adopted legislation. The age of the fleet will hinder the adoption of alternative green fuels due to the expected renewal of the fleet until 2030. In addition, the low percentage of alternative green fuels, as primary fuel, in the ordered newbuilding vessels does not facilitate further the adoption. LNG was considered a bridging fuel to decarbonise the sector decades ago, yet a few bunkering ports exist (SEA-LNG, 2023). The distribution network and the production capacity are enabling elements in the future adoption of green fuel. The construction of the EuroAsia Interconnector will further uptake the percentage of natural gas imported into Cyprus. Greece and Israel alone are responsible for 65% of all port calls on the island for the investigation period (see Figure 2). A specific case was proposed for scenario C2 where a liquid fuel provider continues to trade outside the EU but strategically chooses to import cargo from destinations of more than 300NM (EU ETS threshold). Since the additional traveling time increases the voyage costs (attributed to fuel costs and passage dues) the only viable options are Egypt and Turkey.

5.5. Additional transportation cost and the new unit cost

The algorithm used the selected fuel matrix (see Table 17) for each scenario to estimate the additional cost associated with the legislation. Figure 10 illustrates all the projected scenarios for the smallest liquid cargo carrying size classification. The results supported our hypothesis for scenario C2. The new Operating Expense (OPEX) of the extra small tankers is lower than the scenario where greener fuels are introduced to the fuel mix (B2) until 2030. Liquid carriers of other sizes present similar projections until 2030.

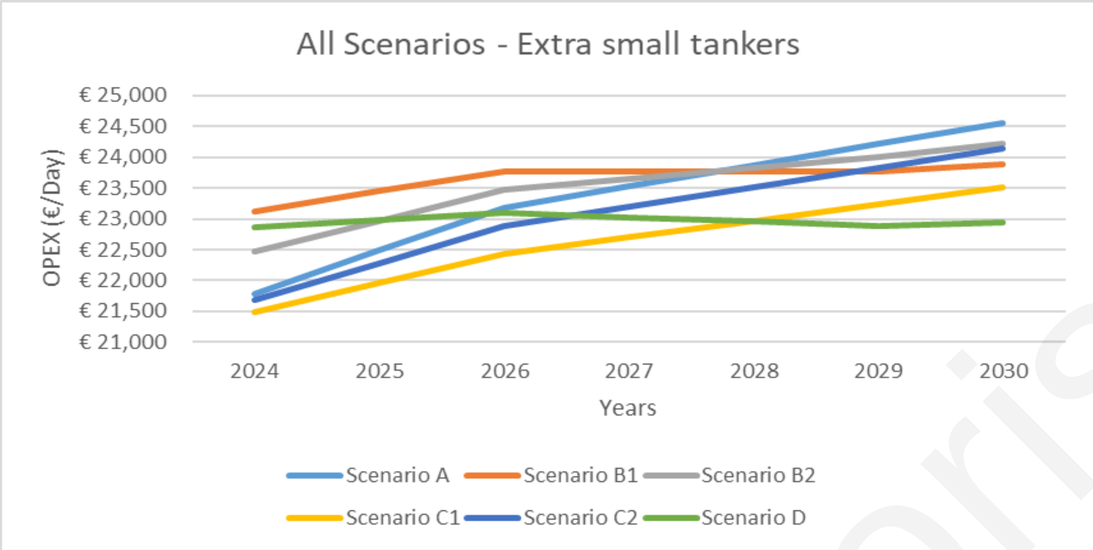

Figure 10: All scenarios for extra small tankers.

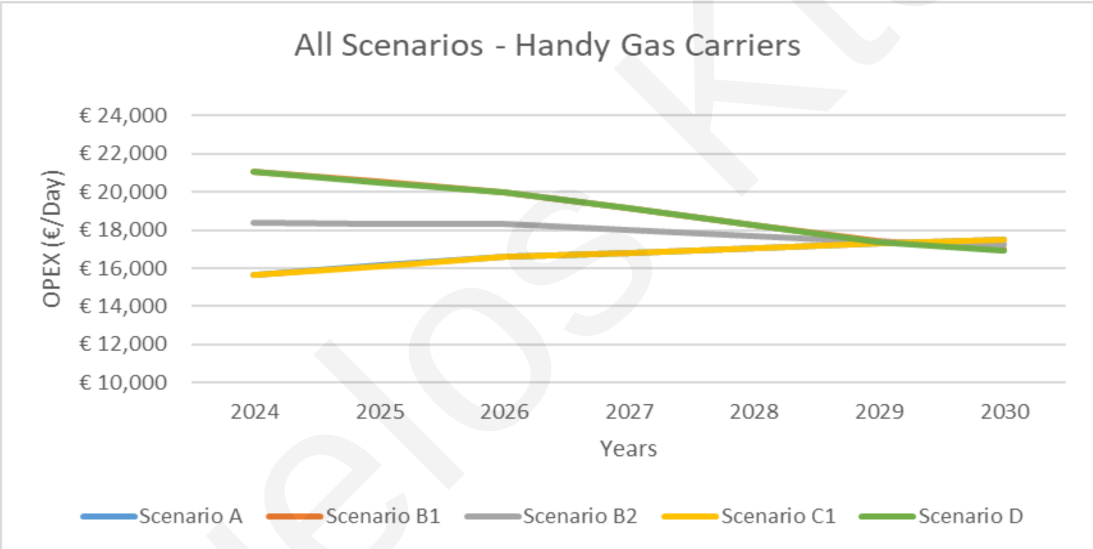

Figure 11: All scenarios for handy gas carriers.

Figure 11 presents the results for the LPG classification handy. Due to the trading destinations of the specific ship type, a potential exception to the EU ETS transit restriction from non-EU ports of less than 300NM will not affect the projections. Scenario B1 equals the best-case scenario D and scenario A is identical to scenario C1. Another observation is that for this specific type of ship, all scenarios intersect between 2029 to 2030. At that point in time, the selected mixture for all scenarios using the projected fuel prices appears to be identical.

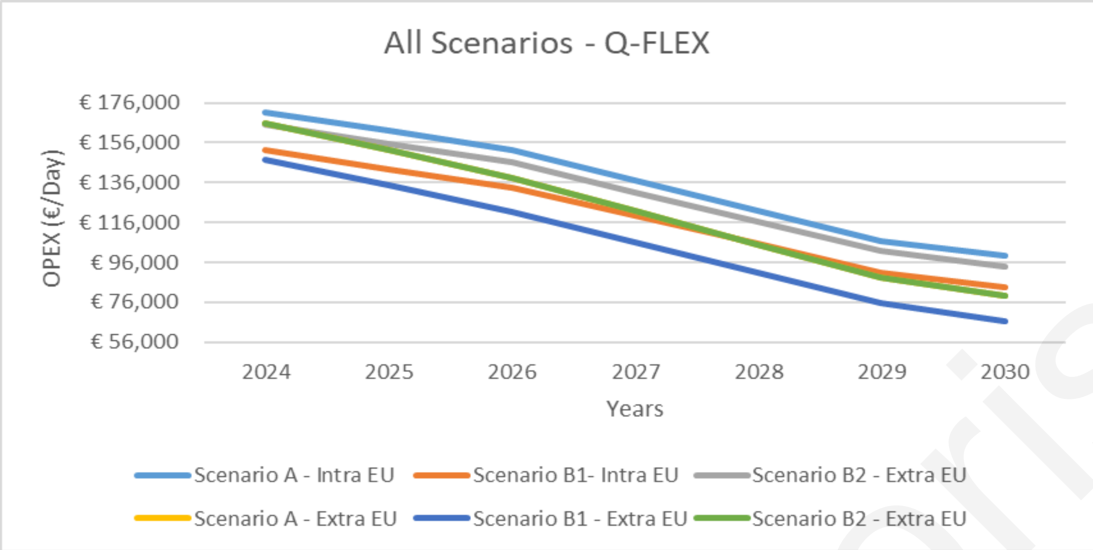

Figure 12: All scenarios for the LNG size Q-FLEX.

LNG carriers are associated with the price of natural gas if used as a primary fuel, since the contribution of a green fuel (biogas) does not alter the curve greatly. The projected low prices for 2030 will facilitate the penetration of the fuel to all investigated ship types and size classifications. No historical data on trading trends of this ship type made in Cyprus exist. The options for intra and extra-EU trade for each scenario were more appropriate. Similarly, like the case of the extra small tanker vessels, an extra-EU destination in a lower uptake of green fuels scenario (B2) is cheaper than an intra-EU with high uptake of green fuels (B1).

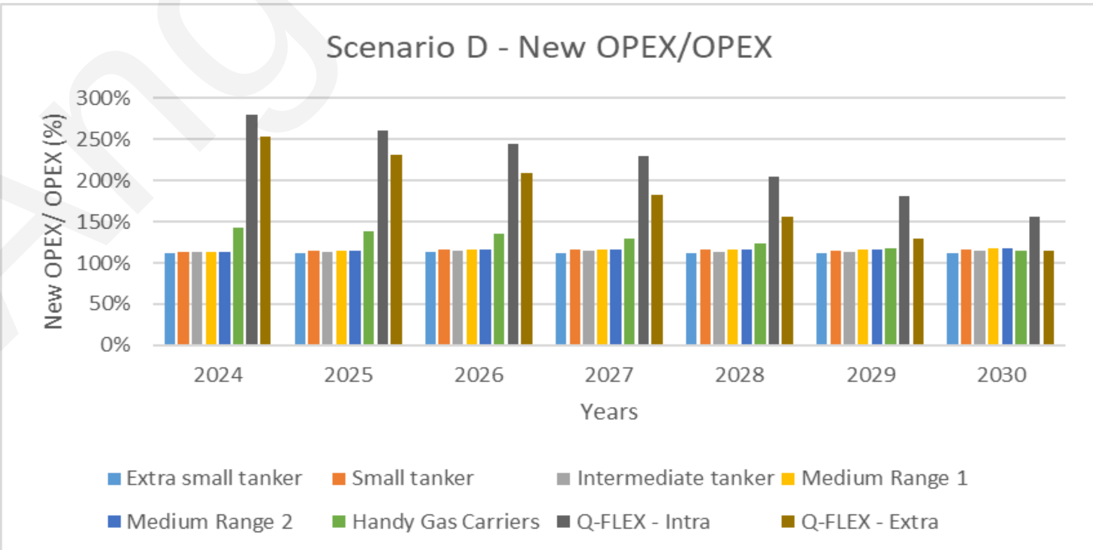

Figure 13: Best-case scenario for all vessels as percentage between the current and projected OPEX.

Figure 13 also shows the correlation between LNG as a bunkering fuel with its projected prices in 2030. In an extra-EU scenario for 2030, the Q-FLEX percentage between the current and projected OPEX appears to be the lowest. The selection of the importing destination of LNG will be based on market values. The methodology shows that destinations from non-EU nations will have an advantage.

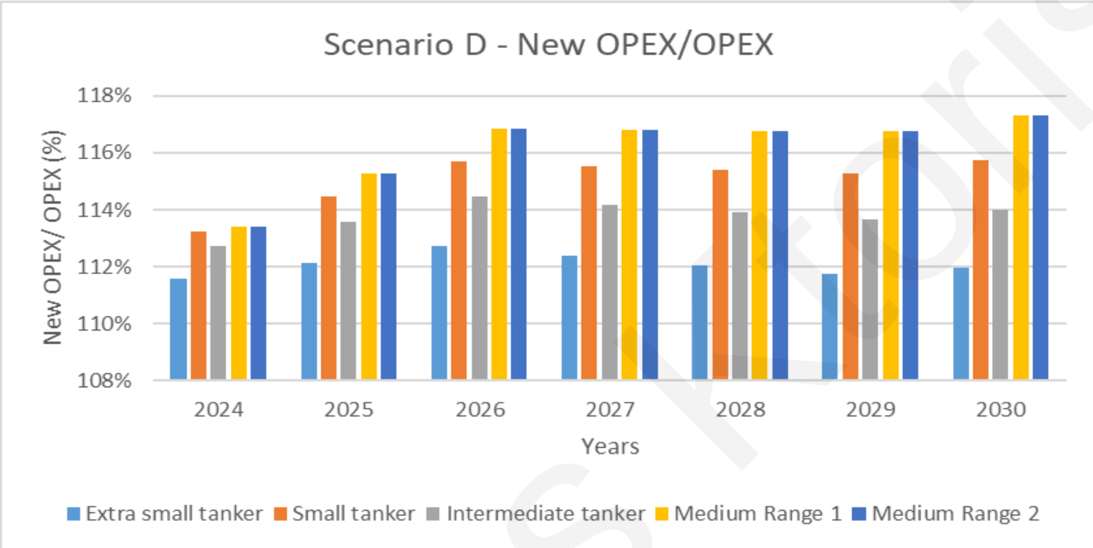

Figure 14: Best-case scenario for liquid cargo carriers.

Figure 14 depicts the best-case scenario for the liquid cargo carriers. The trading destinations for intermediate tankers place the percentage below small tankers for all years. Extra small tanker percentages are the least fluctuated due to the lower additional cost associated with their size/ energy demands/ energy consumption.

The advantage that the extra small tankers had over the other liquid carriers in the ratio between the new over initial OPEX is reversed in Figure 15 due to its small carrying capacity. The findings support the economies of scale model, with the larger vessels being able to absorb the additional cost added with the new legislative package as recently adopted.

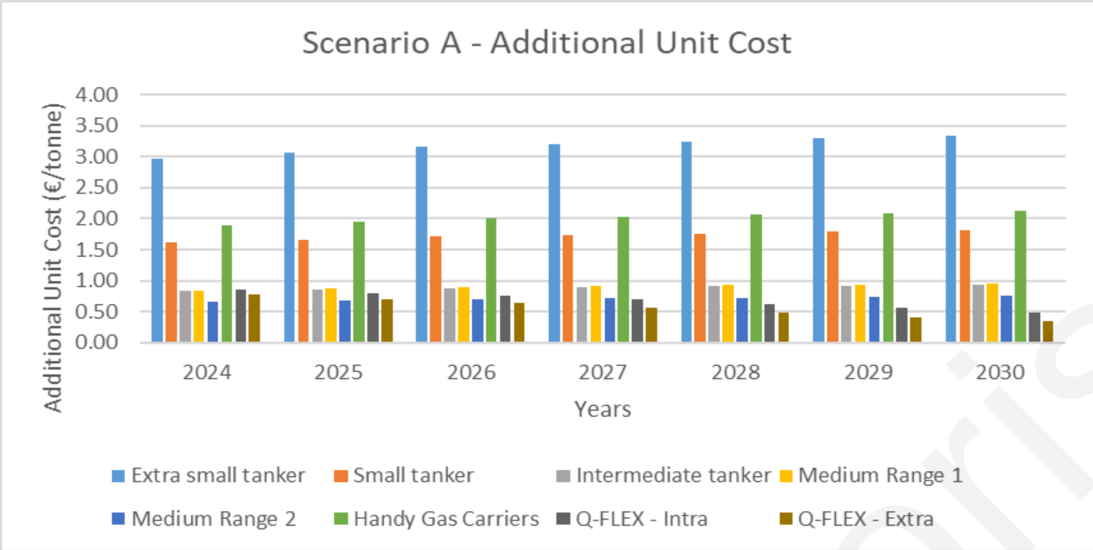

Figure 15: Business as Usual scenario for all vessels for the additional unit cost.

The same applies for scenario D as presented in Figure 16, with slightly lower unit cost values for 2030.

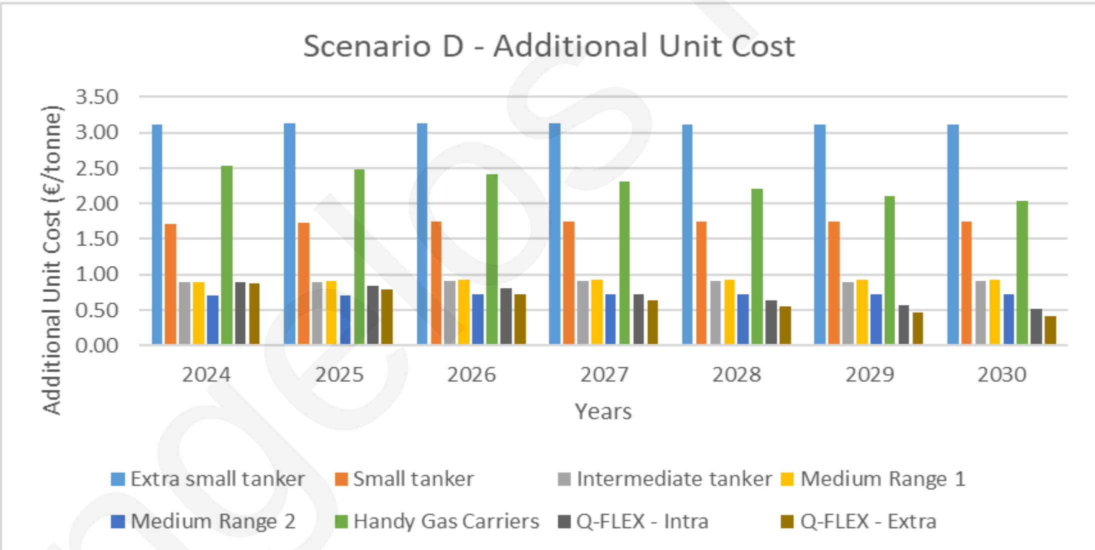

Figure 16: Best-case scenario for all vessels for the additional unit cost.

6. Conclusion

This thesis aimed to assess the impact of the additional cost arising from the adoption of the Fit for 55 legislative provisions, directives, and plans to the end user in Cyprus. The thesis involved the estimation of the new OPEX and new Unit Cost of four selected scenarios. The scenarios were formulated based on the characteristics of the island and the opinion of experts in the national maritime sector.

The MSF455 model has been enhanced by considering updated provisions of the very recent adopted legislation, additional fuels, ship types and size classifications, and the introduction of assessing the Unit Cost. The scenarios following the projected fuel matrix until 2030 included business as usual, additional uptake of LNG and biofuels (liquid and gaseous), exception and strategic reallocation of imported goods to manipulate the EU ETS provisions and best-case scenarios.

The thesis confirmed that the additional operating expenses of vessels carrying liquid and liquified cargo in Cyprus are expected to be significant, thus affecting the Unit Cost of the transported commodities used for road, shipping, aviation transportation, production of electricity, and heating.

To achieve the 2050 targets validation process and feasibility studies of alternative solutions must be exploited. Creating a greener future will come at a cost during the development phase and construction of the relevant infrastructure.

The uptake of LNG as a primary source of bunkering fuel for any type of vessel trading in Cyprus will always be vulnerable to global market price fluctuations. It seems that biofuels can be a way to meet the targets of 2030.

The methodology presented can be used to assess the impact of the legislative package on other Member States' economies, considering any possible scenario based on specific characteristics. For island nations like Cyprus and Malta, implementing the legislative framework is expected to have a greater impact than other less energy-based fossil fuel economies. In addition, an updated version could introduce an optimisation process between having less transferred cargo or paying the emission levy imposed by the legislation or by estimating the pricing policy of technologies minimising the emission footprint of the industry.

The model has limitations in estimating the new demand curve considering the additional unit cost of the transported cargo and how that shift will affect the supply curve in forming the updated equilibrium point. A macroeconomic model can be introduced to assess the effect on the GDP and other economic KPIs. These additions will further strengthen its usability.

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