Study on the Completion of an EU Framework on LNG-fuelled Ships and its Relevant Fuel Provision Infrastructure

Lot 3

Analysis of the LNG market development in the EU

CE Delft

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Abstract

This study analyses the development of the LNG market in the EU by providing a qualitative analysis of the most important drivers and barriers with respect to the use of LNG as a ship fuel; by quantitatively analysing the economic feasibility of the use of LNG in ten ports; and by developing scenarios for the uptake of LNG from 2020 to 2030.

The qualitative analysis shows that amongst the main drivers of demand for LNG are environmental regulations and the price difference between LNG and other fuels.
The main barriers are uncertainty about the availability of LNG in ports, about technical standards, and about the second hand-price of LNG ships.

The case studies show that in most cases LNG is an attractive option from the ship-owner perspective if the fuel price difference is larger than today, as is the case in many projections for 2020-2030. With a smaller price difference between LNG and petroleum fuels, most cost-benefit analyses have a negative outcome.

The future market scenarios indicate that there will be between 2,500 and 4,000 LNG ships in the EU, using 1-5 million tonnes of LNG in the year 2030.

Extrait

Cette étude est une analyse du développement du marché GNL dans l'UE avec une analyse qualitative des principaux facteurs stimulant et limitant l'utilisation de GNL comme carburant pour navires, avec une analyse quantitative de la faisabilité économique de l'utilisation de GNL dans dix ports et un développement de scénarios pour la consommation de GNL de 2020 à 2030.

L'analyse qualitative montre que les réglementations environnementales ainsi que la différence du prix entre GNL et les autres carburants sont les facteurs essentiels stimulant la demande de GNL.
Les principales barrières sont l'incertitude concernant la disponibilité de GNL dans les ports, les normes techniques et le prix d'occasion de navires GNL.

Les études de cas montrent que, dans la plupart des cas, GNL est une option attrayante du point de vue du propriétaire du navire si la différence entre le prix du carburant est supérieure à celle aujourd'hui, ce qui est le cas dans un grand nombre de projections pour 2020 - 2030. Si la différence de prix entre GNL et les carburants dérivés du pétrole est inférieure, la plupart des analyses prix-bénéfice produisent un résultat négatif.

Les scénarios du marché dans le futur indiquent la présence de 2500 à 4000 navires GNL dans l'UE qui consommeront 1−5 millions de tonnes de GNL en 2030.

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Contents

Glossary

CAPEX – Capital expenditures

CBA – Cost-Benefit analysis

ECA – Emission Control Area

EGR – Exhaust Gas Recirculation

HFO – Heavy Fuel Oil

IFO 180 / 380 – Intermediate Fuel Oil

LNG – Liquefied Natural Gas

MDO – Marine Diesel Oil

MGO – Marine Gas Oil

Mmbtu – Milion British Thermal Units

MTOE – Million Tonnes of Oil Equivalent

NO_x – Nitrogen Oxide

NPV – Net Present Value

OPEX – Operational Expenditures

PM – Particulate Matter

PSV – Platform Supply Vessel

PTS – Pipeline-to-Ship

SCR - Selective Catalytic Reduction

SECA – Sulphur Emission Control Area

SO_x – Sulphur Oxide

STS – Ship-to-Ship

TEN-T port – port part of the Trans-European Transport network

Tier I – NO_x emission limit for new diesel engines on ships from 2000 to 2011

Tier II – NO_x emission limit for new diesel engines on ships after 2011

Ton / tonnes – thousand kg

TTS – Tank truck-to-ship

Executive summary

A decrease in the use of petroleum fuels and increased use of LNG by European shipping could lessen the EU's dependence on oil imports from politically unstable regions and help reduce air pollutant emissions from maritime transport.
The Alternative Fuels Infrastructure Directive[1] adopted by the EU has, amongst its goals, creation of a network of LNG fuelling points in the main European ports in order to facilitate the shift to LNG. The Directive specifies that a decision on location of the LNG refuelling points at ports should be based on a cost-benefit analysis, including an examination of the environmental benefits.

This study provides an overview of the current LNG market and scenarios of its future development. The overview analyses the drivers and barriers with respect to the deployment of LNG as a bunker fuel. The scenarios are based, amongst other things, on a series of cost-benefit analyses of case studies of the use of LNG by specific ships in specific ports in a number of EU countries.

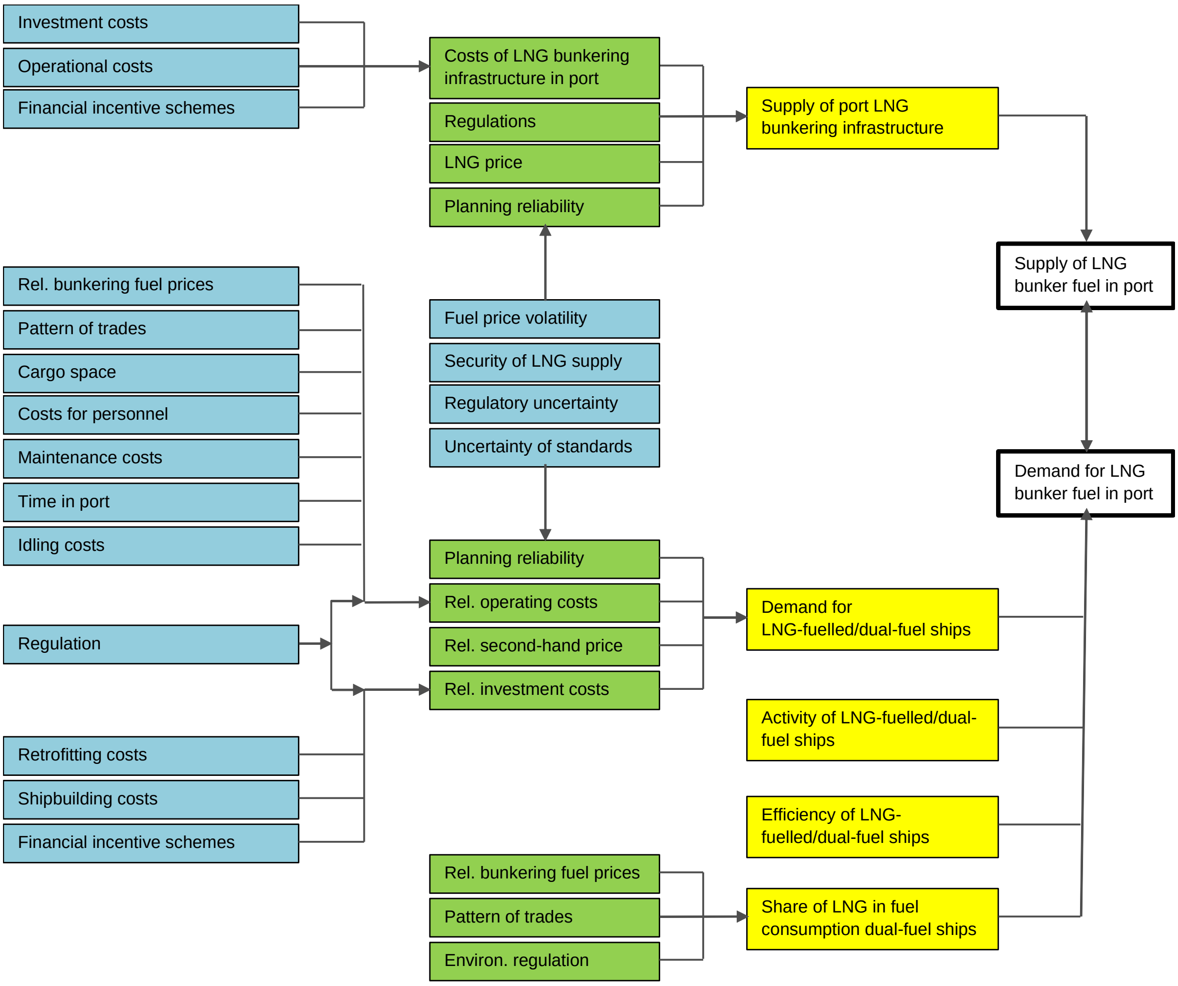
Overview of the LNG market, drivers and barriers

Currently, the volume of the LNG bunker fuel market is limited compared to the market for petroleum fuels. LNG is currently available as a bunker fuel for maritime shipping at seven EU sea ports and several Norwegian ports. In addition, several ports are preparing for LNG bunkering. According to Clarksons World Fleet Register, there were 215 LNG fuelled ships (of which 81 were not designed as LNG carriers) in the world fleet by the end of 2015. This number is expected to double in the next few years. As a reference, the world fleet comprises about 60,000 transport ships and 50,000 non-transport ships (service vessels, tugs, yachts, etcetera).

The supply and demand for LNG bunker fuel in ports depends on a number of factors, which are presented in a coherent way in Figure 1. Amongst the main drivers for LNG demand are environmental regulations, especially with regard to fuel sulphur content, and the price difference between LNG and other fuels. The main barriers are uncertainty about the availability of LNG in ports, about technical and safety standards, and about the second hand-price of LNG ships (which depends, amongst other factors, on the future availability and price of LNG as a bunkering fuel).

[1] EC, 2014a. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance, Brussels: European Commission.

Figure 1 Factors determining supply and demand for LNG bunker fuel in ports



End-user costs and benefits of using LNG

Compared with petroleum-fuelled vessels, LNG ships require additional investments in engines, tanks and piping. When sailing in Sulphur Emission Control Areas like the North Sea or the Baltic Sea, or when sailing to EU ports post-2020, LNG ships do not require additional investments in exhaust-gas cleaning systems as is the case for ships sailing on heavy fuel oil (HFO) (although not all LNG engines meet Tier III NO_x standards). Ships sailing on the more expensive marine gasoil or marine diesel also do not require these investments. Still, on balance, LNG ships require higher investments than conventional ships. Typically, the additional investments range from several million euros for general cargo coasters to several tens of millions of euros for cruise ships, or between 6 and 40% of the new build price.

The price of LNG is often lower than that of other marine fuels, although this depends on the bunkering option. In the absence of LNG bunkering price statistics, an LNG bunkering price has here been calculated by adding the costs of bunkering to the LNG import price.

There are three ways to supply a ship with LNG:

- tank truck-to-ship, which typically adds 40-45% to the import price of LNG;
- pipeline-to-ship, which has a wide range of costs, depending on whether a storage tank needs to be built: 6-380% in the cases we studied;
- ship-to-ship, which, depending on the size of the bunkering vessel, adds 6-16% to the import price of LNG.

LNG delivered by truck is often more expensive than HFO, but less expensive than distillate fuels, whereas LNG delivered by a bunker ship is often less expensive than either HFO or distillates.

The total cost of ownership of LNG coastal ships is lower than that of HFO-fuelled ships with a scrubber if LNG costs around 20% less than HFO per unit of energy. LNG ships are more cost-effective than MGO ships in most cases when fuel costs are the same per unit of energy. These are just crude estimates, and the results depend on the cost of capital, vessel design and type, and scrubber cost.

Case studies of LNG bunkering

For this study, several LNG bunkering case studies were developed in 10 EU ports, considering 5 ship types and from 1 to 3 bunkering options per port. A total of 56 cases were developed, covering a wide range of possible bunkering options. For all cases, a cost-benefit analysis has been carried out.

The cases are based on information provided by ports, fuel suppliers and ship operators. The ports were located in different sea regions (Baltic, North Sea, Mediterranean and Black Sea) and the ship types and sizes were typical for coastal ships at the ports concerned. The bunkering options assumed a full or partial shift to LNG bunkering. Table 1 presents the cases.

Table 1 Selection of cases

	Northern and Western Europe ECA	Southern and Eastern Europe
Car and passenger ferries	**Stockholm (SE),** Dover (UK)	**Civitavecchia (IT)**
Platform supply vessels	**Kristiansand**	
Cruise	Southampton (UK)	**Civitavecchia (IT)**, Marseilles-Fos (FR)
Container vessels	**Antwerp (BE)**	Marseilles-Fos (FR), Constanza
General cargo/bulk	HaminaKotka (FI)	**Cartagena**

Five of the selected ports (in bold in the table) have experience with LNG bunkering; four ports have had at least one bunkering operation with tank trucks, and one (Stockholm) has a LNG bunkering vessel in operation. Most ports have developed plans for expansion of bunkering options or are planning feasibility studies.

Costs and benefits of cases (CBAs)

The cost-benefit analysis shows that in many cases, LNG coastal ships are more cost-effective than HFO-fuelled ships with a scrubber when fuel suppliers have invested in the best bunkering option (this is true in 9 of the 12 cases analysed). These results assume a weighted average cost of capital of 10%, an LNG import price and fuel prices in line with the World Bank long-term forecast, and a write-down of the additional investment in 10 years. If a lower interest rate is used (4%) or if the LNG import price is 25% lower relative to HFO, all cases have positive returns. On the other hand, if LNG import prices are 25% higher than projected by the World Bank, all cases are negative.

If smaller scale bunkering ships are used, the CBAs remain positive but the pay-back time increases by about a year. If LNG were supplied by tank trucks, an LNG ship would not be an attractive option compared with an HFO-fuelled ship with a scrubber. Compared with an MGO-fuelled ship, all CBAs have positive net present values with pay-back times ranging from 5 to 8 years, even when fuel is supplied by tank trucks.

Future development of the LNG bunkering market

This study has developed three scenarios based on drivers (economic growth, transport demand, LNG import prices, bunkering options), and barriers (uncertainty of standards, uncertainty of second hand-prices) with respect to LNG bunker fuel supply and demand. The scenarios all assumed that uncertainty about LNG supply in EU ports would be solved. Moreover, it was assumed that by 2020 all ships sailing to EU ports will comply with the EU Marine Fuels Sulphur Directive. Quantification of the scenarios was achieved using a model developed for this purpose, using existing data on the number of ships, fuel use and transport demand projections.

Table 2 shows the relevant assumptions and inputs for the three scenarios, as well as the results for number of LNG ships and LNG bunker demand. Note that the current fuel prices (September 2015) reflect the assumptions in the low scenario.

Table 2 LNG Bunkering Market Scenarios

	Maximum scenario	Medium scenario	Low scenario
Economic growth	High	Medium	Low
Transport demand growth Fleet growth	1.55% p.a.	1.40% p.a.	0.95% p.a.
LNG import price relative to HFO and MGO	25% below base case	Base case	25% above base case
Preferred LNG bunkering option	Large-scale supply vessels in most TEN-T core ports	Medium-scale supply vessels in most TEN-T core ports	Medium-scale supply vessels in specific ports
Uncertainty about technical and safety standards	Low (full harmonization)	Low (full harmonization)	Medium (partial harmonization)
Uncertainty about second hand-price of LNG ships	Low (implementation of global low Sulphur requirements by 2020; LNG ships in other ECAs)	Medium (implementation of global low Sulphur requirements by 2020)	High (implementation of global low Sulphur requirements by 2025; LNG ships in other ECAs)
Uncertainty about technology	Low	Medium	High
Ship types for which LNG is an attractive option	Ships on intra-EU voyages	Ships on intra-EU voyages	Vessels that sail on specific routes, e.g. ferries, platform supply vessels
Number of LNG ships (2030)	3,200-5,500	370–2,600	120-500
LNG Bunker Demand (Million tonnes, 2030)	3.7–6.3	0.4 -2.8	0.25–1
Related NO_x emission reduction (t)	3,000-5,100	350-2,300	200-800
Related SO_x emission reduction (t)	4.2-7.2	0.5-3.2	0.3-1.2
Related PM emission reduction (t)	3.4-5.9	0.4-2.6	0.2-0.9

Synthèse du rapport

Une diminution de l'utilisation de carburants dérivés du pétrole et l'utilisation accrue de GNL par le transport maritime en Europe pourrait réduire la dépendance de l'UE de l'importation du pétrole des régions politiquement instables et contribuer à réduire les émissions polluant l'air provenant du transport maritime.
La directive sur l'infrastructure de carburants alternatifs[2] adoptée par l'UE vise, entre autres, la création d'un réseau de points de ravitaillement dans les grands ports européens afin de faciliter la transition vers le GNL. La directive spécifie qu'une décision basée sur l'emplacement des points de ravitaillement GNL dans les ports doit être basée sur une analyse coût-bénéfice, y compris une étude des bénéfices pour l'environnement.

Cette étude offre une synthèse du marché GNL actuel avec des scénarios de son développement futur. La synthèse analyse les pilotes et barrières par rapport au déploiement de GNL comme combustible de soute. Ces scénarios sont basés, entre autres, sur une série d'analyses de coût-bénéfice de différentes études de cas sur l'utilisation de GNL par des navires spécifiques dans un nombre de pays de l'UE.

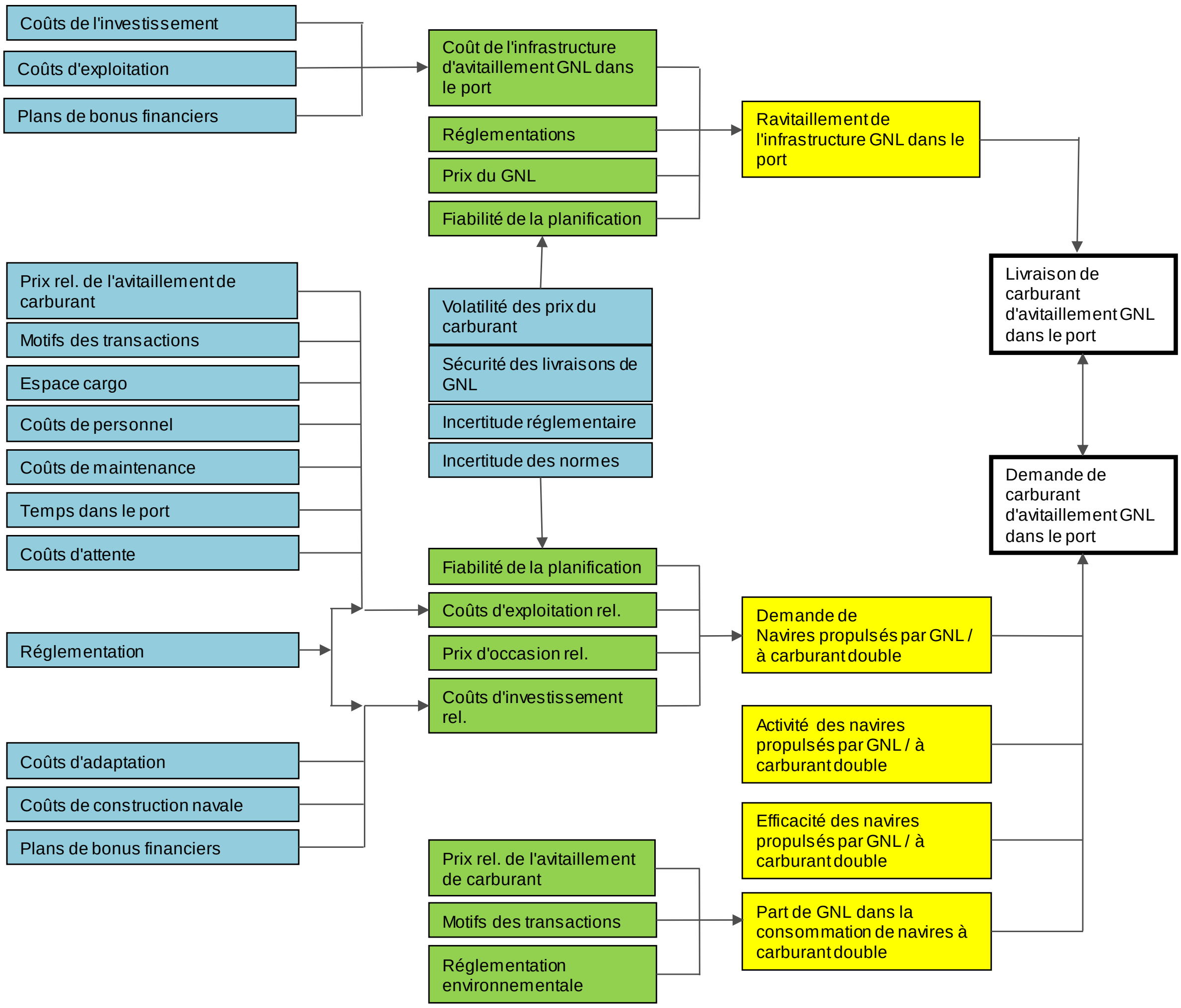
Vue d'ensemble du marché GNL, pilotes et barrières

Actuellement, le volume du marché de combustible de soute GNL est limité en comparaison avec le marché des carburants dérivés du pétrole En ce moment, GNL est disponible comme un combustible de soute pour les transports maritimes dans sept ports de mer de l'UE et plusieurs ports norvégiens. Fin 2015, Selon Clarksons World Fleet Register, il y avait 215 navires à GNL (dont 81 n'étaient pas construit comme transporteurs de GNL). Ce nombre devrait doubler dans les années à venir. Comme référence, les flottes mondiales comptent quelque 60 000 navires de transport et 50 000 bateaux qui ne sont pas destinés au transport (vaisseaux de service, remorqueurs, yachts, etc.).

Offre et demande pour un combustible de soute GNL dans les ports dépendent d'un nombre de facteurs, présentés de manière cohérente dans Figure 1. Parmi les principaux facteurs stimulant la demande du GNL, nous pouvons citer les réglementations environnementales, en particulier en ce qui concerne la teneur en soufre, ainsi que la différence des prix entre GNL et d'autres carburants. Les principales barrières sont l'incertitude concernant la disponibilité de GNL dans les ports, les normes techniques et de sécurité et le prix d'occasion de navires GNL (qui dépend, entre autres, de la future disponibilité et du prix de GNL comme combustible de soute).

[2] CE Delft, 2014a. *Directive 2014/94/UE du Parlement européen et du Conseil du 22 octobre 2014 concernant le déploiement de l'infrastructure de carburants alternatifs Texte présentant de l'intérêt pour l'EEE,* Bruxelles : Commission Européenne.

Figure 2 Facteurs déterminant offre et demande de GNL comme combustible de soute dans les ports



Coûts survenant pour l'utilisateur final et avantages de l'utilisation de GNL.

En comparaison avec les navires à pétrole, les bateaux à GNL demandent des investissements supplémentaires en matière de machines, réservoirs et tuyauterie. Pour la navigation dans des zones à contrôle d'émission de soufre comme la Mer du Nord ou la Mer Baltique, ou dans les ports de l'UE après 2020, les navires GNL n'auront pas besoin d'investissements supplémentaires en systèmes d'épuration des gaz d'échappement comme c'est le cas pour les navires propulsés par le pétrole lourd (cependant, il y a des moteurs GNL qui ne remplissent pas les normes NO_x niveau III). Les navires qui fonctionnent avec le gazole ou diesel marin plus cher ne remplissent pas non plus ces exigences. Il est vrai que, globalement, les navires GNL demandent des investissements plus importants que les navires conventionnels. Les investissements requis vont typiquement de plusieurs millions d'EUR pour les navires côtiers à des dizaines de millions d'EUR pour les croisières et se situent entre 6% et 40% du prix d'un navire neuf.

Le prix du GNL est souvent inférieur à celui des autres carburants marins, mais il dépend de l'option de l'avitaillement. Sans les statistiques disponibles pour les prix d'avitaillement de GNL, le prix d'avitaillement a été calculé ici par addition du prix d'avitaillement au prix d'importation de GNL.

Il existe trois méthodes de ravitailler un navire en GNL:

- camion-citerne > navire, où typiquement 40-45% du prix d'importation de GNL est ajouté ;
- gazoduc > navire, avec une grande fourchette de coûts, dépendant de la question si un réservoir de stockage doit être acheté : 6-380% des cas étudiés ;
- navire > navire ce qui ajoutera, selon la taille du navire d'avitaillement 6-10% au prix d'importation de GNL.

GNL livré par camion est souvent plus cher que le pétrole lourd mais moins cher que les carburants distillés, alors que GNL fourni par un navire d'avitaillement est souvent moins cher que le pétrole lourd ou les produits distillés.

Le coût de propriété total des navires côtiers GNL est inférieur à celui de navires propulsés par pétrole lourd avec un épurateur de gaz si le GNL coûte environ 20% en moins de que le pétrole par unité énergétique. Les navires GNL sont souvent plus avantageux que les navires MGO, si le coût du carburant est égal par unité énergétique. Ce sont quelques estimations globales seulement, le résultat dépendra du coût du capital, de la conception et du type de navire ainsi que du coût d'épuration.

Études de cas d'avitaillement GNL

Pour cette étude, plusieurs études de cas GNL ont été développées dans 10 ports de l'UE, sur 5 types de navires et avec 1 à 3 options d'avitaillement par port. Au total, 56 cas ont été développés couvrant une vaste gamme d'options d'avitaillement. Pour tous les cas, une analyse coût-bénéfice a été menée.

Les cas sont basés sur des informations fournies par les ports, fournisseurs de carburant et exploitants de navires. Les ports sont localisés dans différentes régions maritimes (Mer Baltique, Mer du Nord, Mer Méditerranée et Mer Noire), et les types et tailles de navire étaient typiques pour les vaisseaux côtiers dans les ports en question. Les options d'avitaillement partaient de l'hypothèse d'une transformation complète ou partielle vers l'avitaillement GNL. Table 1 présente les cas.

Tableaux 3 Sélection des cas

	Europe du Nord et de l'Ouest ECA	Europe du Sud et de l'Est
Transbordeurs de véhicules et passagers	**Stockholm (SE),** Dover (UK)	**Civitavecchia (IT)**
Vaisseaux de ravitaillement de plateforme	**Kristiansand**	
Croisière	Southampton (UK)	**Civitavecchia (IT)**, Marseille-Fos (FR)
Porte-conteneurs	**Anvers (BE)**	Marseille-Fos (FR), Constantza
Cargo/matières en vrac	HaminaKotka (FI)	**Carthagène**

Cinq des ports sélectionnés (en gras dans le tableau) ont de l'expérience avec l'avitaillement GNL ; quatre ports avaient au moins une activité d'avitaillement avec des camions citernes, et dans un port (Stockholm), un navire d'avitaillement de GNL est actif. La plupart des ports ont développé des plans d'expansion des options d'avitaillement, ou ils sont en train de mener des études de faisabilité.

Coûts et bénéfices des cas

L'analyse des coûts et bénéfices montre que souvent, des navires côtiers GNL sont plus économiques que les vaisseaux à pétrole lourd avec épurateur si les fournisseurs de carburant ont investi dans la meilleure option d'avitaillement (c'est le cas pour 9 des 12 possibilités examinées). Ces résultats présupposent un coût du capital moyen pondéré de 10%, un prix d'importation de GNL et des prix du carburant qui correspondent aux prévisions à long terme de la Banque Mondiale et une dépréciation de l'investissement supplémentaire de 10 ans. En appliquant un taux d'intérêt plus bas (4%) ou si le prix d'importation GNL est inférieur de 25% au pétrole lourd, le rendement est positif pour tous les cas. D'autre part, si le prix d'importation de GNL est supérieur de 25% aux prix projetés par la Banque Mondiale, le résultat sera négatif pour tous les cas.

Si des navires d'avitaillement de taille inférieure sont utilisés, le résultat sera toujours positif, mais la durée de retour sur l'investissement s'accroîtra d'environ un an. Si le GNL est fourni par des camions citernes, un navire GNL ne sera pas une option intéressante en comparaison avec un navire é pétrole lourd et équipé d'un épurateur. Par rapport aux vaisseaux à carburant MFO, toutes les analyses coûts-bénéfices ont un résultat net positif avec un délai de retour sur l'investissement de 5 à 8 ans, même si le carburant est fourni en camion-citerne.

Développement futur du marché d'avitaillement GNL

Cette étude a développé trois scénarios basés sur les facteurs stimulant la demande (croissance économique, demande de transport, prix d'importation de GNL, options d'avitaillement) et la limitant (incertitude des normes, incertitude des prix d'occasion) par rapport à l'offre et la demande de carburant d'avitaillement GNL. Tous ces scénarios sont basés sur l'hypothèse que l'incertitude relative à la livraison de GNL dans les ports de l'UE sera résolue. De plus, ils se basent sur la présupposition qu'en 2020, tous les navires naviguant dans les ports de l'UE seront conformes à la directive de l'UE sur le soufre dans les carburants marins. La quantification des scénarios était obtenue à l'aide d'un modèle mis au point dans ce but, appliquant les données existantes au nombre de bateaux, à la consommation de carburant et la demande de transport projetée.

Le tableau 2 montre les hypothèses et informations pertinentes pour les trois scénarios, ainsi que les résultats du nombre de navires GNL et de la demande d'avitaillement GNL. Les prix de carburant actuels (septembre 2015) correspondent aux suppositions du scénario suivant.

Tableau 4 Scénarios du marché d'avitaillement en GNL

	Scénario maximum	Scénario moyen	Scénario bas
Croissance économique	Forte	Moyenne	Faible
Croissance de la demande de transports Croissance de la flotte	1.55% p.a.	1.40% p.a.	0.95% p.a.
Prix d'importation de GNL en comparaison avec le pétrole lourd et MGO	25% sous la référence	Référence	25% au-dessus de la référence
Option d'avitaillement GNL préférée	Vaisseaux d'avitaillement grande échelle dans les ports importants TEN-T	Vaisseaux d'avitaillement moyenne échelle dans les ports importants TEN-T	Vaisseaux d'avitaillement moyenne échelle dans les ports spécifiques
Incertitude relative aux normes techniques et de sécurité	Faible (harmonisation complète)	Faible (harmonisation complète)	Moyenne (harmonisation partielle
Incertitude concernant le prix d'occasion des navires GNL	Faible (implémentation des exigences globales sur la faible teneur en soufre jusqu'en 2020 ; navires GNL dans d'autres ECA)	Moyenne (implémentation des exigences globales sur la faible teneur en soufre jusqu'en 2020)	Élevée (implémentation des exigences globales sur la faible teneur en soufre jusqu'en 2025 ; navires GNL dans d'autres ECA)
Incertitude relative à la technologie	Faible	Moyenne	Élevée
Types de navires susceptibles de profiter du GNL	Navires de voyages au sein de l'UE	Navires de voyages au sein de l'UE	Vaisseaux sur des routes spécifiques, comme des transbordeurs, vaisseaux d'alimentation de plates-formes.

	Scénario maximum	Scénario moyen	Scénario bas
Nombre de navires GNL (2030)	3 200-5 500	370-2 600	120-500
Demande d'avitaillement GNL (millions de tonnes, 2030)	3,7-6,3	0.4 -2.8	0,25-1
Réduction des émissions NO_x associées (t)	3 000-5 100	350-2 300	200-800
Réduction des émissions SO_x associées (t)	4,2-7,2	0,5-3,2	0,3-1,2
Réduction des émissions PM associées (t)	3,4-5,9	0,4-2,6	0,2-0,9

1. Introduction

1.1. Background to the study

The European Commission's communication "Clean Power for Transport: A European alternative fuels strategy" (EC, 2013b) identifies LNG and biofuels as fuels that could reduce oil dependence of Europe's maritime transport and contribute to a reduction of greenhouse gas and air pollutant emissions. A reduction of the fuel dependence is a means to lessen the EU's dependence on politically unstable regions and lower the expenditures on imports. Decreasing air pollutant emissions is important in the context of, amongst others, the Marine Fuels Sulphur Directive (EC, 2012)[3], which sets limits for SO_x emissions of vessels on the North Sea and the Baltic Sea (which are Sulphur Emission Control Areas), that can be met, amongst others, by using LNG.

The Alternative Fuels Infrastructure Directive (EC, 2014a) requires that a core network of refuelling points for LNG is available in TEN-T ports by the end of 2025. (Refuelling points for LNG include, inter alia, LNG terminals, tanks, mobile containers, bunker vessels and barges). The Directive specifies that a decision on the location of the LNG refuelling points at ports should be based on a cost-benefit analysis including an examination of the environmental benefits. In order to facilitate the establishment of a refuelling network, Regulation (EU) No 1315/2013 (EC, 2013a) ensures that infrastructure, e.g. LNG terminals, are eligible for funding from the Connecting Europe Facility (CEF).

Because of the importance of providing LNG bunkering infrastructure to maritime vessels, the Commission has initiated a study on the Completion of an EU Framework on LNG-fuelled Ships and its Relevant Fuel Provision Infrastructure. This report, which is Lot 3 out of a total of four Lots under this study, is called "Analysis of the LNG market development in the EU".

1.2. Aim of the study

The specific objective of this study is to provide a market overview and estimations on LNG, and to assess the hindrances that prevent a quick, gradual deployment of LNG as a bunker fuel.

To that end, the study first provides an analysis of the LNG bunkering fuel market, taking into account factors like LNG supply and demand in Europe and worldwide, the LNG bunkering infrastructure, the number of ships that are either LNG-fuelled or LNG-ready, and the availability of low sulphur fuels.

Second, the study analyses the cost-structure of LNG-fuelled ships and compares it with LNG-ready ships, with ships running on low sulphur fuel where required and with those where a scrubber has been the option for compliance with air emissions' regulations.

[3] EC, 2012. Directive 2012/33/EU of the European Parliament and of the Council of 21 November 2012 amending Council Directive 1999/32/EC as regards the sulphur content of marine fuels, Brussels: European Commission.

Third, it identifies trends in the supply chain management of LNG bunkering, the challenges the various options pose to the transport system and the economic, environmental and social impacts. It performs a number of generic cost-benefit analyses for different scenarios and develops general advice and information to industry stakeholders based on these analyses.

1.3. Methodology and sources

The study comprises five tasks:

- provide an overview of the LNG bunkering fuel market (LNG supply and demand, and resulting prices), both globally and in the EU;
- provide information about the price-structure of LNG for the end-user of the ship, being the owner or the charterer of the ship, and about the cost-structure of LNG-fuelled ships;
- develop case studies of LNG bunkering;
- carry out a generic cost-benefit analyses for each of the cases;
- provide an outlook of the future development of LNG bunkering in the EU, based on the results of the other tasks.

The tasks are interconnected, as shown in Figure 3.

Figure 3 Tasks in the study

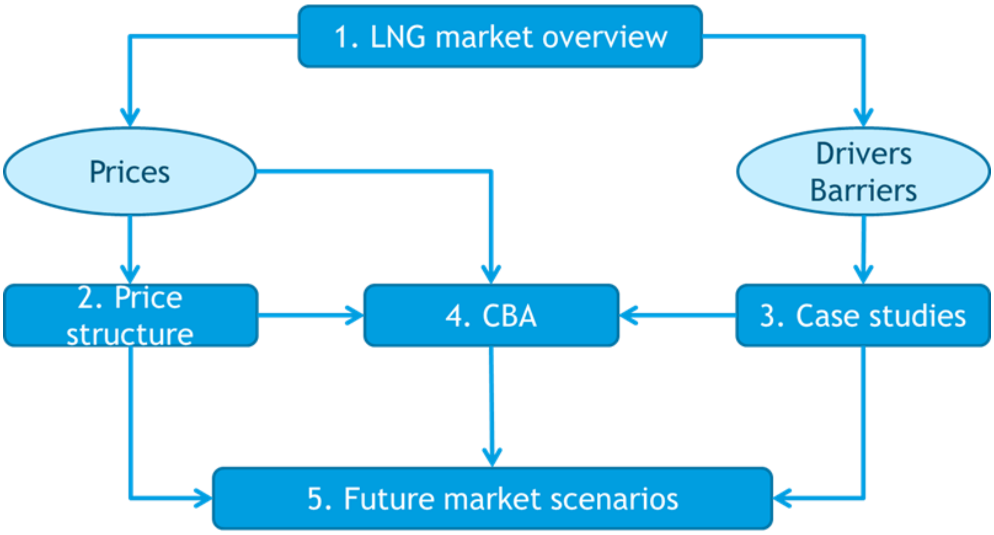


Table 5 shows the main aim and methods for each of the tasks, and how the outputs provide inputs for other tasks.

Table 5 Description of tasks

Task	Main aim and approach	Main outputs	Provides inputs for
Task 1: LNG bunkering market	Provide an overview of the current end future LNG bunkering market, building on a literature review and stakeholder consultation.	LNG price projections Model of the LNG bunkering market.	Task 2, 3 and 5
Task 2: Price structure	Analyse the price structure of LNG and LNG ships for shipping companies and charterers, building on a literature review and stakeholder consultation.	Price structure of LNG as a function of location and bunkering method. Cost-structure of an LNG ship compared to alternative ships.	Task 4 and 5
Task 3: Develop case studies	Identify trends in LNG storage, bunkering, handling, distribution and supply chain management at EU and global level, based on a literature review and interviews with stakeholders.	Cases for the cost-benefit analysis addressing different ports, ship types and bunkering/refueling option.	Task 4 and 5
Task 4: Generic cost-benefit analyses	Carry out a number of generic cost-benefit analyses for several cases of LNG as a bunker fuel.	Generic cost-benefit analyses addressing different ship types, different forms of LNG refuelling points and different local/regional conditions on different sea basins. General advice and information to shipping industry's stakeholders.	Task 5
Task 5: Outlook of the future development of LNG bunkering in the EU	Using the market model developed in Task 1, analyse how regulatory and economic factors will affect the quantities of LNG bunkered.	Final report.	Final report

The main methods and sources for this study are summarised in Table 6.

Table 6 Main methods and sources used in this study

Task	Main methods	Sources
Task 1: LNG bunkering market	Literature review. Stakeholder consultation.	Literature on natural gas price projections; on LNG market projections; and on shipping LNG market projections. Interviews with LNG providers, bunker fuel providers, and energy companies.
Task 2: Price structure	Literature review. Stakeholder consultation.	Task 1 results. Studies on the cost-structure of LNG as a marine fuel and LNG-fuelled ships. Interviews with shipping companies, equipment manufacturers, yards, LNG providers, bunker fuel providers, and energy companies.
Task 3: Develop case studies	Stakeholder consultation.	Task 1 results. Interviews with port authorities, shipping companies and other relevant stakeholders.
Task 4: Generic cost-benefit analyses	Cost-benefit analysis.	Task 1, 2 and 3 results. Literature on external effects of shipping and external costs of emissions. Interviews with port authorities, shipping companies, equipment manufacturers, yards, LNG providers, bunker fuel providers, and energy companies.
Task 5: Outlook of the future development of LNG bunkering in the EU	Scenario analysis.	Task 1, 2, 3 and 4 results.

A list of stakeholders contacted is provided in Table 7, Table 8 and Table 7.

Table 7 Stakeholders contacted – Ports

Port	Contact person
Port of Stockholm	Mr. Ola Oslin Head of Energy Ports
Port of Civitavecchia	Mr. Calogero Giuseppe Burgio Environmental & Technological Development division, Director
Port of HaminaKotka	Captain Markku Koskinen Traffic Operations Director
Port of Cartagena	Mr. Jose Maria Gomez Fuster Head of Planning
Port of Antwerp	Ms. Tessa Major Technical Manager Environment
Port of Dover	Mr. Richard Christian Corporate Affairs Manager
Port of Marseille	Captain Radu Spataru Department Head - Eastern Harbours - Harbour Master's Office
Port of Kristiansand	Mr. Thomas Granfeldt Chief Operations Officer
Port of Southampton	Mr. Clive Thomas Port Manager
Port of Constanta	Mr. Ambroziu Duma Port Operations, Safety and Security Director

Table 8 Stakeholders contacted – Vessels

Vessel type	Contact person
Car and passenger ferries	Mr. Kari Granberg Project Manager Viking Line
Cruise	Mr. Tom Strang Senior Vice President Marine Operations Costa Crociere
Container vessels	Mr. Jacobus Varossieau Operations Manager Nordic Hamburg
General cargo/bulk	Mr. Vidar Eidsvaag Operations Manager Eidesvaag Anonymous shipping company

Table 9 Stakeholders contacted – Others

Factsheet	Source description
Energy Companies	**Anonymous LNG bunker fuel supplier**
Equipment manufacturers	Anonymous LNG engine manufacturer
Financial Institutions	European Investment Bank, François Gaudet
European Sustainable Shipping Forum LNG subgroup[4]	Presentation at two meetings

4 More info on: http://ec.europa.eu/transport/themes/sustainable/news/2013-09-25-essf-call-for-applications_en.htm

1.4. Outline of this report

Chapter 2 analyses the driving factors for LNG bunkering prices and develops a model for the LNG bunkering market that includes drivers and barriers to the further development of the market. Annex A provides more details on the literature on which this chapter is based. The cost-structure of LNG-fuelled ships is presented in Chapter 3. Chapter 4 presents case studies and scenarios of LNG bunkering in ten TEN-T ports throughout the EU. Details on specific ports and ship types are included in Annex B and Annex C, respectively. Analyses of the costs and benefits of using LNG, both from a ship owner perspective and from a social perspective, are in Chapter 5. Furthermore the chapter presents an outlook of the future development of LNG bunkering in the EU, based on the results of the CBA. Chapter 7 provides the main conclusions of the study.

2. The LNG bunkering market

2.1. Introduction

This Chapter provides an overview on the current and future EU LNG market and EU LNG bunkering market.

Section 2.2 focuses on the total EU LNG market. Firstly, the EU LNG relation to the wider EU LNG market is described. Since the LNG bunkering price is determined to a large degree by the LNG import price, the factors that determine the LNG import price are discussed and, where possible, quantified. Finally, historical and current LNG import prices and LNG import price projections are presented.

Section 2.3 focusses specifically on the EU LNG maritime bunkering market. The current EU LNG maritime bunkering market is described, the drivers and barriers in the LNG bunkering market analysed, and an outlook is provided of how the EU LNG bunkering market can be expected to develop in the future. Subsequently, historical and current bunker fuel prices, bunker fuel price projections, and the bunker fuel prices that will be used in the cost-benefit analyses in Chapter 5 are presented.

2.2. The natural gas and the LNG market

In principle, natural gas can be transported over long distances in two ways, either via pipeline or, after being liquefied, by means of LNG carriers. If transported as LNG by means of an LNG carrier, LNG can be regasified in the importing country and can be used by the conventional natural gas consumers which are power plants, industrial consumers, and households. In Figure 4 the supply chains for small and large-scale LNG consumers are illustrated. Here the conventional natural gas consumers are depicted at the bottom right.

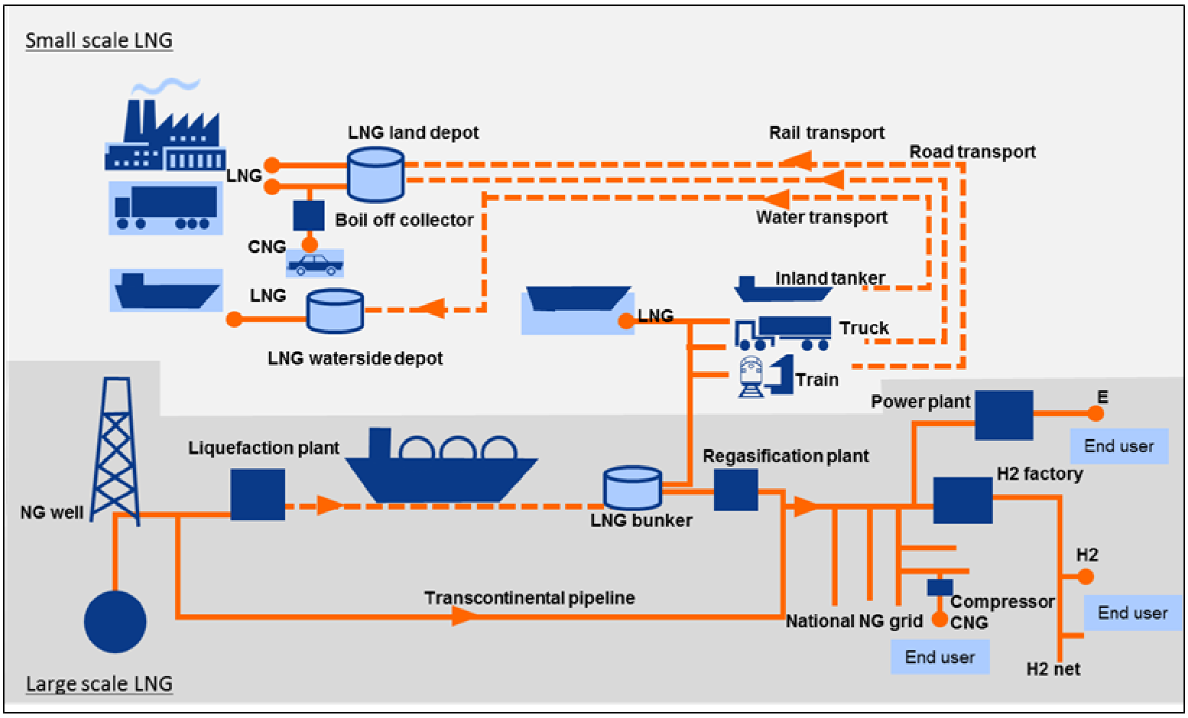
In addition, there are small-scale consumers in the industry and the transport sector using LNG that is not regasified (see top left of Figure 4). In the transport sector, the potential LNG consumers are heavy duty road vehicles, inland navigation vessels, and seagoing vessels.

The LNG bunker market for seagoing vessels in the EU is the focal point of this study. Figure 4 shows that this market for seagoing vessels cannot be analysed without considering the total LNG market and the natural gas market too. Since the LNG bunker price depends firstly on the LNG import price, the LNG import price will be analysed first in this subsection, before turning to the LNG bunker price in the following subsection (2.3).

Subsequently, the following subjects will be presented in this section:

- different natural gas pricing mechanisms;
- factors that determine the EU LNG import price;
- overview of historical LNG import prices, and
- natural gas price projections.

Figure 4 Supply chain for small and large-scale LNG



Source: (CE Delft, TNO and ECN, 2013).

2.2.1. Natural gas pricing mechanisms

Globally, four main regional types of gas pricing mechanisms can be discerned (Natgas, 2015):

- Natural gas prices are volatile and not linked to the price of other energy carriers. The natural gas market is typically liberalized and characterized by a large number of suppliers and buyers and there is ample natural gas infrastructure.
- Natural gas prices are linked to the price of other energy carriers, especially oil-based products or coal. The natural gas market is typically characterized by many buyers but a limited number of suppliers and a natural gas infrastructure that is controlled by few actors.
- Natural gas prices are linked to the oil price. The natural gas market is typically characterized by a large share of imported gas and a limited number of suppliers and buyers with the buyers controlling the domestic natural gas infrastructure.
- Natural gas prices are mandated in regulated markets.

Regarding Europe, two regions are being differentiated regarding the price setting of natural gas (Natgas, 2015): continental Europe and the UK. The UK is considered to be the most liquid hub in Europe, thus falling more into category one than in category two. For continental Europe natural gas prices are predominantly linked to the prices of other energy carriers, especially oil-based products or coal, i.e. category 2 above (Natgas, 2015), but, particularly in North-western Europe, a move towards a hybrid pricing system, taking also hub pricing into account, can be observed, i.e. a combination of category 1 and 2 (IGU, 2015).

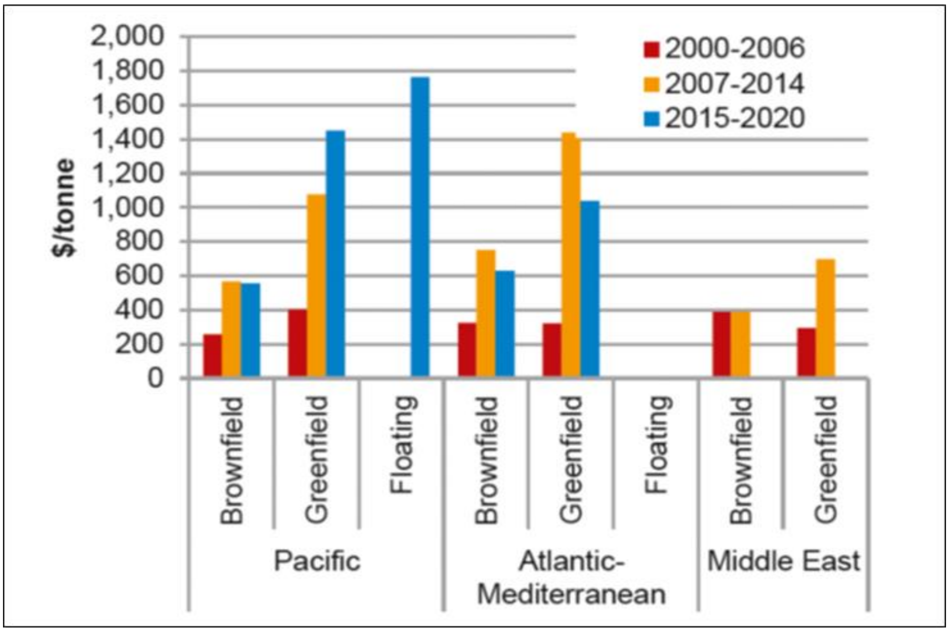
Regarding the other world regions, the current natural gas pricing of the US and Canada falls into category one, for Japan, South Korea, and Taiwan (that account for more than 50% of the LNG net imports worldwide) into category three, and the Middle East, Russia and China into category four.

2.2.2. Factors determining the EU LNG import price

The EU LNG import prices can, just as natural gas prices in Europe be directly and contractually be linked to the price of other energy carriers. If this is not the case, the following factors can be expected to have an impact on the LNG import price:

1. **LNG import costs** (determined by the costs for natural gas production, liquefaction, shipment, etc.). These costs will differ between exporting countries, not only due to the different transport distances, but also depending on costs for the emerging liquefaction plants. Liquefaction plant CAPEX differs highly between green- and brownfield projects. Greenfield projects that have to be set up from scratch are naturally associated with higher CAPEX than brownfield projects and have, according to IGU (IGU, 2015), turned out to be unexpectedly high in 2012 and 2013. In Figure 5, the average liquefaction unit costs are given by basin and project type. Currently, most of the EU LNG imports (77%) stem from Qatar, Algeria and Nigeria.

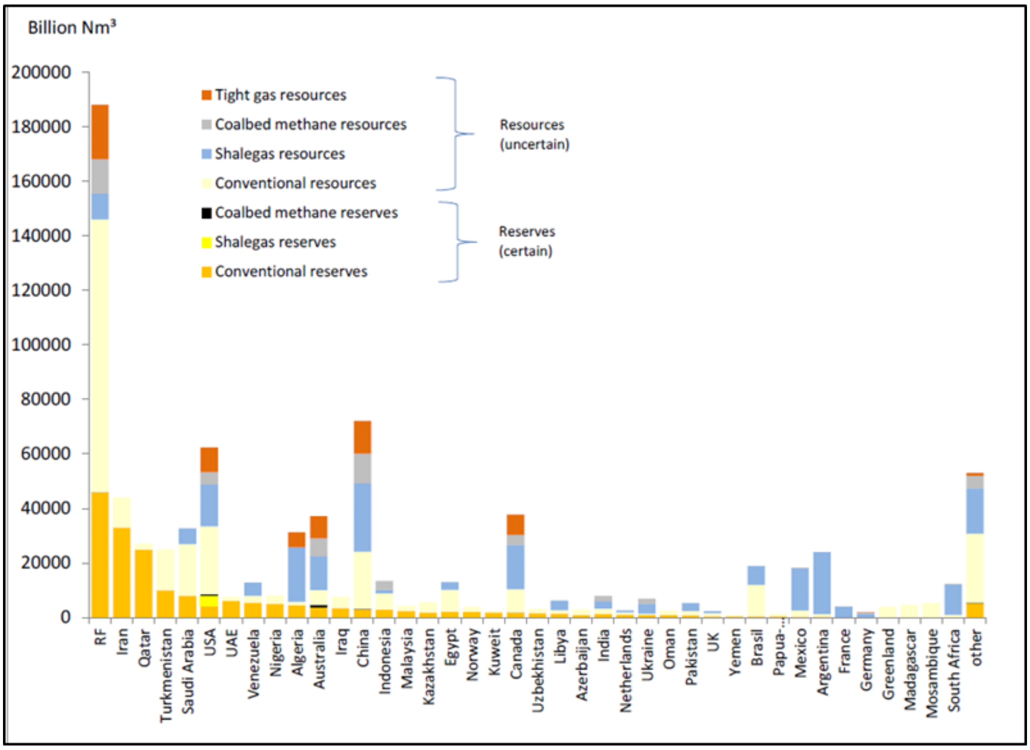
Figure 5 Average liquefaction unit costs in real USD/tonne by basin and project type



Source (IGU, 2015).

2. **Extent of the gas reserves** from conventional or unconventional sources of the exporting countries (see Figure 6). In the US for example, an increase in the availability of natural gas has prompted many producers to apply for a licence to export LNG from domestic production. If these licenses are granted - almost all projects have received approval to export to countries with which the U.S. has a free trade agreement, but most of the applications regarding the export to countries with which the U.S. has not (yet) entered into a free trade agreement are still pending - the increased supply on the LNG market could lead to lower LNG prices.

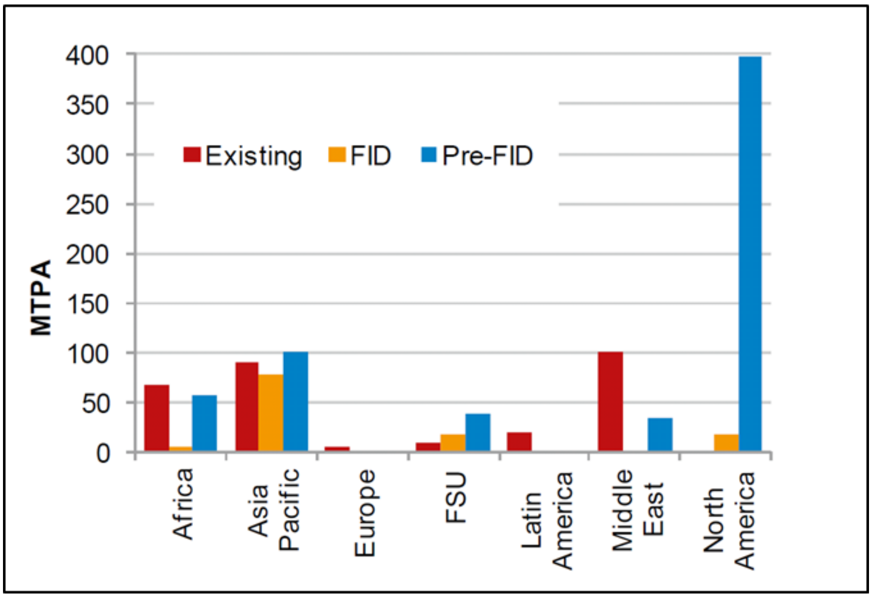
Figure 6 Natural gas availability



Source: (DLR, et al., 2014).

3. **Amount of LNG that can be supplied**. This depends on the capacity of the LNG infrastructure (e.g. capacity of the liquefaction plants and total capacity of LNG carriers) in the exporting countries and in the EU (e.g. storage and regasification capacity of import terminals). By the end of 2014, global existing nominal liquefaction capacity amounted to 301 million ton per annum (MTPA). Most of the existing capacity (see Figure 7) is located in the Middle East, the Asian Pacific Region, and Africa and most of the planned capacity in North America and the Asian Pacific region (IGU, 2015).

Figure 7 Nominal liquefaction capacities by status and region, as of Q1 2015



Source: (IGU, 2015); FID = final investment decision, MTPA = Mt per annum.

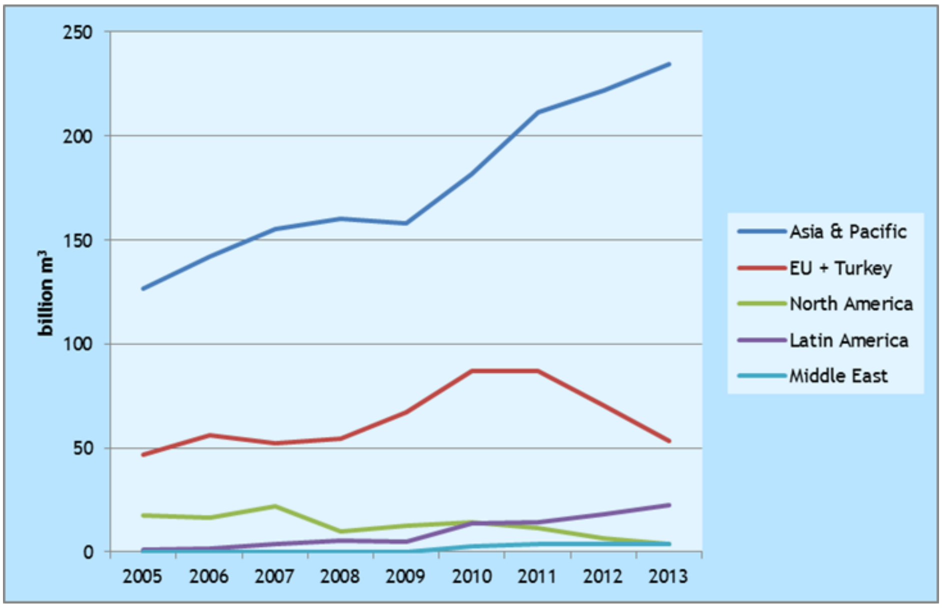
In 2015 (as by April 2015), there were 23 LNG import terminals in EU countries[5] with a nominal annual regasification capacity of around 325 billion m^3 in terms of LNG and of around 200 billion m^3 in terms of natural gas (IEA, 2015). According to Gas Infrastructure Europe (GIE, 2015b), additional large-scale import terminal capacity of 20 billion m^3 in terms of natural gas is under construction in EU-28 countries and another 145 billion m^3 in terms of natural gas is planned.

4. **Demand for LNG**. This will depend on the economic growth and the growth of the specific submarkets using natural gas and LNG, the degree to which countries want to diversify their gas sources (specifically for EU this entails the extent of the EU gas reserves), on political decisions and on regulations, such as environmental regulations. A relevant political decision outside of Europe is whether Japan, which currently is the largest global LNG importer, will significantly reduce its dependency on nuclear power in the future.

   Figure 8 illustrates the development of the global LNG import volumes for different regions for the period 2005 to 2013.

[5] The 23 LNG import terminals consist of 17 large and 2 small on-shore terminals, 2 floating storage regasification units (FSRUs), 1 large off-shore terminal, and a gas port for FSRUs.

Figure 8 World LNG import volumes by regions



Source: IEA, 2010, 2012, 2014.

The largest share of the exported LNG is sold in the Asian Pacific region. Japan and Korea have been the countries that have imported most LNG in the world. China, India, Taiwan are the other major importers in the Asian Pacific Region. The imported LNG volume by countries in the Asian Pacific region has risen significantly, 85% compared to 2005.

The EU import volume is significantly lower than the import volume of the Asian Pacific region, but at the same time higher than of the other world regions. EU LNG import levels peaked in 2010 and 2011 and dropped in 2012 and 2013, with the 2013 level being almost back to the 2005 level. The EU 2013 LNG imports amounted to 14% of the global LNG import volumes. The LNG imports to the EU are 14% of the total net gas imports from non-EU countries - the remaining 86% being imported by means of pipelines (Eurogas, 2014)

In the EU there are currently 10 countries that import LNG from outside the EU: Spain, UK, France, Italy, Belgium, Portugal, Netherlands, Greece, Poland[6], and Lithuania (in order of the 2013 import volumes). EU 2013 LNG imports mainly stem from Qatar (45%), Algeria (21%) and Nigeria (13%) (IEA, 2015).

Regarding other three world regions depicted in Figure 8, Northern American LNG import volumes show a decreasing, whereas Latin America and the Middle East an increasing trend.

6 LNG is transferred by road; construction of the LNG import terminal is significantly delayed.

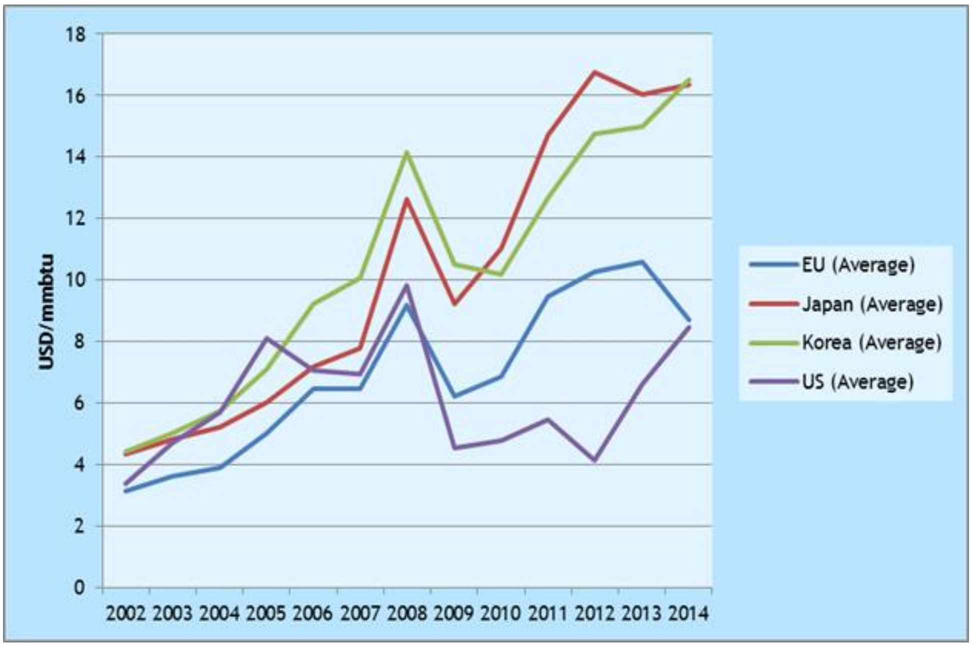
5. **Opportunity costs of the LNG exporters**. If for example an LNG exporter could make a higher profit by exporting his LNG to Asia, he would only be willing to export LNG to the EU if LNG import prices are high enough to ensure a similar profit. The IEA (IEA, 2015) for example stated that in 2013, Asia had, due to the high LNG price difference between Asia and Europe, been able to divert LNG away from Europe, leading to a collapse of EU LNG imports, leaving the EU with a share of 14% of the global LNG imports.

6. **Willingness of the (EU) consumer to pay for LNG**. For the natural gas consumers this depends on the 'non-LNG' natural gas price of the gas stemming from EU production or from pipeline imports[7], on the price of energy carriers that can be used to substitute natural gas, as well as the premium the consumers are willing to pay for the diversification of their natural gas sources. For the LNG consumers in the transport sector, his willingness to pay for LNG will depend on their opportunity costs, i.e. their costs if they choose the best other option available to them. These opportunity costs for example comprise the costs for the alternative transport fuels.

2.2.3. Historical LNG import prices

In Figure 9 the development of LNG import prices over the period 2002 to 2013 is given for the EU, Japan, Korea and the US.

Figure 9 Historical nominal LNG import prices



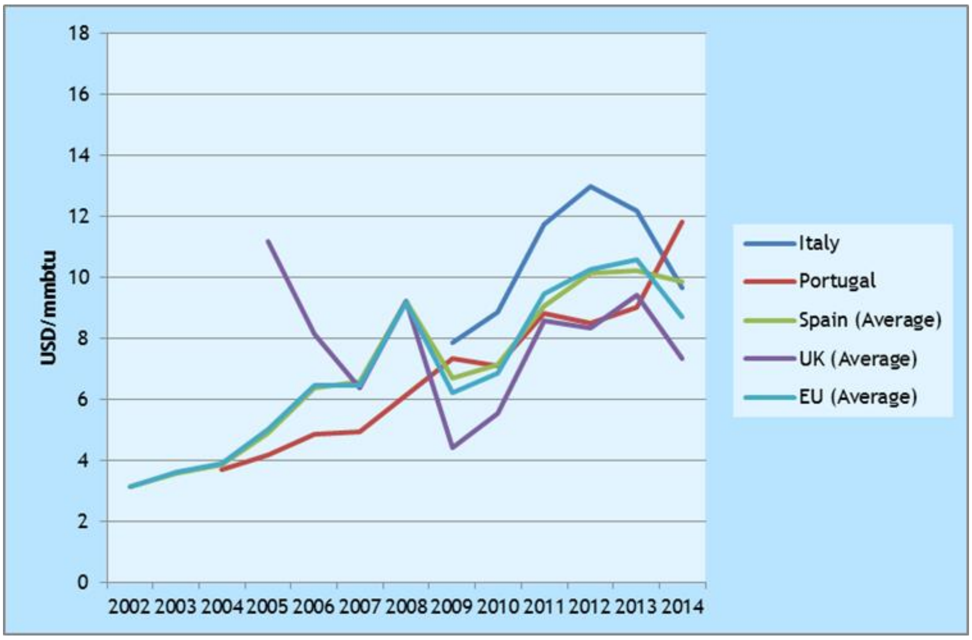
Source: IEA, 2010, 2012, 2014, 2015.

[7] According to (Eurogas, 2014; Eurogas, 2014), the EU28 natural gas supplies stemmed in 2013 for 34% from own production, for 21% from Norway, for 27% from Russia, and the remaining 18% mainly from North Africa and the Middle East.

Whereas the 2002 LNG import price difference between regions is rather low, a significant difference can be seen between the regions in 2014, with the Asian LNG import prices being much higher than the EU and the US LNG import prices. The Asian and the EU import price thereby feature a rising trend. The US import price fluctuates without showing a clear trend in the period 2002-2014, with the US and the EU import price reaching almost the same level in 2014.

For four of the nine EU countries that have imported LNG in 2013, IEA reports LNG import prices on an individual level (see Figure 10).

Figure 10 Historical nominal LNG import prices for different EU countries



Source: IEA, 2010, 2012, 2014, 2015.

The presented LNG import prices differ, which can probably be explained by the different countries from which the EU countries import the LNG.

Since 2014, LNG import prices have changed dramatically:

- The Japanese Ministry of Economy, Trade and Industry reports a steady decline of the Japanese LNG price from 18 USD/mmbtu[8] in March/April 2014 to under 8 USD/mmbtu in June 2015, with price rising slightly in July and August 2015.
- The US LNG import price has been very volatile, but featuring a declining trend from mid-2014 on, with a price of around 5 USD/mmbtu in June 2015.
  The US Henry Hub natural gas spot price, which reflects the supply of domestic production too, has declined from 6 USD/mmbtu in February 2014 to 2.8 USD/mmbtu in July 2015 (U.S. Energy Information Administration, 2015).

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[8] mmBtu stands for million British thermal units. mmBtu is a commonly used unit for measuring gas and other energy sales quantities and is a measure for the energy content of fuels. The internationally agreed value for the Btu is 1,055.06 joules (OECD & IEA & Eurostat, 2005).

Data on the recent development of EU LNG import prices is hardly available from public sources. From data available for January 2015 (Platts, McGraw Hill Financial, 2015) however, it can be concluded that the EU LNG import price has also declined, but to a lesser extent than the Japanese LNG import price, narrowing the price gap between these two regions and that the US price has also declined more than the EU price, widening the price gap between these two regions.

2.2.4. LNG import price projections

In the natural gas price statistics, up to four natural gas prices are typically given, i.e. for the US (often Henry Hub spot price), for Japan (or the Asian Pacific region), for the UK (National Balancing Point price) and for continental Europe. According to the World Bank Commodity Price Forecast from April 2015, the average 2014 natural gas price in US was about 56% lower and in Japan about 58% higher compared to the natural gas price in Europe, showing that the market is rather fragmented.

In most of the current natural gas price projections, the regional gas price differences prevail, but at the same time many projections see the prices converging to a certain extent.

This is where LNG plays an important role. LNG can either be produced by domestically liquefying natural gas that stems from existing sources (own production, import via pipeline) or, and this could contribute to a convergence of the regional natural gas prices, it can be liquefied abroad and can be imported as LNG which makes it possible to import natural gas from countries to which no pipeline connection is possible.[9] LNG can then be used by the current consumers of natural gas (industry, power sector, households) but could also serve new markets, like maritime transport, inland navigation or road freight transport. For the current consumers of natural gas, the imported LNG needs to be regasified and additional connections to the existing natural gas grid would have to be created (large-scale LNG), whereas for the LNG consumers, the large-scale LNG shipments would have to be split into smaller parcels for distribution (so called small-scale LNG or break bulk service).

LNG import price projections can be found in different literature sources, with the different price projections depending on the regional scope of the studies.

For the US LNG market, which will lean on the liquefaction of domestic gas, the LNG price projections are a combination of a domestic gas price projection and a cost mark-up for the expected liquefaction and distribution costs e.g. (GDF Suez, 2014).

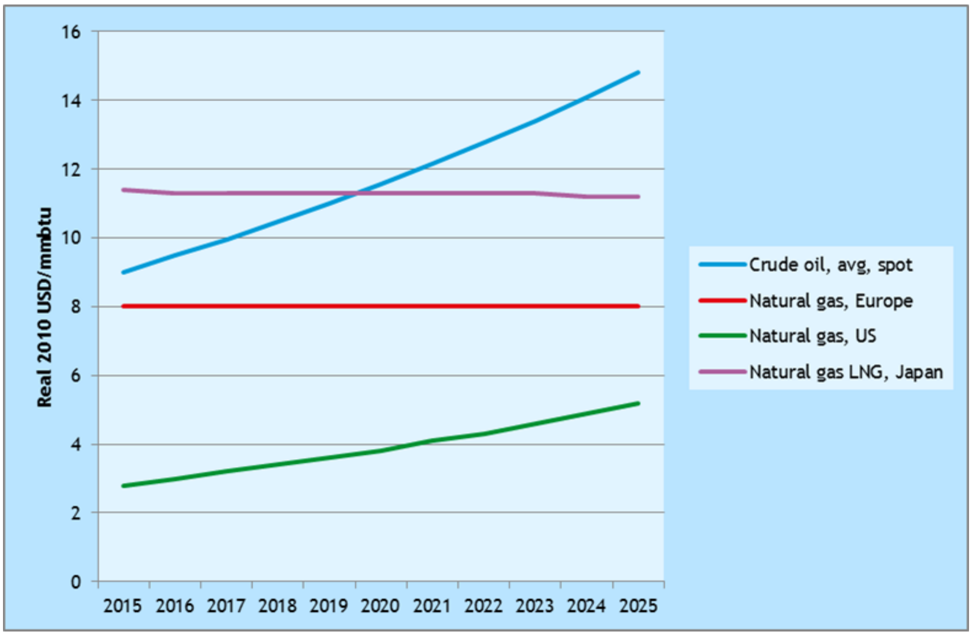
For the Asian market there are, on one hand, LNG price projections based on oil price predictions, assuming that oil-linked pricing will prevail in the future (e.g. Commodities Price Forecast and, on the other hand, there are studies that analyse the impact of increased imports stemming from the US, Canada or Australia which could lead to a decline of the Asian LNG price e.g. (EY, 2014).

[9] Note that in the very long run, the maritime transport sector could, as an internationally mobile LNG consumer, contribute to a further convergence of regional natural gas prices, but this effect lies clearly out of the time scope of this study, in which the LNG demand of seagoing vessels can be expected to be marginal.

Regarding Europe, two types of price projections can be differentiated. Firstly, there are natural gas price projections (see Annex A.3) which can be used to estimate the future LNG import prices, assuming that LNG import prices plus regasification costs equal the natural gas import prices. Secondly, there are LNG import price projections related to the shipping sector and in general (see Annex A.2).

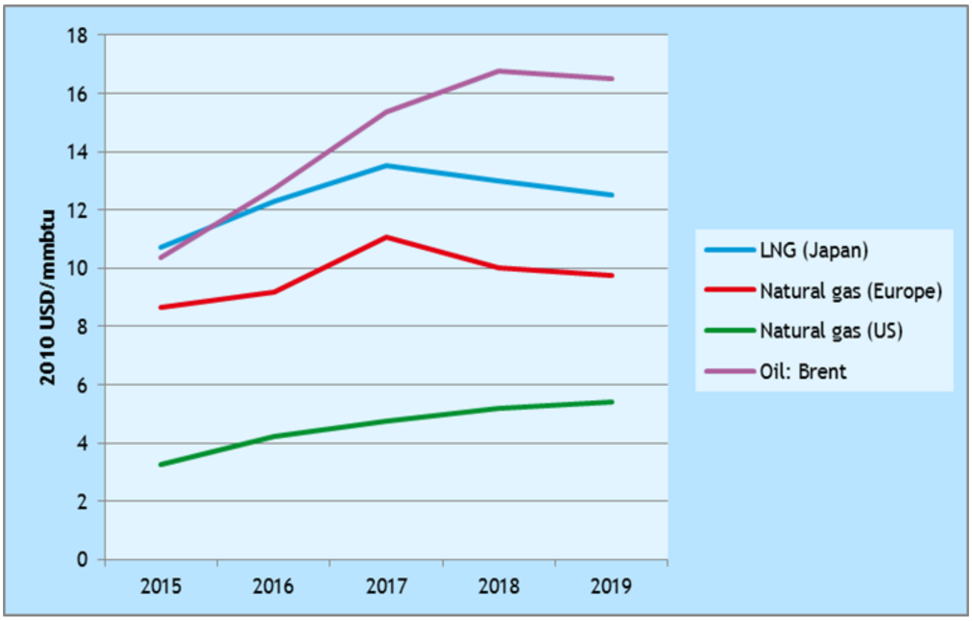
The natural gas and LNG import price projections for Europe still foresee, at least in the short and medium run, a regional differentiation of the (L)NG price between Europe, Asia and the US, with the European (L)NG price falling in between the Asian Pacific price and the US price. However, the projections differ regarding the extent to which the future (L)NG price in Europe and in the Asian Pacific region is assumed to be linked to the crude oil price, as illustrated by the price projections by the World Bank (Figure 11) and by The Intelligence Unit of The Economist (Figure 12).

Figure 11 Crude oil and gas price projections of the World Bank



Source: World Bank Commodities Price Forecast, April 2015.

Figure 12 Crude oil and gas price projections by the Intelligence Unit of The Economist



Source: The Economist, Intelligence Unit, Global Forecasting Service.

Regarding the level of the projected European (L)NG price, the more recent projections expect the 2020 price to lie in the range of 8-10 2010 USD/mmbtu, whereas projections from before 2014 expect a higher crude oil and thus a higher L(NG) price (e.g. Primes reference scenario prices). For the year 2025, there are not many (L)NG price projections for Europe. In fact, only find the World Bank projection is found to be suitable for the purpose of this study. The World Bank estimates the natural gas price for Europe to be around 8 2010 USD/mmbtu in 2025.[10]

2.3. Bunkering market for LNG as fuel for shipping

In Europe, LNG is currently available as bunker fuel for maritime shipping at the following seven EU sea ports (GIE, 2015a):

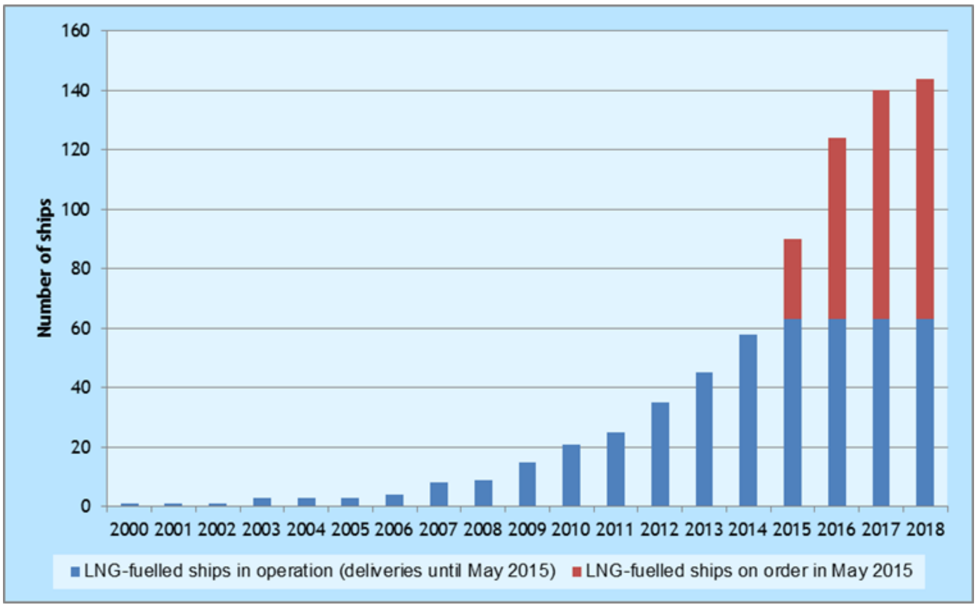
1. Port of Stockholm (ship-to-ship bunkering);
2. Port of Antwerp (truck-to-ship bunkering);
3. Port of Zeebrugge (truck-to-ship bunkering);
4. Port Amsterdam (truck-to-ship bunkering);
5. Port of Moerdijk (NL) (truck-to-ship bunkering);
6. Port of Brunsbüttel (GER) (truck-to-ship bunkering); and
7. Port of Hirtshals (DK) (shore-to-ship bunkering).

[10] The UK Department of Energy & Climate Change (DECC) provides fossil fuel price projections until 2035, but since the natural gas price in the UK has been rather low compared to the average European natural gas price, the World Bank price projection has been used in this study. For 2025, the DECC gives a natural gas price range of around 5-12 2010 USD/mmbtu.

In addition, LNG can be bunkered at several Norwegian ports.

The number of LNG-fuelled ships in the global fleet is still limited. According to DNV GL (DNV GL, 2015b) 63 LNG-fuelled vessels have, in addition to the LNG carriers that are often LNG-fuelled and in addition to LNG-fuelled inland waterway vessels, been operational in 2015 (as of May 2015). By end of 2015, about 90 LNG-fuelled ships are expected to be in operation. The number of LNG-fuelled ships is expected to increase by 60% in the next three years, as shown in Figure 13.

Figure 13 LNG ships in operation and under construction



Source: DNV GL, 2015.

2.3.1. Main drivers and barriers in the LNG bunkering market

The main drivers and barriers for the demand and the supply of LNG bunkering fuel for seagoing vessels in European ports are discussed below.

First, the demand side and then the supply side are thereby analysed. In addition, a graphical overview of the different factors that determine the supply of and the demand for LNG bunker fuel in ports is given (Figure 14). When discussing the main drivers and barriers regarding the demand and the supply of LNG bunkering fuel reference to Figure 14 will be made whenever relevant.

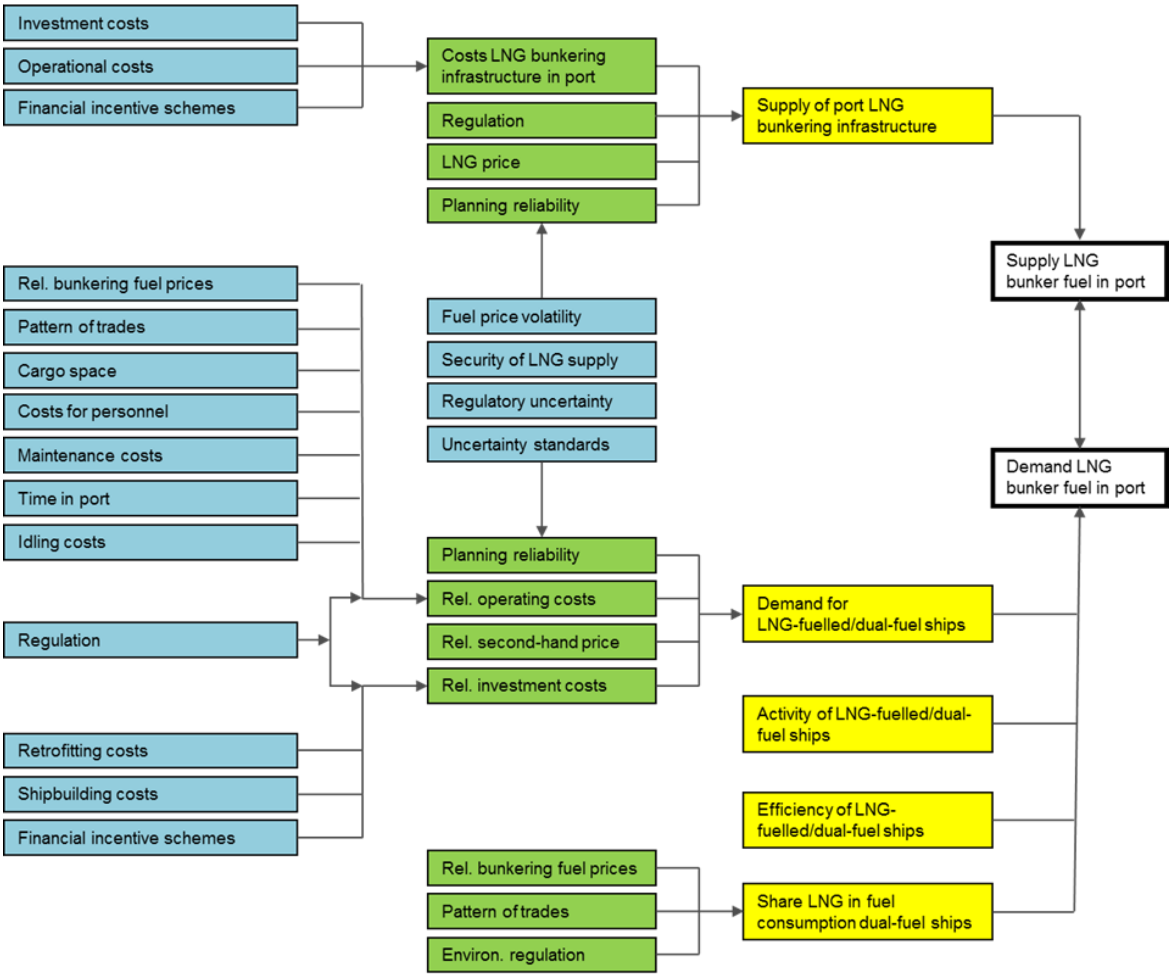
Main drivers and barriers for the demand of LNG as fuel for shipping

Environmental regulation

Since an LNG-fuelled ship emits, at least in the gas mode, almost no SO_x and PM emissions and 85-90% less NO_x emissions[11] compared to a ship that uses HFO or distillate fuels (WPCI, 2015a) **environmental regulation** is expected to lead to a higher demand for LNG-fuelled ships and LNG bunkering fuel in the future.

Regarding ships sailing to and from EU ports, the IMO sulphur oxides and nitrogen oxides controls (MARPOL Annex VI, Regulation 13 and Regulation 14) as well as the EU Marine Fuels Sulphur Directive that regulates the sulphur content of marine fuels (EC, 2012) are relevant in this context.

Figure 14 Factors that determine the supply and the demand for LNG bunker fuel in ports



11 Depending on internal combustion engine technology.

IMO has regulated through MARPOL Annex VI sulphur oxide and nitrogen oxide emissions, by prescribing the maximum sulphur content of the bunker fuel used and by setting NO_x limits for diesel engines and dual fuel engines that operate on diesel pilot fuel.

The sulphur regulation has two different stringency levels: one stringency level that holds in so called Emission Control Areas (ECAs) and another, less strict stringency level, outside these ECAs, also referred to as global requirements. Currently, the IMO sulphur limit for the fuel used inside ECAs is 0.1% mass sulphur/mass fuel (m/m), whereas the sulphur limit outside ECAs is 3.5% m/m.

The NO_x regulation currently sets emission limits for ships constructed on or after January 2000 (Tier I requirements) and more strict (Tier II) requirements for ships constructed on or after January 2011.

For both SO_x and NO_x regulation it also holds that the requirements will get more stringent over time: regarding the sulphur regulation, the global (outside the ECA) IMO sulphur limit will decrease from 3.5 to 0.5% in 2020[12] and regarding the nitrogen oxide regulation, stricter requirements (so called Tier III requirements) will hold in ECAs. In the currently established ECAs to limit NO_x emissions (North American ECA and the United States Caribbean Sea ECA) Tier III will hold for engines installed on ships constructed on or after January 2016.[13] (see Table 10 and Figure 14). In ECAs which may be designated in the future, Tier III will apply to ships constructed on or after the date of adoption of such an emission control area by the MEPC, or a later date as may be specified in the amendment designating the NO_x ECA.

Table 10 IMO NO_x emission limits

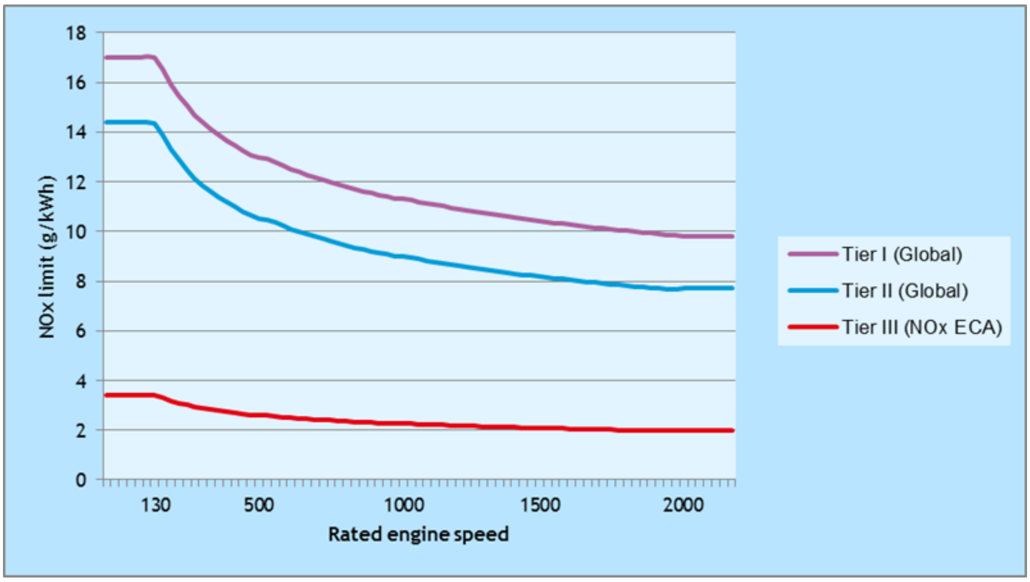
	Diesel engines installed on ships constructed	NO_x limit (g/kWh)*		
		n < 130	130 ≤ n < 2,000	n ≥ 2,000
Tier I	From 1 January 2000 to 1 January 2011	17.0	$45*n^{-0.2}$	9.8
Tier II	After 1 January 2011	14.4	$44*n^{-0.23}$	7.7
Tier III	After 1 January 2016 when operating in NO_x ECA	3.4	$9*n^{-0.2}$	2.0

*n = engine's rated speed (rpm).

12 Although, Depending on a review of low Sulphur fuel availability to be concluded in 2018, the introduction date may be postponed to 2025.

13 For marine diesel engines of less than 500 gross tonnage, of 24 m or over in length, which has been specifically designed and is used solely for recreational purposes, Tier III requirements do not apply prior to January 2021.

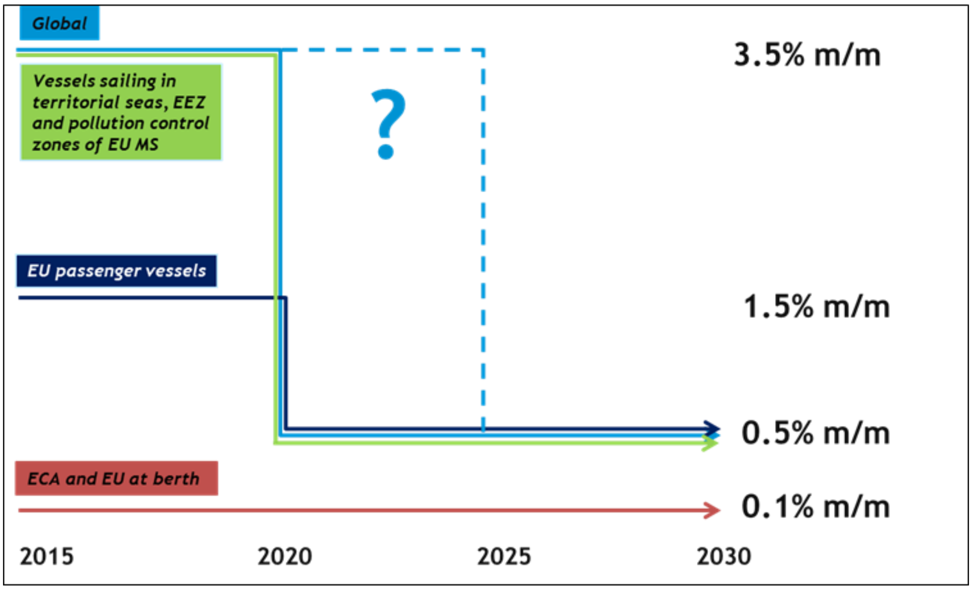
Figure 15 Illustration of IMO NO_x limits



The EU Marine Fuels Sulphur Directive that regulates the sulphur content of marine fuels (EC, 2012) implements MARPOL Annex VI Regulation 14 in EU legislation and sets the following additional requirements: ships berthed or anchored in European Community ports are not permitted to consume marine fuels with a sulphur content exceeding 0.1% and passenger ships are required to use marine fuel with a maximum sulphur content of 1.5% until stricter sulphur standards apply to all ships. The EU Directive obliges vessels from 2020 on to use fuel with a sulphur content of not more than 0.5% m/m when sailing in territorial seas, exclusive economic zones (EZZ) and pollution control zones of EU Member States. In contrast to the IMO regulation, the EU Directive does thereby not leave the door open for a potential postponement of the 0.5% m/m requirement until 2025.

In Figure 16 an overview is given of the current and upcoming IMO and EU SO_x requirements, with the uncertainty of whether the stricter global IMO sulphur limit will come into force in 2020 or in 2025.

Figure 16 Overview of current and upcoming IMO and EU SO_x requirements



Source: This report.

In principle, there are several methods with which ships can comply with the sulphur requirements. Three main compliancy strategies are distinguished:

- keep using HFO as a main fuel, but clean exhaust gasses to prevent sulphur oxide emissions to the atmosphere (HFO + scrubber);
- using distillate or diesel bunkering fuel with a low sulphur content, like Marine Diesel Oil (MDO), Marine Gas Oil (MGO) or Low Sulphur Heavy Fuel Oil (LSHFO);
- switching to alternative fuel, like for example LNG.

As far as NO_x is concerned, whereas Tier I and Tier II requirements can be met by engine design and calibration this is not the case for the Tier III requirements which are 80% stricter than Tier I limits (see Figure 14). In their final report the Correspondence Group on Assessment of Technological Developments to Implement the Tier III NO_x Emissions Standards (MEPC 65/4/7), identified the following technologies to have the potential to achieve the NO_x Tier III limits, either alone or in some combination with each other:

1. Selective Catalytic Reduction (SCR).
2. Exhaust Gas Recirculation (EGR).
3. The use of LNG, either in dual-fuel (diesel pilot injection with gaseous LNG as main fuel) or alternative fuel arrangement. And
4. Other technologies: direct water injection, humid air motor (HAM), scrubbers, treated water scrubber, variable valve timing and lift, Dimethyl Ether as an alternative fuel.

Regarding European waters, the North and the Baltic Sea are currently defined as ECAs with respect to sulphur emissions.

Comparison of different options to meet environmental regulations

A ship owner/operator who considers retrofitting an existing ship to make it ready for LNG use or to buy a new LNG-fuelled ship will thus compare the **total cost of ownership** of the different options for compliance with environmental regulation.

Regarding LNG-fuelled ships, four different types of LNG ship engines are relevant, a dedicated gas engine type and three kind of dual fuel types. Table 11 gives an overview of the four engine types and their main characteristics.

Table 11 LNG ship engine types and their characteristics

	2-stroke engine	4-stroke engine
Dual fuel low pressure	Otto-cycle. Pre-mixed lean burn combustion. Runs in gas mode on gas and 1% diesel (pilot fuel). Sensitive to methane slip. Sensitive to gas quality. Does meet IMO Tier III requirements in gas mode and Tier II in diesel mode. ECA sulphur regulation compliance depends on actual fuel mix used.	Runs in gas mode on gas and 1% diesel (pilot fuel). Runs in diesel mode on 100% diesel. Otto-cycle in gas mode and Diesel-cycle in diesel mode. Sensitive to methane slip. Sensitive to gas quality. Does meet IMO Tier III requirements in gas mode and Tier II in diesel mode. ECA sulphur regulation compliance depends on actual fuel mix used.
Dual fuel high pressure	Runs on various gas/diesel mixtures (at least 5% diesel pilot fuel in gas mode) or on diesel alone. Combustion of gas, diesel and air mixture in Diesel-cycle. No methane slip. Not sensitive to gas quality. Does **not** meet IMO Tier III requirements in gas mode. ECA sulphur regulation compliance depends on actual fuel mix used.	
Spark-ignited lean-burn gas engine		Otto-cycle. Spark ignition. Sensitive to methane slip. Sensitive to gas quality. Does meet IMO Tier III requirements. Meets ECA 0.1% sulphur limit.

Source: (DNV GL, 2014b; Wärtsila, 2015) (WPCI, 2015a).

While all four LNG ship engine types meet NO_x Tier II requirements, not all four engine types can meet NO_x Tier III requirements – a ship equipped with a dual fuel high pressure engine would need one of the above mentioned additional exhaust gas treatment to meet NO_x Tier III requirements. The two dual fuel engine types that can meet Tier III requirements, i.e. the dual fuel low pressure engines, would have to be operated in the gas mode to fulfil Tier III requirements.

In principle, with all four LNG ship engine types, ships can comply with all sulphur requirements. (For the dual fuel engines this of course depends on the actual fuel mix used.) For sulphur requirements, an alternative for an LNG-fuelled ship could for example be an HFO-fuelled ship retrofitted with a scrubber.

When a scrubber is the option chosen a number of different costs need to be considered. For this specific emission abatement method initial investment costs will depend primarily on the type of scrubber selected, ranging from open-loop to closed-loop and hybrid systems. Recurring costs, also dependent on the type of system chosen, will invariably consist of water (sludge) disposal, water treatment and equipment power consumption, and maintenance.

When a ship owner considers investing in a ship that can be fuelled with LNG or into a retrofit that would enable his existing ship to be fuelled with LNG, a Life-Cycle approach is taken to assist decision making. Investment costs, operating costs, and second hand-price are compared to those of a ship that cannot be fuelled with LNG but still fulfils all the relevant requirements like the environmental regulation.

Converting a ship into an LNG-fuelled ship requires a substantial investment and the technical scope, feasibility, and applicability depends on the ship type/size. For new ships, LNG engines are still more expensive than diesel/distillate-fuelled engines.

For both retrofitted and new build LNG-fuelled ships, the relative operating costs, i.e. their operating costs compared to the operating costs of ships that are not LNG-fuelled but also compliant with the environmental regulation, will depend on several factors and may be difficult to estimate for ship operators in advance (see also 'relative operating costs' in Figure 14). The factors can be translated into specific variables affecting operational costs:

- LNG price per unit of energy will be higher/lower compared to the other bunker fuels.
- Operational profile of a ship, including the distance sailed in the ECAs, is crucial for the operational costs of a ship.
- Potential loss of cargo space due to the amount of space required by LNG tanks can lead to a loss in sales.
- Personnel working on an LNG-fuelled ship may have to follow additional training, leading to extra costs.
- Maintenance costs of an LNG-fuelled ship may differ from the maintenance costs of ship that cannot be fuelled with LNG. The cleaner combustion of gaseous fuel reduces maintenance expenses for cleaning the ship and also reduces maintenance expenses for boilers and exhaust gas boilers. In addition, the gas engine needs less and cheaper additives, i.e. lubricating oil. On the other hand, maintenance and repair of the gas engines could be more expensive than for fuel oil engines.
- Duration and frequency of bunkering may differ which could lead to more/less time spent in port.

- Natural boil-off. Due to the boil-off of the LNG in the on board LNG tanks, the gas must be either re-liquefied or consumed in case of long lay-up periods (or released in case of an emergency), potentially increasing the idling costs of ships that can be fuelled with LNG. The natural boil-off rate depends on the thermal insulation of the fuel tank used.

Regarding the resale value of LNG-fuelled ships, there is an additional risk relative to other ships, because the resale value is likely to be affected by LNG prices and price forecasts, and fuel availability. This risk is larger for dedicated LNG ships than for dual-fuel ships.

Other demand drivers

The **difference between the LNG price and the price for the other bunker fuel types** as well as future environmental policy (e.g. more ECAs, CO_2 regulation for international shipping) will play a crucial role in the uptake of LNG-fuelled ships. The price difference between LNG bunker fuel and HFO/MGO/MDO mainly determines the fuel expenditure difference between an LNG-fuelled ship and a HFO/MGO/MDO-fuelled ship. Since fuel expenditure savings have to be sufficiently high to compensate for the higher investment costs of an LNG-fuelled ship, the relative LNG bunker price is a very crucial factor on the demand side of the LNG bunker fuel market. The bunker prices of HFO/MGO/MDO have historically developed in line with the crude oil price and since mid-2014, the bunker prices have been falling along with the crude oil price. If EU LNG import prices are not linked to the crude oil price, then the relative price of LNG bunker fuel will rise, discouraging the uptake of LNG-fuelled ships.

Regulatory uncertainty regarding environmental regulation and the **uncertainty regarding the future prices** of the different bunker fuels makes it difficult for a ship owner to predict whether an investment into an LNG-fuelled ship will be profitable (see 'Planning reliability' in Figure 14).

In addition, there are other factors adding to this uncertainty. Firstly and most importantly, there is the **uncertainty about the future availability of bunkering infrastructure** in European ports, secondly, there is the **uncertainty** whether **sufficient supply of LNG** can be guaranteed for the European market, thirdly, there is **uncertainty about technical standards,** and fourthly there is the **regulatory uncertainty regarding safety standards**.

The uncertainty about standards is likely to be reduced in the coming years. The European Commission has requested the European standardisation organisations to develop uniform technical standards and the International Code of Safety for Ships using Gases or other Low flashpoint Fuels (IGF Code) has been adopted by the IMO Maritime Safety Committee in June 2015[14], but a regulatory framework for bunkering LNG as fuel for ships including relevant regulations of the LNG supply chain is not available yet (Germanischer Lloyd, 2013).[15] Existing standards and guidelines can be used to fill this gap, but rules may then differ between ports/countries, leading for example to different risk assessments and approval procedures. The LNG stakeholders and ports have an incentive to harmonise the procedures. This is why there are initiatives like the harmonized bunkering checklists for LNG operations in port as developed by the IAPH's WPCI LNG working group, but since these initiatives and guidelines from the industry might be overruled by regulation in the future, some degree of uncertainty remains. In the following table, the possible impacts on the demand side of the LNG bunker fuel market due to the uncertainty regarding standards and bunkering rules/regulations are listed. Please see the Lot 1 report of this study (DNV GL; PWC, not yet published) for further details on technical and safety standards regarding the LNG bunker fuel supply chain.

Table 12 Possible impacts on the demand side of the LNG bunker fuel market due to uncertainty w.r.t. standards

	Impact on demand side (DNV GL; PWC, not yet published)
No/insufficient safety standards	Probability that accident happens is higher, discouraging investment. Costly risk assessment of LNG systems and components.
No/insufficient technical standards, leading to technical incompatibilities	Ship might not be able to bunker in certain ports. Investment in LNG ships may be reduced if bunkering is constrained to a limited set of ports.
Introduction of standards that have not been anticipated	Additional extra measures may have to be taken leading to unexpected costs and/or earlier investments may become obsolete.
Different bunkering rules/regulations between ports	Costly for ship operators to keep track of and fulfil different rules/regulations. Ship might not be allowed to bunker in certain ports.

[14] The IMO's Maritime Safety Committee (MSC) adopted the IGF Code, along with amendments to make the Code mandatory under the International Convention for the Safety of Life at Sea (SOLAS). The IGF Code contains mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuels. The MSC also adopted related amendments to the International Convention on Standards of Training, Certification and Watchkeeping. for Seafarers (STCW), and STCW Code, to include new mandatory minimum requirements for the training and qualifications of personnel on ships subject to the IGF Code. Date of entry of both the amendments to SOLAS and to STCW is 1 January 2017 (IMO, 2015).

[15] Some progress has been made after the publication of this report - in August 2015, DNV GL released a class notation for gas bunker vessels – but a comprehensive regulatory framework is still not available yet.

Note that many of the factors that add to an uncertainty of planning on the demand side of LNG bunker fuel overlap with the according factors on the supply side where these factors make it difficult for a potential LNG supplier to assess whether his investment in port bunkering infrastructure will be a positive business case.

Main drivers and barriers for LNG bunkering supply

LNG is currently available as bunker fuel for maritime shipping at seven EU sea ports (GIE, 2015a) as presented in the beginning of this section.

In principle, there are three LNG bunkering methods feasible: truck-to-ship, shore-to-ship, and ship-to-ship bunkering. The availability of space and the ship types that call at a port might make one of the three methods more suitable for a specific port.
A potential supplier of LNG in a port will only invest into any of these LNG bunkering options if he expects the investment to be **a positive business case**. This is naturally determined by three main factors, the costs for the bunkering infrastructure in port, including the operational costs, the LNG price and the demand for LNG.

Currently, LNG imported from Africa and the Middle East is offered as bunkering fuel in Europe - liquefying pipeline gas from Europe and Russia in Europe is not cost-effective at the moment. The LNG bunkering price will thus be determined by the LNG import price (see Section 2.2 for the factors that determine the LNG import price) and the supply chain costs from the import terminal to actual bunker location in the EU.

Just as for the demand side, there are factors that make it difficult for a potential LNG supplier to assess whether an investment in port LNG bunkering infrastructure will be profitable. First there is the **uncertainty on whether there is sufficient demand for LNG bunkering fuel**, second there is **uncertainty regarding the future LNG price**, third there is the question whether sufficient LNG will become available for the European market, fourth there is **regulatory uncertainty regarding safety standards**, and fifth there is **uncertainty regarding technical standards** that have not been fully established yet or (see ‘Planning reliability’ in Figure 14). The regulatory uncertainty will be reduced when standards have been developed.

In the following table, the possible impacts on the supply side of the LNG bunker fuel market due to the uncertainty regarding standards are listed. Please see the Lot 1 report of this study (DNV GL; PWC, not yet published) for further details on technical and safety standards regarding the LNG bunker fuel supply chain.

Table 13 Possible impacts on the supply side of the LNG bunker fuel market due to uncertainty w.r.t. standards

	Impact on supply side
No/insufficient safety standards	Probability that accident happens is higher, discouraging investment. Costly risk assessment of LNG infrastructure. Approval procedure may take much time, discouraging investment.
No/insufficient technical standards, leading to technical incompatibilities	Certain ships might not be able to make use of bunkering facilities in place.
Introduction of standards that have not been anticipated	Additional extra measures may have to be taken, leading to unexpected costs and/or earlier investments may become obsolete.
Different bunkering rules/regulations between ports	Level playing field between ports can be distorted. Certain ships might not be allowed to bunker in the port.

From Figure 14, which illustrates the factors influencing the market for LNG as marine fuel, it becomes clear that a **chicken and egg problem** has to be solved in order to create a functioning market for LNG bunker fuel in ports: only if LNG bunkering infrastructure is available in ports will ship owners/operators be willing to buy ships that can be LNG-fuelled and only if there is sufficient demand for LNG bunkering fuel, will LNG bunkering infrastructure become available in ports.

The EU Alternative Fuels Infrastructure Directive (EC, 2014a)[16] contributes to overcome this chicken and egg problem by obliging Member States to ensure that by end of 2025 an appropriate number of refuelling points for LNG, including inter alia LNG terminals, tanks, mobile containers, bunker vessels and barges, are put in place at maritime ports, to enable LNG seagoing ships to circulate throughout the TEN-T Core Network.

National and EU funding/co-funding for LNG infrastructure, for pilot projects and for R&D can play an important role here too. Under the Connecting Europe Facility (CEF)[17] sources are made available to co-fund LNG infrastructure in the EU via e.g. the TEN-T or the Motorways of the Sea Programme.

[16] EC, 2014a. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance, Brussels: European Commission.

[17] The Connecting Europe Facility (CEF) aims at accelerating investment in the field of trans-European transport, telecommunications and energy networks (Regulation 1316/2013).

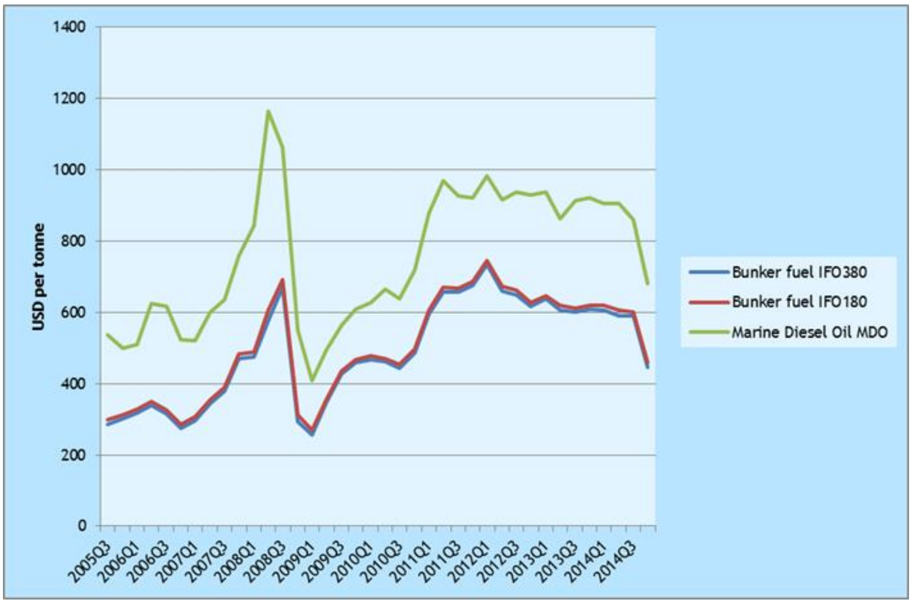
2.3.2. Bunker prices

Historical and current bunker prices

According to (IMO, 2010), the relationship between the crude oil price and the IFO 180 price[18] has been very stable in the past: the IFO price in terms of USD/tonne has been approximately five times higher than the crude oil price in terms of USD/barrel in the period 2000-2010.

The IFO 180 price thus fluctuates just as the crude oil price and, illustrated by Figure 17, so do the IFO 380[19] and the MDO price. In the past, the MDO price has structurally been higher than the HFO-price. In the third quarter of 2014, MDO has been about 50% more expensive than HFO.

Figure 17 Marine bunker fuel spot prices (average unit value, FOB-Singapore)



Source: New Zeeland Ministry of Transport, 2015.

Bunkerworld (Petromedia Ltd., 2015) reports for 28 May 2015, the following bunker prices for Singapore:

- IFO 380: 372 USD/tonne;
- IFO 180: 390 USD/tonne;
- MDO: 563 USD/tonne.

[18] IFO 180 is a heavy fuel oil grade.
[19] IFO 380 is a heavy fuel oil grade.

This means that the HFO and MDO bunker prices have decreased since the third quarter of 2014 and that the price difference between MDO and HFO has narrowed only slightly.

EU LNG bunker fuel price data is hardly available. Currently, only seven ports in the EU are selling LNG as bunker fuel and they sell it to a very small number of ship operators. Prices therefore tend to be determined on a contractual basis and are not published.

In addition, the seven ports offering the LNG only started selling LNG in 2013 or 2014 which makes data available also difficult.

Bunker fuel price projections

In the literature there are not many bunker fuel price projections including the LNG bunker price.

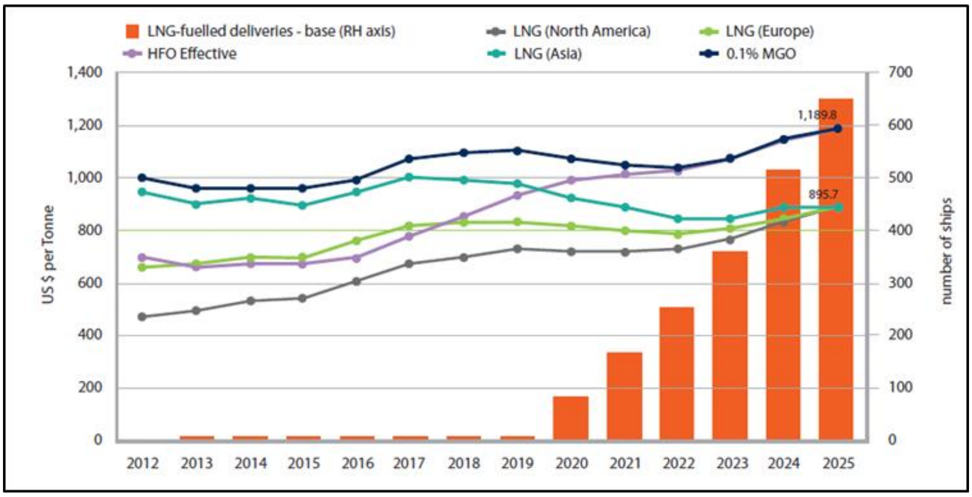
The bunker fuel price projections that do include the LNG price (Germanischer Lloyd, 2011; Lloyds Register, 2012; DMA, 2012; Lloyd's Register and UCL, 2014) Ricardo-AEA et al., 2013, all expect MGO/MDO to stay the most expensive bunker fuel, but differ in their expectations regarding the other bunker fuel prices.

The following particular aspects of each mentioned projection can be highlighted as follows:

- Lloyd’s Register (Lloyds Register, 2012) expects in the base case projection (see Figure 18[20]), that, regarding Europe, LNG is slightly cheaper/comes at comparable costs than HFO (IFO180 and IFO 380) but that over time HFO gets more expensive than LNG.
- Lloyd’s Register & UCL (2014) expect (see Figure 19) HFO to be cheaper than LNG and low sulphur HFO (LSHFO) and that LNG is at first more expensive than LSFO but becomes cheaper than LSFO over time.
- Germanischer Lloyd (Figure 20) and Ricardo-AEA (Figure 21) expect the LNG price to be and stay the lowest fuel price.
- In the DMA 2012 study, not a development of future bunker fuel prices is given but rather an estimation of the bunker fuel prices for one year, i.e. 2030 is given. Here, in each of the scenarios, the LNG bunkering price is also expected to be lower than the HFO bunkering price.

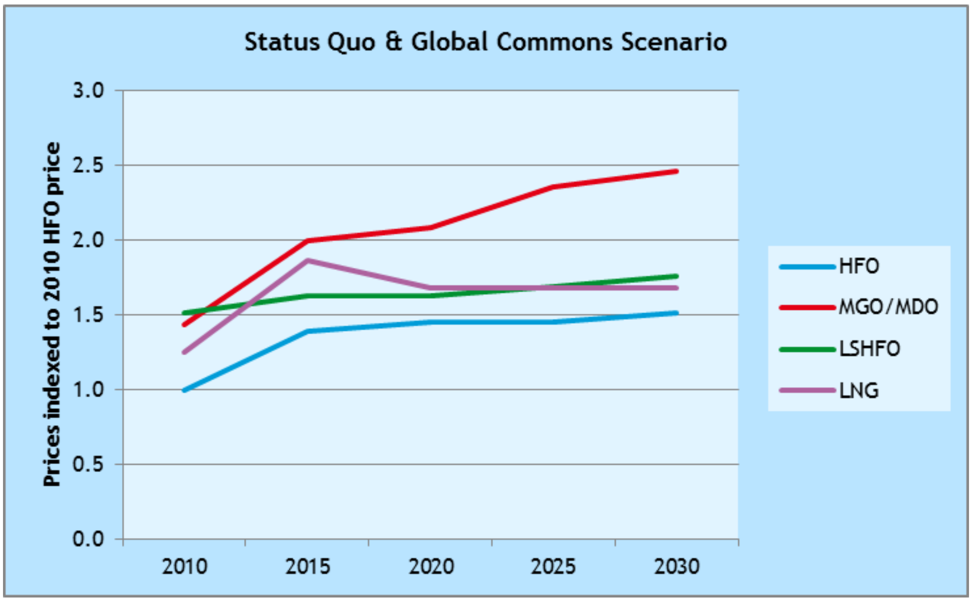
[20] Note that Figure 18 gives the prices in terms of USD/tonne and not in USD/energy unit.

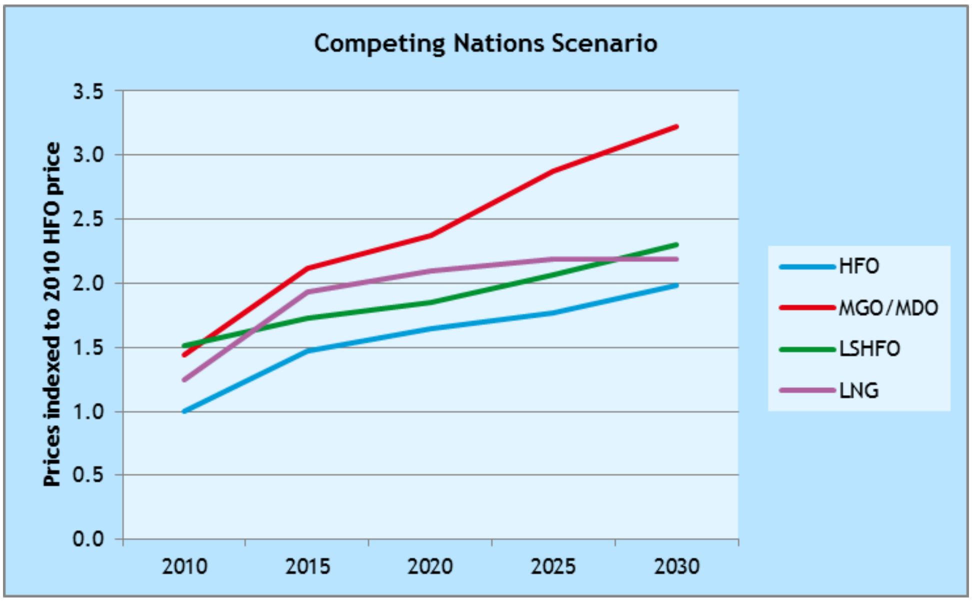
Figure 18 Bunkering fuel price forecast of Lloyd's Register (2012); Base case



Source: Lloyd's Register, 2012; with 'HFO Effective' means HFO with any variant of sulphur content higher than ECA or global limits at the given period.

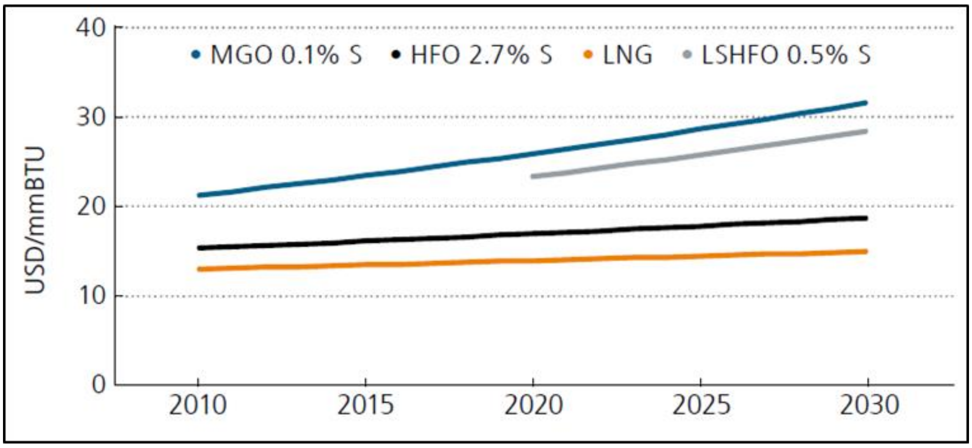
Figure 19 Bunkering fuel price forecast by Lloyd's Register and UCL (2014)





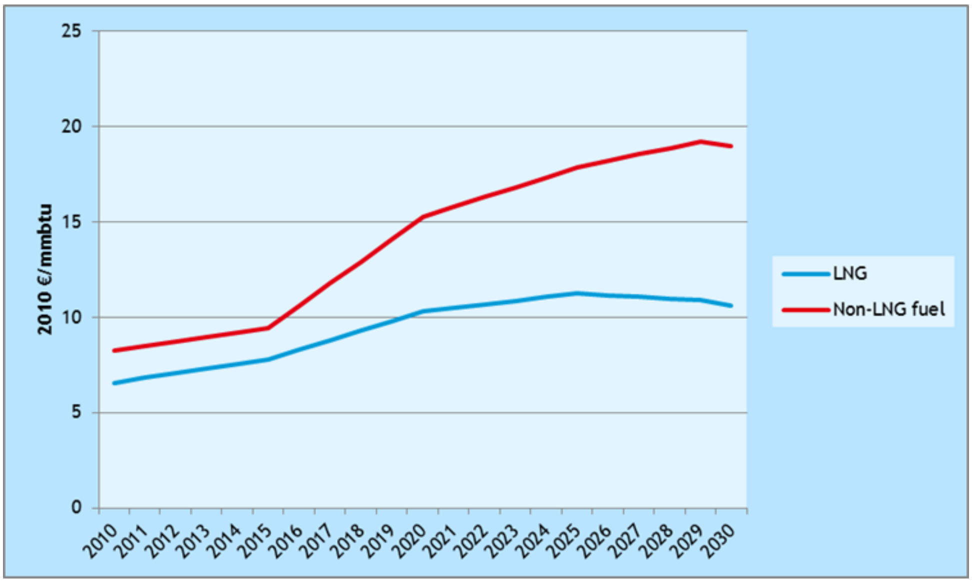
Source: Lloyd's Register and UCL (2014).

Figure 20 Bunkering fuel price forecast by GL (2011)



Source: Germanischer Lloyd, 2011.

Figure 21 Future bunkering fuel price as used in Ricardo-AEA et al. (2013)



Source: Ricardo-AEA et al., 2013.

Bunker fuel prices used in this study

Since the projections presented in the previous sub-chapter show such diverse expectations for the future bunkering fuel price, the following approach has been used to determine the bunkering fuel prices to be used in the cost-benefit analysis of this study:

1. Starting point was the projection of the natural gas[21] and crude oil price for Europe. In order to work with a consistent estimation for 2020 and 2025, the World Bank Commodities Price Forecast for the gas as well as for the crude oil price projection was used. For 2030 it was assumed that the trend that the crude oil price and natural gas price feature in the World Bank price forecast for the period 2015 to 2025 applies for the period until 2030 too.
2. The LNG import price the LNG supply chain costs between the import terminal in Europe and the LNG-fuelled receiving ship were added, so as to determine the future LNG bunkering fuel price (see Chapter 3 for the respective cost estimations).
3. For the alternative bunker fuel types, an estimation based on the crude oil price projections and the historical relationship between the crude oil price and the price of these alternative bunker fuels was made: From IMO (IMO, 2010) the relationship between the crude oil price and the IFO 180[22] price has been stable over the period 2000-2010: the HFO-price in terms of USD/tonne has been approximately five times higher than the crude oil price in terms of USD/barrel. Further, the price relationship between HFO and MDO was assumed to be the same as in Lloyd's Register and UCL (2014).[23]

[21] The World Bank natural gas price projection for Europe as described under Section 2.2.4 is thereby converted from 2010 USD/mmbtu to 2014 €/mmbtu.
[22] IFO 180 is a heavy fuel oil (HFO) grade.
[23] For 2020 relationship HFO/MDO is thereby 0.65 and in 2025 0.57.

In Table 14 the resulting prices are given in 2014 EUR/mmbtu.

Table 14 Current and future fuel prices that will be used for the cost-benefit analysis (2014 EUR/mmbtu)

	2020	2025	2030
LNG import price*	7	7	7
HFO bunkering price	8	10	12
MDO/MGO bunkering price	12	17	19

* Note that these are import prices including regasification costs; note further that the bunker fuel price is higher than the LNG import price, due to costs and profit margins in the supply chain between import terminal and bunker location in port.

In terms of 2014 USD/tonne the projected HFO and MDO prices are as follows:

- 2020: 400 USD/tonne HFO and 610 USD/tonne MDO;
- 2025: 510 USD/tonne HFO and 880 USD/tonne MDO;
- 2030: 580 USD/tonne HFO and 1,000 USD/tonne MDO.

In a sensitivity analysis it is accounted for the uncertainty of the future bunkering fuel prices by considering two additional sets of bunker fuel prices, considering a 25% higher and a 25% lower LNG import price than specified in Table 14.

3. Price and cost-structure of LNG for end-users

This chapter presents the price structure and cost-structure of LNG ships for end-users, i.e. ship owners or operators. The structures depend on the bunkering options and on the characteristics of the ships. Bunkering options and the related price of LNG are analysed in Section 3.1. The cost-structure of LNG-fuelled ships is analysed in Section 3.2. Section 3.3 presents an analysis of how the total costs of ownership of vessels with different types of fuel depend on the LNG price. The conclusions are in Section 3.4.

3.1. Price structure LNG bunkering

This section presents a cost analysis of transporting LNG from a terminal to a ship, as a function of (a) the transport method; (b) the amount of LNG to be bunkered; and (c) the distance to the terminal. The costs of LNG bunkering are described for the following bunkering methods: 1) ship-to-ship bunkering (STS), 2) tank truck-to-ship bunkering (TTS), 3) LNG intermediary terminal-to-ship via pipeline bunkering (PTS), and 4) LNG intermediary terminal-to-ship via small bunkering vessels (ship to ship bunkering with a small bunkering vessel and a local storage facility). The last option is a combination of the STS-bunkering method and an intermediary LNG terminal.

Which bunkering solution will be chosen depends on several factors such as distance, traffic intensity, volume, frequency, safety, vicinity to other LNG bunkering ports and land-based demand (DMA, 2012)[24]. An overview of the LNG supply chain and the three bunkering options is presented in Figure 22 and Figure 23 (note that the fourth option is a variant of the first). LNG has to be loaded at the import terminal and then transported by the feeder vessel or bunker barge, to the receiving vessel or intermediate LNG terminal. The receiving vessel can therefore be bunkered directly from the bunker vessel, from the intermediate terminal, by pipeline or, alternatively, by truck.

[24] DMA 2012. Danish Marine Authority. North European LNG Infrastructure Project. A feasibility study for an LNG filling station infrastructure and test of recommendations.

Figure 22 The LNG supply chain (DMA, 2012)

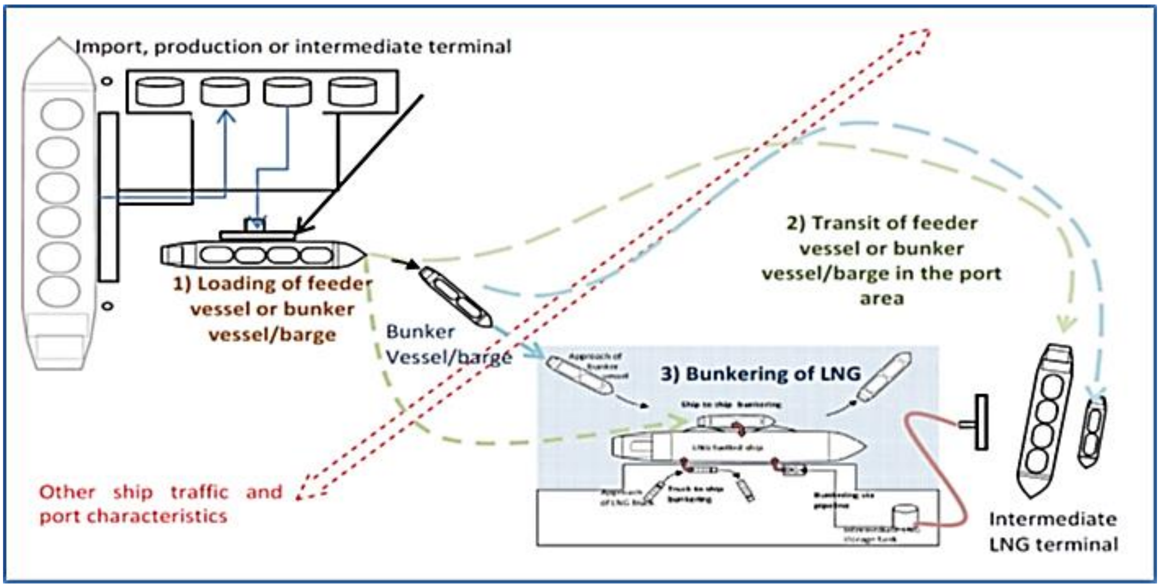
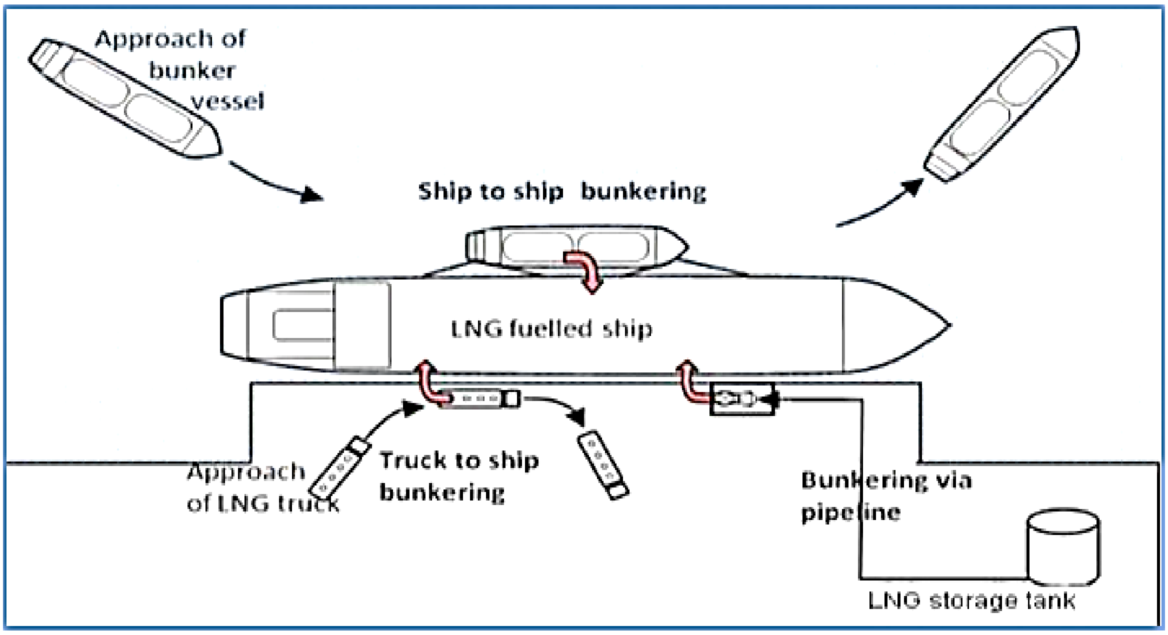


Figure 23 Bunkering scenarios (DMA, 2012)



The costs of supplying bunker fuel consist of two main parts: 1) price of the fuel at the import hub; and 2) infrastructure cost of storage and transshipment from a hub to the ship (in some cases via local port facilities). These infrastructure costs (see Table 13) depend on the bunkering method, and an overview of these costs will be given in the next sections.

Table 15 Overview of costs LNG bunkering per bunkering method

	Ship-to-ship bunkering (STS)	Truck-to-ship bunkering (TTS)	LNG terminal-to-ship bunkering via pipeline (PTS)	LNG terminal-to-ship bunkering via bunker vessels
Investment costs	LNG bunkering equipment.	LNG bunkering equipment.	LNG bunkering equipment.	LNG bunkering equipment.
	Bunkering vessels.	Tank trucks (incl. filling station).	Land-based (storage) tanks.	Bunkering vessels.
	License costs/Safety measures/ Training of personnel.	License costs/ Safety measures/ Training of personnel.	License costs/ Safety measures/ Training of personnel.	License costs/ Safety measures/ Training of personnel.
	Installation of quay (optional).	Installation of quay (optional).	Installation of quay (optional).	Installation of quay (optional)[25].
				Land-based (storage) tanks.
Operational costs	Operational costs of bunker vessel.	Operational costs of tank truck.	Operational costs of pipeline.	Operational costs of bunker vessel.
	LNG terminal take-out fee. Transshipment costs from import hub.	LNG terminal take-out fee. Transshipment costs from import hub.	LNG terminal take-out fee. Transshipment costs from import hub.	LNG terminal take-out fee. Transshipment costs from import hub.

3.1.1. Investment costs of LNG bunkering terminals per bunkering method

Investments in LNG bunkering terminals can vary from 15 to 137 million EUR and operational costs can vary from 3 to 17 million EUR a year. DMA (2012) estimates the distribution costs per ton LNG at between 118 and 194 EUR given a pay-back time of 10 years, depending on the size of LNG terminal, the yearly LNG turnover at this terminal and type of bunkering. For example, which investments are made (tank truck or bunker vessels) and how many are assumed to be needed for a specific harbor results in different numbers for these distribution costs per ton LNG.

The focus in this section is on the distribution part of bunkering costs, which are dependent on the type and size of the terminal. Shipping and terminal operations are characterized by high fixed costs and economies of scale as these are capital intensive industries. In this section, a literature overview of the investment and operational costs for the three bunkering options is given (STS, TTS and PTS). The fourth bunkering option is a combination of STS-bunkering and installing an intermediate

[25] The installation of a quay depends on the site-specific issues per harbor, as some harbors do not bunker LNG but if in the future this will happen more, more space might be needed for these specific vessels to bunker at. Therefore this is added as an optional cost.

LNG terminal, of which the costs are given in the overview of the first three mentioned bunkering options. Most investments costs which will be described in this section come from the DMA study, which is the major independent study on LNG bunkering costs.

In the calculations for the cost-benefit analysis in Chapter 5, data from this literature review and the results from interviews will be used.

Ship-to-ship bunkering (STS)

STS-bunkering is the transfer of LNG from one vessel to another vessel. Some non-financial advantages of this bunkering method are that it allows for flexibility in bunkering and location, which can be at sea or at the port. However, bunkering at sea is restricted by weather conditions, such as waves, winds and currents. In addition, STS-bunkering allows for logistical flexibility as bunkering can happen at the same time as other activities while docked, with the quay side free for cargo handling operation and/or passenger embarkation/disembarkation. Also proper training for crew and operators involved with LNG bunkering operations is critical in order to establish and maintain safe bunkering practices (DNV GL, 2014c; DMA, 2012).

STS-bunkering is a suitable method for vessels that have bunker volumes of or above 100 m^3 LNG (basically all maritime vessels). When bunker vessels are moored alongside the LNG-fuelled ship, good mooring opportunities have to be provided. The capacity of bunker vessels may range from 1,000 to 10,000 m^3 (although also smaller ships are currently used in some ports) (DMA, 2012).

Loading the LNG feeder vessel often takes place at an import terminal or storage facility. LNG bunker vessels are smaller than LNG feeder vessels. Supplying the bunker vessel will be done at dedicated jetties that accommodate small size LNG carriers or feeders and bunker vessels. These jetties or quays can be constructed close to the import terminal or at intermediate LNG terminals (DMA, 2012). The investment costs depend on the distance from the loading point to the LNG import terminal and the size of bunkering ship.

An overview for the investments for this scenario is given in Table 10. Most of the data is from the DMA study as this study presents the costs for several types of bunkering ships. The data from CBSS (2013) has mainly been used for estimating costs for the installation of a new LNG terminal, including the installation of a quay and its accompanying communication and lighting facilities. Regarding the investment costs for bunkering ships, there is a large difference between the numbers from the DMA study and the CBSS study (13 million EUR for the same vessel type). Since it is possible to bunker at an existing quay and normal deck lighting should be sufficient in most cases when bunkering happens at night (SMTF, 2010), investment costs for quays, communication and lighting installations are optional in case of building a new LNG terminal.

Table 16 Investments and operating costs of LNG bunkering with STS-scenario

Type of investment	Unit	Price	Source
Investment costs LNG bunkering ship[26] ▪ 1,000 m^3 ▪ 3,000 m^3 ▪ 4,000 m^3 ▪ 10,000 m^3	EUR	 20 million 28 million 32 million 41 million	(DMA, 2012)
Operational costs LNG bunkering ship[27] ▪ 1,000 m^3 ▪ 3,000 m^3 ▪ 4,000 m^3 ▪ 10,000 m^3	EUR/year	 1,8 million 2,4 million 2,5 million 3,2 million	(DMA, 2012)
Engineering services (documentation, supervision)	% of total investment cost	6	(CBSS,2013)
Transport cost of bunker vessel from LNG import harbor to receiving vessel	EUR/t HFO	530/t	(DMA, 2012)
Transshipment cost from import hub (per million m^3 at 1% price surcharge)	EUR	2 million	(DMA, 2012)
LNG terminal take-out fee	EUR	8/m^3	
Safety/wage technical personnel/evaporation LNG		unknown	

Tank truck-to-ship bunkering (TTS)

TTS bunkering is the transfer of LNG from a truck to a vessel which is moored to a dock or jetty. A flexible hose or flexible connection arm is used in this bunkering option. A tank truck can carry about 50 m^3 of LNG[28] and can transfer this in approximately an hour. The loading of LNG can happen at any jetty, thus only require a port that permits shore side LNG bunkering from a jetty. Transferring LNG via TTS for large volume transfers is limited by the transfer rate and number of trucks required (DNV GL, 2014).

Tank trucks are a flexible way of bunkering vessels with (very) small LNG bunker volumes. This option is suitable for receiving vessels with up to 200 m^3 given that the turnaround time is long enough. An overview for the investments for this scenario is given in Table 17.

[26] These bunkering ships have a lifetime of 20 year, base year is unknown.
[27] This study does not specify maintenance costs per type of bunkering vessel.
[28] A tank truck was used of about 80 m^3. Tank trucks cannot be filled up to the maximum.

Table 17 Investments and operating costs LNG bunkering with TTS-scenario

Type of investment	Unit	Price	Source
LNG tank truck (50 m^3)[29]	1 unit	0.2 million EUR	CBSS, 2013
LNG tank truck (50 m^3) incl. filling station[30]	1 unit	80 million EUR	DMA, 2012
Operational costs of tank truck	EUR/year	40 thousand	DMA, 2012
Transport cost of tank truck from LNG import harbor to receiving vessel	EUR/l gasoline	Depending on the distance	
LNG terminal take-out fee	EUR	3,750 per load	
Safety/wage technical personnel/evaporation LNG		Unknown	

LNG terminal-to-ship via pipeline bunkering (PTS)

PTS bunkering is the transfer of LNG from a fixed storage tank on land through a pipeline with a flexible end piece or hose to a vessel which is moored to a dock or jetty. Because onsite storage can be scaled, larger volumes of LNG can be bunkered when compared to TTS. The transport of LNG to the storage tank can happen in several ways, for example by truck or bunker barge. It is also possible to allow for onsite production of LNG via a small-scale liquefaction facility. As there is a fixed location for bunkering, the receiving vessel will have to make arrangements to allow bunkering at the same time as other activities, to save time spent at the port.

An intermediate LNG storage location with bunkering capability requires an LNG storage tank and supply of LNG to the onsite storage by a feeder vessel, tank trucks, pipelines or a small-scale liquefaction plant receiving natural gas (DNV GL, 2014). LNG storage tanks can vary from small (200 m^3) to quite large (100,000 m^3).

Storage tanks have to be placed close to the berths when bunkering operations are performed due to technical, operational and economic difficulties with long pipelines. Because of limited space in combination with the safety measures and other terminal activities, TPS is not always possible (DMA, 2012).

An overview for the investments with an intermediate LNG terminal for this scenario is given in Table 18. In this table, the investment costs for the supply of LNG to the intermediate terminal via feeder vessels or tank trucks.

[29] Lifetime unknown.
[30] Lifetime of 10 years.

Table 18 Investments and operating costs LNG bunkering with PTS-scenario

	Type of investment	Unit	Price	Source
LNG supply by feeder vessel	Cost LNG feeder vessel (20,000 m^3)	EUR	57 million	(DMA, 2012)
	LNG terminal take-out fee	EUR	8/m^3	
	Transport cost of feeder vessel from LNG import harbor to intermediate LNG terminal.	EUR/t HFO	530/t	(DMA, 2012)
LNG supply by truck	LNG tank truck LNG tank truck (50 m^3) incl. filling station Operational costs of tank truck	1 unit 1 unit EUR/year	0.2 million EUR 80 million EUR 40 thousand	(CBSS, 2013) (DMA, 2012) (DMA, 2012)
	LNG terminal take-out fee	EUR	3750 per load	
	Transport cost of tank trucks from LNG import harbor to intermediate terminal	EUR/l	Differs per country	(EC, 2015)[31]
LNG bunkering by pipeline	Terminal (3,500–5,000 m^3) Receiving and regasification terminal, 500 m^3 storage tank	EUR EUR	11-13 million 5 million	(DGC, 2012) (DCG, 2012)
	LNG infrastructure on jetty	EUR	15 million	(DMA, 2012)
	Acquisition of land	EUR/ha	Depends on port	(CBSS, 2013)
	Land-based storage tanks ▪ 700 m^3 (thermos tank) ▪ 20,000 m^3 ▪ - 50,000 m^3	 EUR EUR EUR	 7 million 40 million 80 million	(DMA, 2012)
	Price of connection to natural gas pipeline Pipeline and manifold connected to tank	EUR/m EUR	31 0.5 million	(CBSS, 2013) (DMA, 2012)
	Operational costs of pipeline	EUR/year	50 thousand	(DMA, 2012)
	Constructing quay for bunkering	EUR/m EUR per berth	31 thousand 20 million	(CBSS,2013) (DMA, 2012)
	Communication and engineering works (electricity, lighting, transformer station)	EUR	78 thousand	(CBSS,2013)
	Engineering services (documentation, supervision)	% of total investment cost	6	(CBSS,2013)
	Administrative costs (application and license costs)	EUR	0.4 million	(DMA, 2012)
	Safety/wage technical personnel/evaporation LNG		Unknown	

[31] European Commission, 2015. Weekly Oil Bulletin. https://ec.europa.eu/energy/en/statistics/weekly-oil-bulletin.

3.1.2. Distance to LNG terminal

The fuel costs of LNG bunkering depend significantly on whether the LNG-fuelled vessel is near an LNG import terminal or an intermediate LNG terminal.

A particular insight on the investment costs is proposed by the case studies that are taken in this research and especially on the relevance and impact of the availability and distance to an LNG import terminal or LNG intermediate terminal. Table 19 gives an overview of availability of an import terminal and a rough estimation of the distance to this LNG terminal via road for the selected case studies in Section 4.2.5. Here, only the import terminals relatively close to the case study harbors which will be introduced in Chapter 4 are presented. Constanta does not have an import terminal in the vicinity. This port is currently considering investing in an LNG import terminal (please refer to Chapter 4).

Table 19 Overview availability of LNG terminals per case and distances to port

	Nearby LNG import terminal	Road distance between port and import terminal (km)	Sea distance between port and import terminal (km)
Stockholm (Sweden)	Nynäshamn (SE)	60	200
Dover (UK)	Grain Terminal, Isle of Grain (UK)	100	100
	South Hook near Milford Haven(UK)	525	730
	Dragon near Milford Haven(UK)	525	730
	Zeebrugge (BE)	-	120
Calais (FR)	Zeebrugge (BE)	130	115
	Dunkirk (FR)	45	40
Southampton (UK)	Grain Terminal, Isle of Grain (UK)	200	325
	South Hook(UK)	375	550
	Zeebrugge (BE)	-	344
	Dunkirk (FR)	-	295
Kristiansand (NO)	Øra nearby Fredrikstad (NO)	230	235
	Fredrikshavn (DK)	-	220
Civitavecchia (IT)	Panigaglia near La Spezia (IT)	135	290
Antwerp (BE)	Zeebrugge (BE)	95	160
	Rotterdam (NL)	120	290
HaminaKotka (FI)	Helsinki (FI)	135	160
Marseille-Fos (FR)	Fos Tonkin (FR)	0	0
	Fos Cavaou (FR)	0	0
Cartagena (ES)	Cartagena (ES)	0	0
Constantza (RO)	Marmara Ereglisi (TR)	944	520

Source: gasinfocus.com; sea-distances.org.

The table shows that most of the selected case harbors have an import terminal at relatively close distance which allows for bunkering via tank trucks or vessels.
In addition, it shows where the supply of LNG could come from for the selected harbors, given the distance to the import terminal. In some cases the distance is quite large leading to the hypothesis that considering an intermediate LNG terminal would turn out to be a more economical configuration.

According to the DMA research (DMA, 2012), an intermediate LNG terminal is economical if the distance to the import terminal is longer than what is economically feasible, namely up to 100 nautical miles for bunker vessels and 350-600 kilometers for trucks. This will be analyzed in Chapter 5, following specific calculation developed for this study.

3.2. Cost-structure of LNG ships and of alternative ships sailing in the SECA

This section will compare the total ownership costs of LNG-fuelled ships (dual fuel or spark-ignited gas engine) with the costs of a ship with a combination of HFO and a scrubber or sailing on MGO/MDO. An overview of investment costs for different compliance design options, for both retrofit and new builds, is presented in Table 20 to Table 24. Generally, there are no large differences in operational costs apart from the fuelling costs, except for additional equipment such as scrubbers and SCR/EGR[32] (DMA, 2012), which are given in Table 22, Table 23 and Table 24.

Spark-ignited lean-burn gas engine

The specific data for different parts of the LNG fuel system of a vessel equipped with a four stroke spark ignition engine are given in Table 20, including installation costs. The data from SSPA (2012) are total investments costs, while the DMA research specifies the costs for different types of investment.

Table 20 Estimated investment costs for vessels with spark-ignited gas engine

Type of investment	Retrofit	New build	Source
Total investment costs four stroke spark-ignition engine	740 EUR/kW	1,300 EUR/kW	SSPA, 2012
Investment gas engine		350 EUR/kW main	DMA, 2012
Investment Generators, Electric system, (Propulsion, Steering)		400 EUR/kW main	DMA, 2012
Investment LNG fuel gas supply system + tank	245 EUR/kW main	245 EUR/kW main	DMA, 2012
Investment conversion HFO -> LNG	175 EUR/kW main		DMA, 2012
Installation cost	150 EUR/kW main + aux	100 EUR/kW main + aux	DMA, 2012

32 SCR= Selective Catalytic Reduction; EGR= Exhaust Gas Recirculation.

Low-pressure dual fuel engine

The investments costs for a LNG-fuelled ship with a four stroke dual fuel engine are the same costs as a spark-ignition engine (SSPA, 2012). The DMA research provides more specific data for different parts of the LNG fuel system, as given in Table 21.

Table 21 Estimated investment costs for with low-pressure dual fuel engine

Type of investment	Retrofit	New build	Source
Total investment costs engine	740 EUR/kW	1,300 EUR/kW	SSPA, 2012
Investment gas engine for dual fuel		350 EUR/kW main	DMA, 2012
Investment Generators, Electric system		400 EUR/kW main	DMA, 2012
Investment LNG fuel gas supply system + tank	245 EUR/kW main	245 EUR/kW main	DMA, 2012
Investment conversion HFO -> LNG	175 EUR/kW main		DMA, 2012
Installation cost	150 EUR/kW main + aux	100 EUR/kW main + aux	DMA, 2012

High-pressure dual fuel engine

The investment costs for vessels equipped with this type of engine are specified in different types of investments and given in Table 22.

Table 22 Estimated costs for vessels with high-pressure dual fuel engine

Type of investment	Retrofit	New build	Source
Total investment costs two stroke high pressure dual fuel engine	655 EUR/kW	1,400 EUR/kW	SSPA, 2012
Investment dual fuel engine		280 EUR/kW main	DMA, 2012
Investment SCR (incl. installation new built)	45 EUR/kW main + aux	45 EUR/kW main + aux	DMA, 2012
Installation cost SCR/EGR	9 EUR/kW main + aux		DMA, 2012
Investment Generators, Electric system, Propulsion, Steering		400 EUR/kW aux	DMA, 2012
Investment LNG fuel gas supply system + tank	245 EUR/kW main	245 EUR/kW main	DMA, 2012
Investment conversion HFO --> LNG/HFO	40 EUR/kW main		DMA, 2012
Installation cost	150 EUR/kW main + aux	100 EUR/kW main + aux	DMA, 2012
O&M SCR	0.007 EUR/kWh main		DMA, 2012

HFO and scrubber

The costs of a vessel on HFO engine including a scrubber and SCR is 560 EUR/kW for retrofit vessels and 2,060 EUR/kW for new vessels, according to the SSPA study (2012). Regarding the costs of scrubbers, the data on this differs from 3 million EUR (CNSS, 2013). These costs depend on the type of scrubber and are not specified per kW, therefore the data from the DMA study (DMA, 2012) and CE Delft (CE Delft, 2015) are used in this study. The investment costs of this type of engine specified in different types of investments are given in Table 23.

Table 23 Estimated investment costs for vessels with HFO and scrubber (DMA, 2012)

Type of investment	Retrofit	New build	
Investment scrubber (incl. waste storage)	150 EUR/kW main	150 EUR/kW main	(DMA, 2012)
Investment open scrubber	156 EUR/kW	122 EUR/kW	(CE Delft, 2015)
Investment scrubber open loop	200 EUR/kW	100 EUR/kW	(CE Delft, 2015)
Investment scrubber closed loop	400 EUR/kW	200 EUR/kW	(CE Delft, 2015)
O&M costs scrubbers	2.5 EUR/MWh		(DMA, 2012)
O&M costs scrubbers (large ships)	0.3 EUR/MWh		(CE Delft, 2015)
O&M costs scrubbers (small ships)	0.8 EUR/MWh		(CE Delft, 2015)
Investment SCR (incl. installation new built)	45 EUR/kW main + aux	45 EUR/kW main + aux	(DMA, 2012)
Investment engine		180 EUR/kW main	(DMA, 2012)
Investment Generators, Electric system, Propulsion, Steering		240 EUR/kW aux	(DMA, 2012)
Installation cost scrubber	225 EUR/kW main	180 EUR/kW main	(DMA, 2012)
Installation cost SCR/EGR	9 EUR/kW main + aux		(DMA, 2012)
O&M cost SCR	0.007 EUR/kWh main		(DMA, 2012)

MGO/MDO

The investment costs of this type of engine specified in different types of investments are given in Table 24.

Table 24 Estimated investment costs for vessels with MGO/MDO (DMA, 2012)

Type of investment	Retrofit	New build	Source
MGO – engine conversion, SCR and EGR	180 000 USD + 75 USD/kW	140 000 USD + 63 USD/kW	SSPA, 2012
Investment motor conversion/fuel cooler/fuel pumps	130,000 EUR	100,000 EUR	DMA, 2012
Investment SCR (incl. installation new built)	45 EUR/kW main + aux	45 EUR/kW main + aux	DMA, 2012
Installation cost SCR/EGR	9 EUR/kW main + aux		DMA, 2012
Investment engine		180 EUR/kW main	DMA, 2012
Investment Generators, Electric system, (Propulsion, Steering)		240 EUR/kW aux	DMA, 2012
O&M costs SCR	0.007 EUR/kWh main		DMA, 2012

3.3. Overview costs per type of vessel

3.3.1. Total costs of SECA compliance as a function of LNG prices (new builds)

This section analyses the total cost of compliance with the EU Marine Fuels Sulphur Directive for a number of vessels. There are three ways to comply with the directive:

1. By using a petroleum fuel with a sulphur content of 0.1% or less, e.g. a marine distillate fuel.
2. By using conventional fuel and a scrubber that reduces the concentration of sulphur oxides in the exhaust gas to a level that would be achieved when using a petroleum fuel of 0.1% sulphur content.
3. By using LNG, which contains no sulphur.

The first option requires using fuel that is more expensive, but does not require any investments in the tanks, pipings, engine or exhaust of a ship. The second option requires an investment in a scrubber, the third in LNG tanks, piping and engines. Hence, the first option has no additional capital expenditures but higher operational costs, whereas the second and third options have higher capital expenditures and lower fuel costs.

The total costs of compliance compare the sum of capital and fuel expenditures for all three options. They are shown for different ships as a function of the LNG price in Figure 23 through Figure 25 for general cargo ships, container ships and platform supply vessels, respectively. The ship types and corresponding fuel demand are presented in more detail in Chapter 4 and the assumed values for total investment costs of ownership can be found in Section 3.4 and the assumed fuel prices are presented in Chapter 5. The LNG bunkering price is expressed relative to the HFO-price. The price difference between HFO and MGO is based on the 2020 price difference, with MGO being 44% more expensive than HFO per unit of energy.
For each LNG price as proportion of the HFO-price, the total cost of ownership is calculated and presented for each type of vessel in the following figures.

The figures show that the total cost of ownership for these vessels is higher when using MGO than when using HFO in combination with a scrubber. For most types of vessels, the costs of LNG bunkering are lower compared to costs of bunkering HFO until the price of LNG is around 20-10% lower than the HFO-price (30% for container vessels and cargo vessels) and lower than costs of bunkering MGO until the price of LNG is around 10% higher than the HFO-price.

Figure 24 Annual total costs of compliance for new build general cargo vessels for different LNG-HFO proportions for the year 2020

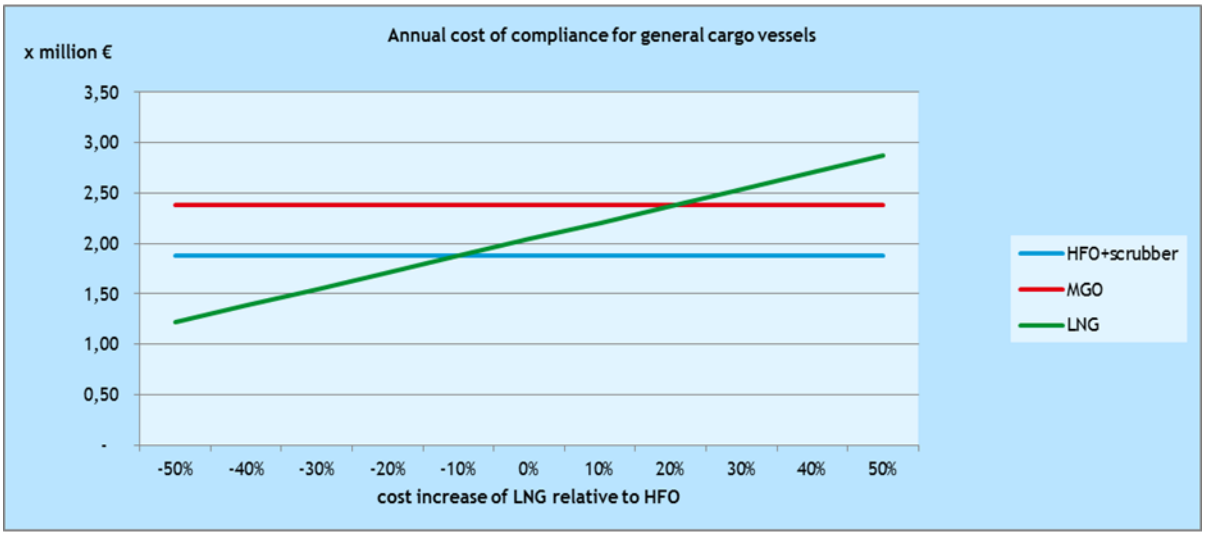


Figure 25 Annual total costs of compliance for new build container vessels for different LNG-HFO proportions for the year 2020

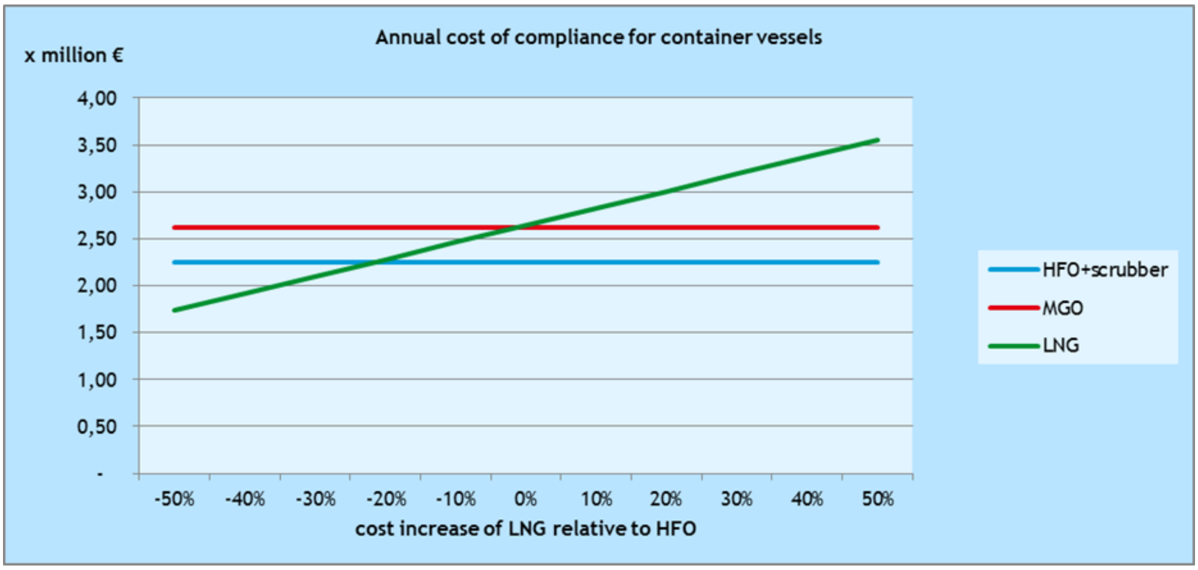


Figure 26 **Annual total costs of compliance for new build platform supply vessels for different LNG-HFO proportions for the year 2020**

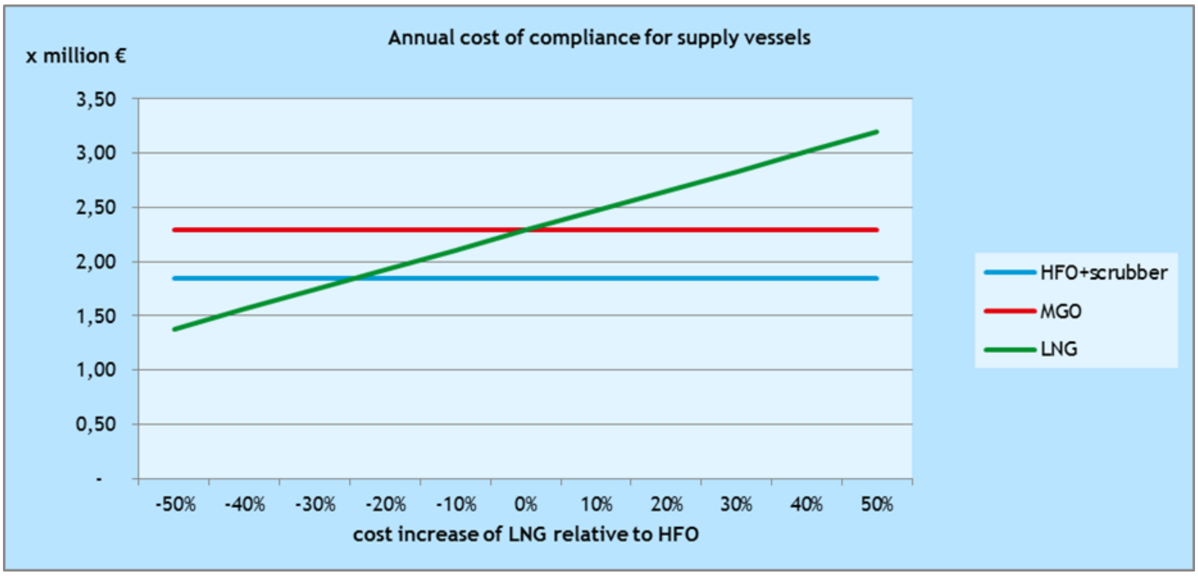


Figure 27 and Figure 28 show the Annual total costs of compliance of ferries and cruise ships as a function of the LNG price. For ferries, specific information on the total additional investment in the ship was used, which was about 30% lower than the estimate based on the figures presented in Section 3.2. The additional investment for cruise ships is scaled accordingly.

Figure 27 **Annual total costs of compliance for new build ferries for different LNG-HFO proportions for the year 2020**

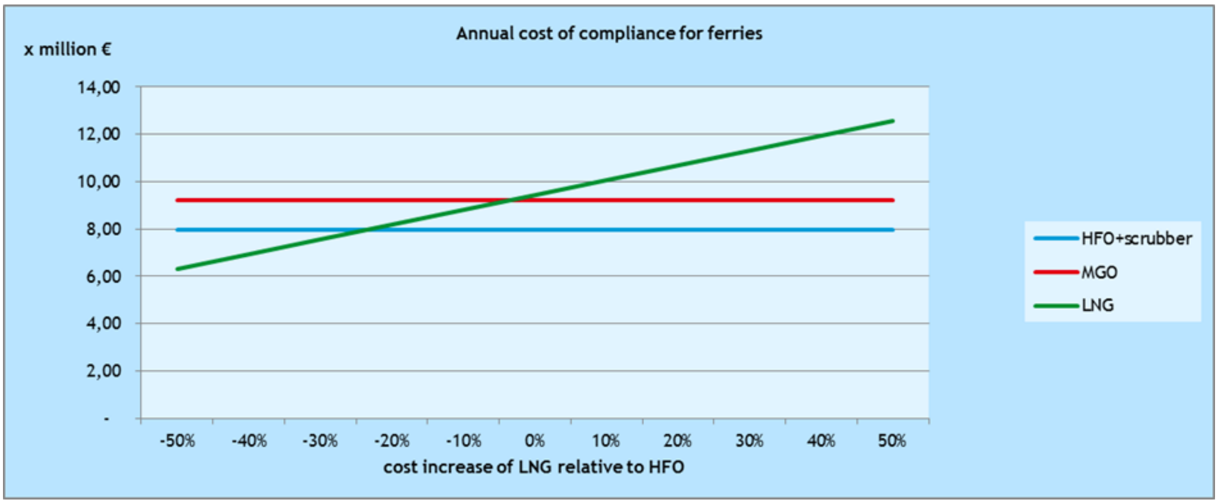
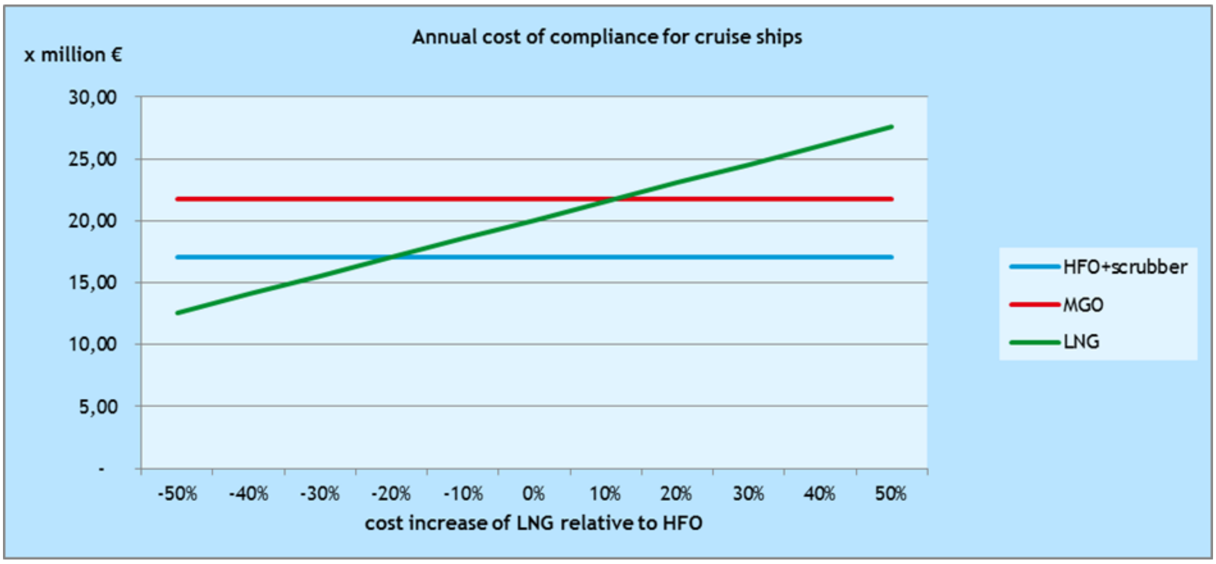


Figure 28 Annual total costs of compliance for new build cruise ships for different LNG-HFO proportions for the year 2020

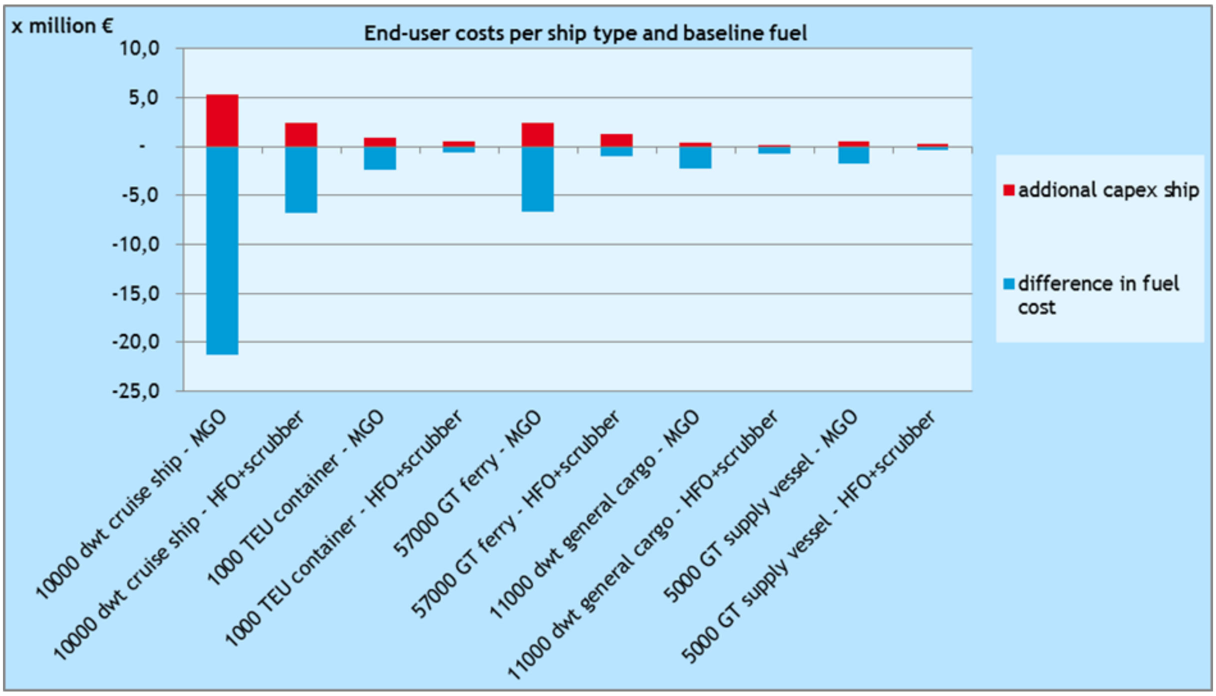


3.3.2. End-user costs for different ship types

The additional investment costs for LNG-vessels and the difference in fuelling costs are presented in Figure 29, for several ship types (for a definition of the ships, refer to Chapter 4. This figure shows that the additional investment costs depend on the type of LNG-fuelled vessel, with cruise ships and ferries having the largest investment costs.

The difference in fuel costs compared to HFO or MGO bunkering depends on the annual fuel demand per ship type. Therefore, the cruise ships and ferries have the largest benefits from the lower fuel costs.

Figure 29 End-user costs for investment of LNG investment compared to other options for different ship types



3.4. Conclusion

The distribution of LNG from the import terminal to the receiving vessel requires several investments, which depend on the type of bunkering and the distance to the import terminal (Table 25). As a result, the LNG price for the end-user will be higher than the LNG import price. This chapter has provided an overview of the most important investment costs for LNG bunkering. Chapter 5 will provide the costs per type of ship, depending on the scenarios, as well as a comparison of fuel prices between LNG and HFO.

Table 25 Estimated range of bunkering infrastructure expenditures excluding transhipment costs

Type of bunkering	Million EUR
Ship-to ship	23-73
Tank truck-to-ship	0.2-100
Pipeline-to-ship	33-237

The investment of LNG-fuelled vessels is not as high as vessels fuelled with other fuels, this is due to the option for compliance with air emissions regulations, according to the SSPA data. It is difficult however to show when the LNG ships are cost-competitive without further calculations. Therefore, a more detailed calculation will be done in Chapter 5, to look at the investment cost for our chosen type of vessels given their technical specification, operational profile and business specifics. A short overview of the estimation of costs of LNG vessels is given in Table 26.

Table 26 Comparisons of total cost of ownership per type of fuel

	MGO /MDO	HFO + scrubber	LNG (retrofit)	LNG (new)	LNG dual fuel (retrofit)	LNG dual fuel (new)
Capital expenditures engine	180 EUR/ kW main	225-400 EUR/ kW main + 240 EUR/kw aux	320 EUR/ kW main + 150 EUR/kw main + aux	995 EUR/ kW main + 100 EUR/kw main + aux	340-420 EUR/kW + 150 EUR/kw main + aux	≈ 950-995 EUR/kW + 100 EUR/kw main + aux
Capital expenditures scrubber		150 EUR/kW main				
Operational expenditure scrubber		2.5/EUR/MWh				
Fuelling	Depends on case study	Depends on case study	Depends on case study	Depends on case study	Depends on case study	Depends on case study
Operational costs	Depends on case vessel	Depends on case vessel	Depends on case vessel	Depends on case vessel	Depends on case vessel	Depends on case vessel

4. LNG cases

4.1. Introduction

In order to get an overview of the potential developments of the European market for LNG as a marine fuel, it is necessary to evaluate the impact of such a transition on both the supply side (ports) and the demand side (ship owners) across Europe. Therefore this chapter identifies trends and cases that will later serve as the main input for the cost-benefit analyses included in the next chapter.

The first part of the chapter focuses on the selection of relevant aspects for three scenario dimensions: vessel segment, port (maritime region), and time horizon. First, five vessel segments are identified as being promising areas for LNG uptake in the considered time frame. Next, a sample of ten ports is selected to represent the large variety in general characteristics (size, focus, growth perspectives) and LNG infrastructure maturity that ports across Europe display. The following step consists of creating ‘port – vessel segment’ combinations by pairing each of the five vessels with the ports where that vessel segment accounts for a significant or rapidly growing share of the traffic.

The selected cases are developed in the second part of the chapter.
This process begins with profiling the current state of play, as well as planned developments envisioned for each port and vessel segment. The following subjects will be discussed in this chapter:

- Ports:
  - main characteristics of the vessel segment associated with the port;
  - port layout;
  - current bunkering infrastructure (all fuel types);
  - current and planned LNG bunkering infrastructure.
- Typical ship for each of the considered vessel segments:
  - Technical and operational characteristics;
  - Operations, safety, environment, financial implications of switching to LNG.

Extended information for each port and vessel segment can be found in Annex A and Annex C.

Next, possible supply infrastructure options are described, taking into account the effects LNG bunkering may have on costs (based on the input from Task 2), operations, safety and other areas. The scenario outcomes are derived from considering which LNG bunkering options best fit the characteristics and development trends of each ‘port – vessel type’ combination.

4.2. Selection of cases

4.2.1. Introduction

As was discussed in Chapter 2 and Chapter 3, the uptake of LNG depends on several drivers. These include:

- Emission regulations. As discussed in Chapter 2, a distinction must be made between different sea basins, for instance between the Northern and Western Europe ECA and the non ECA regions.
- Bunkering profile of the vessel passed on technical and operational characteristics.
- Availability of the supply of LNG.
- Financial (CAPEX & OPEX), operational (supply side availability) and other consequences of switching to LNG.

Based on the drivers mentioned in Chapter 2, cases were selected on three dimensions: maritime region, ship type and time frame. The relevance of each dimension will be briefly illustrated below.

The technical and operational profiles of a ship are important to assess on the potential uptake of LNG. Important aspects in this sense are:

- Technical aspects of the vessel:
  – ship size;
  – engine size;
  – tank size;
  – layout of the vessel.
- Operational characteristics:
  – function of the vessel (freight, passenger, other);
  – average sailing speed;
  – operational hours per year;
  – sailing routes (fixed route or widespread reach);
  – time spend in ECA;
  – time between bunkering.

The above mentioned aspects will influence the financial (CAPEX & OPEX), operational (supply side availability, easiness to switch bunkering fuel) and other (i.e. safety) consequences of switching to LNG.

4.2.2. Selection of ship types

The following table presents an overview of the maritime worldwide fleet.
The maritime fleet in 2015 consists of 110,100 vessels and is roughly equally divided into cargo and non-cargo vessels. Research shows that roughly 25% of the world fleet operates (partly) in Europe (TNO ; MARINTEK ; TML ; ISL, 2015). The table furthermore shows that growth potential up to 2030 is significantly larger for cargo vessels than non-cargo vessels.

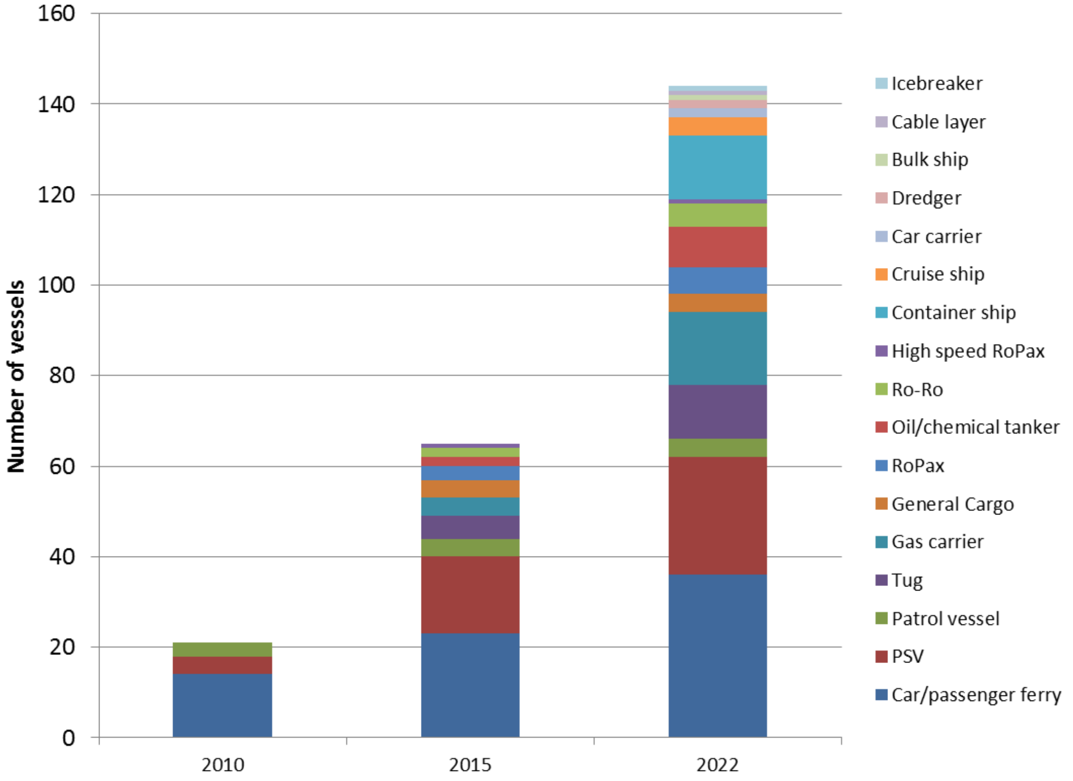
Table 27 Number of vessels and average vessel sizes, 2015 compared to 2030

	Vessel type		Number of vessels		Freight work	
	2015	**2030 Forecast**	**2015**	**2030 Forecast**	**2015**	**2030 Forecast**
Dry Bulk	69,300	98,000	11,200	15,300	22,000	42,400
General Cargo	6,200	7,000	17,000	29,500	2,600	5,100
Container	44,300	77,000	5,600	6,200	9,900	19,100
Reefer	6,000	7,000	1,050	2,300	200	500
RoRo & Vehicle	8,900	11,000	2,600	4,200	600	1,200
Oil Tanker -above 80'dwt mainly crude	185,800	189,000	2,400	4,500	11,000	21,200
Oil Tankers -below 80'dwt mainly product	10,700	12,000	5,400	9,400	2,100	4,100
Chemicals	19,000	29,000	5,400	6,800	2,500	4,800
LNG & LPG	29,000	46,000	1,800	2,100	1,700	3,200
RoPax	1,800	2,300	2,308	5,400	100	300
Average Cargo Vessels	**31,500**	**42,500**	**54,800**	**85,700**	**52,700**	**101,900**
Ferry-Pax only	170	200	3,300	5,600	10	20
Cruise	4,000	4,800	550	900	20	40
Yacht	170	200	1,750	1,750	0	0
Offshore	1,700	1,800	6,500	6,500	140	150
Service	540	600	18,100	18,100	90	100
Fishing	180	180	22,100	22,100	50	50
Other	1,100	1,100	3,000	3,000	20	20
Average Other Vessels	**570**	**600**	**55,300**	**60,500**	**330**	**380**
All Vessels	**15,600**	**19,500**	**110,100**	**146,200**	**53,000**	**102,300**

Source: (TNO ; MARINTEK ; TML ; ISL, 2015). TNO e.a. (2015), GHG emission reduction potential of EU-related maritime transport and on its impacts.

According to recent figures from (DNV GL, 2015a) the number of LNG-fuelled vessels within the world fleet is currently limited, but increasing rapidly.
The current global operational LNG fleet consists of 48 vessels. Another 50 vessels are scheduled for delivery by the end of 2018. As shown in Figure 30, the largest share of this fleet is dominated by non-cargo vessels such as regional ferries, patrol vessels and platform supply vessels (PSV). Taking the planned ships into account (situation of the year 2022), more than 60% of the LNG-fuelled vessels belong to this group of vessels. However, it is also observed that a growing share of the LNG vessels is expected for container ships, general cargo ships and chemical tankers.

Figure 30 Breakdown of LNG-fuelled fleet by vessel type for the current and planned fleet (short) sea shipping (number of ships)



Source: (DNV GL, 2015a), LNG-fuelled vessels. Ship list – Vessels in operation and vessels on order.

For this scenario study, a mix of cargo and non-cargo vessels is proposed. This includes a mix of vessel types that are currently already using LNG as a fuel and ship types that will likely do so in the future. The following ship types are included:

- cars and passenger Ferries (Ro-Pax);
- platform supply vessels (PSV);
- cruise ships;
- container vessels; and
- general cargo vessels.

4.2.3. Selection of ports

The geographical location of the scenario was chosen based on the following criteria:

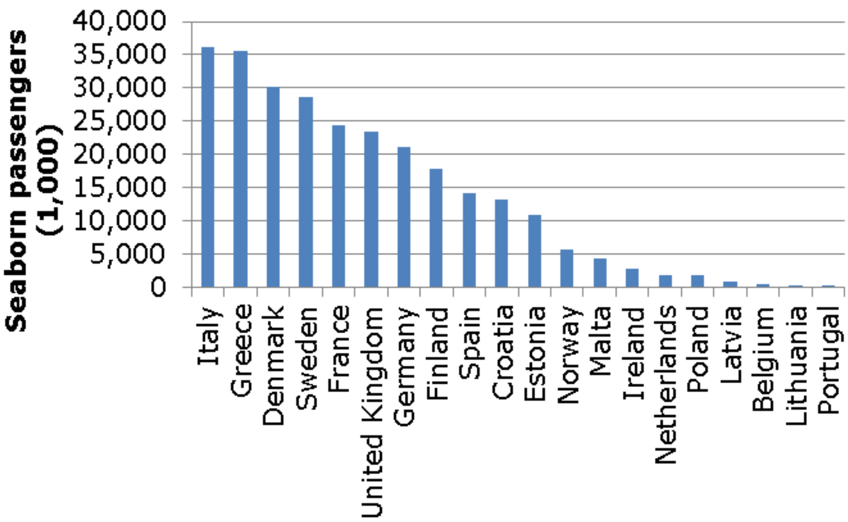
- port is part of Northern and western Europe ECA or not (a mix of this was required);
- LNG import terminal available or not (a mix of this was required);
- ports have a large share of calls in one of the defined ship segments;
- port is part of the Ten-T core network[33]; and
- the ports should represent different member states to identify trends for the wider European Community.

Based on these criteria for each shipping segments some main ports were chosen, for which the expected data availability was high.

Car and passenger ferries

Figure 30 presents an overview of the seaborne non-cruise passengers in countries in the European Union. The main countries in the Northwest ECA area are strongly interlinked and mainly involve international transport between namely Denmark – Sweden and France – United Kingdom. Ferry transport in the Mediterranean area (Italy and Greece) is mainly national transport between mainland and the Isles.

Figure 31 Seaborne non-cruise passengers in countries in the European Union in 2013 (1,000s)



Source: (Eurostat, 2015).

33 An overview of the TEN-T core Network, including detailed maps of the maritime core ports can be found through this link: http://ec.europa.eu/transport/infrastructure/tentec/tentec-portal/site/en/maps.html

For the case studies three ports were chosen:

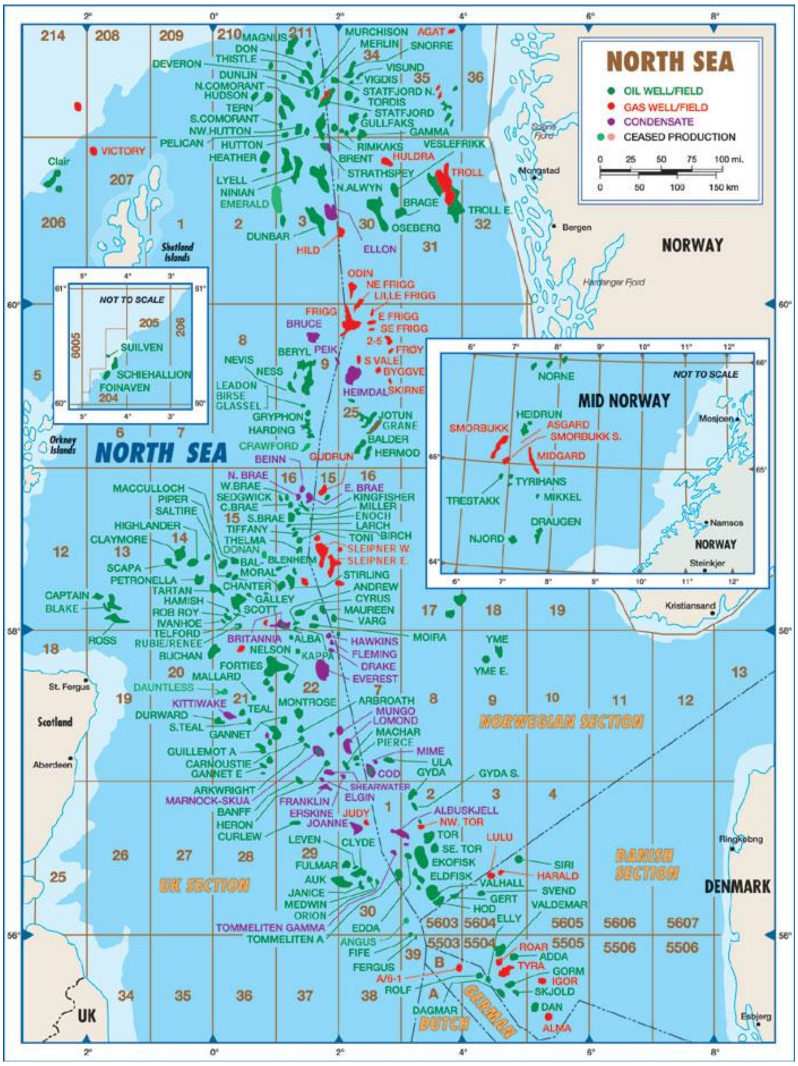
- Civitavecchia (IT)(together with cruise - see below);
- Stockholm (SE);
- Dover (UK).

Platform supply vessels

Platform supply vessels (PSVs) are used for supplying offshore locations, primarily for the oil and gas industry. No general statistics are available on port calls by PSVs. Selection was therefore based on the location of oil and gas fields, which are primarily located in the North Sea.

Platforms here can be found in northern and southern part of the North Sea (see the following figures). As shown in the figures, the majority of the fields are located in the UK and Norway.

Figure 32 Locations of oil and gas fields in the North Sea



Source: (Acorn Petroleum Services, 2013).

For this study, a port in Norway was chosen:

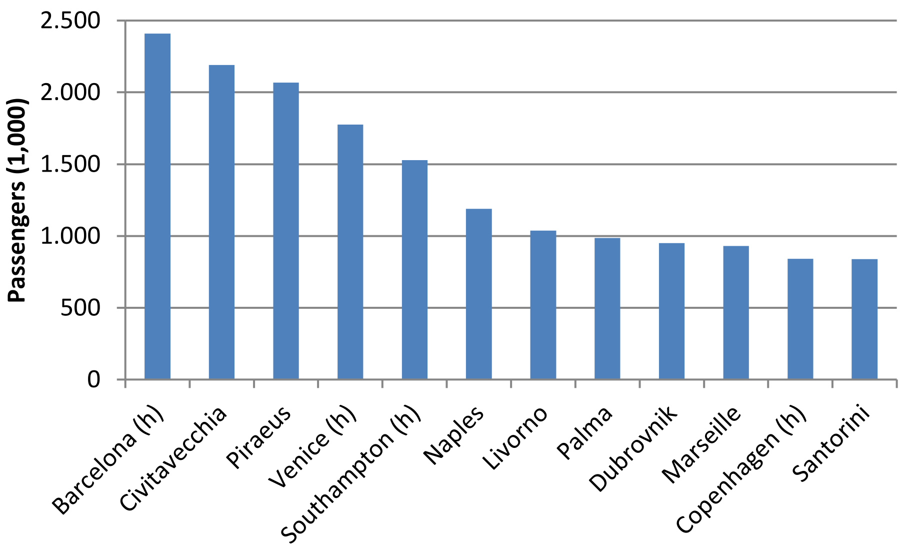
- Port of Kristiansand (NO).

Cruise ships

The following figure presents the major cruise ports in the Europe (based on number of passengers). Cruise ports can be distinguished by home ports (origins and final destination of the cruise ship) and stops. Main relevance in the statistics is that passengers (and also ships) are counted twice (departure and final arrival).

The main cruise ports found in the Mediterranean are located in Italy, Spain and Greece.

Figure 33 Major cruise passengers ports in the European Union in 2012 (1000s of passengers)



Source: (Ashcroft and Associates, 2013).

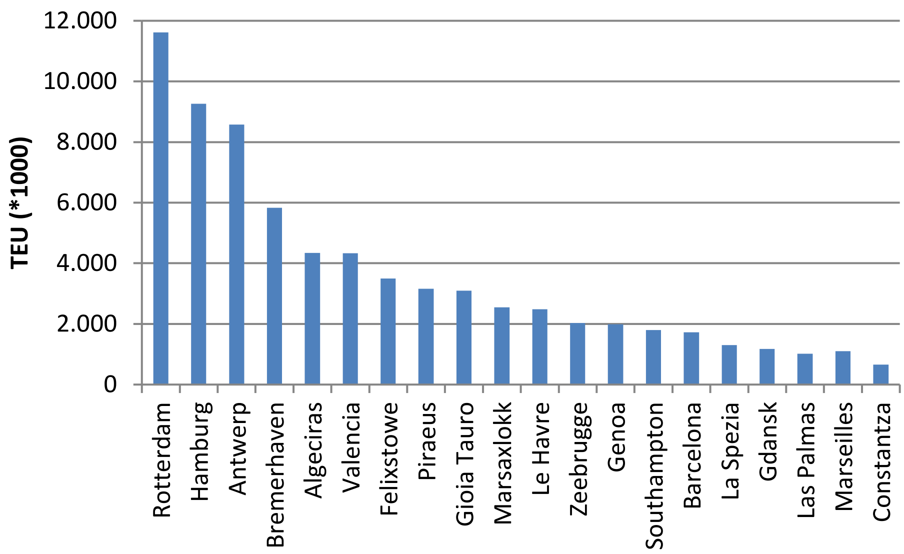
Three ports were chosen for the cases:

- Civitavecchia (IT): the main cruise stop in Europe (together with ferries – see above);
- Marseilles-Fos (FR): together with the container port (see below);
- Southampton (UK); the main Northwest European cruise port.

Container vessels

The main container ports in Europe can be found in Hamburg – Le Havre range and in the Mediterranean (see Figure 34).

Figure 34 Major Container ports in the European Union in 2013 (1,000s of TEU)



Source: Rotterdam Port Authorities, (2014); Vlaamse Havencommissie, Grand Port Maritime de Marseille, (2014) and Constanza Port, (2015).

Three ports were chosen for development of cases:

- Antwerp (BE): large container port in Northwest Europe;
- Marseilles-Fos (FR): together with the Cruise port (see before);
- Constantza (RO): main container port for the Black Sea area.

General cargo

The selection for general cargo ports was based on three criteria:

- countries/marine areas that have not yet been covered in the previous section;
- current or future LNG import terminals;
- TEN-T port.

Based on these criteria the following ports were chosen:

- Cartagena (ES): Ten-T bulk port (2.3 million ton) and the location of a Mediterranean LNG import terminal;
- HaminaKotka (FI): Second port of Finland (1.2 million tons) and location of a planned LNG terminal.

4.2.4. Selection of relevant time scope

The time scope for the case selection mainly depends on relevant EU regulations, as discussed in Task 1. Important years for possible adaptation to LNG are:

- 2015: Introduction of the 0.1% sulphur limit in the SECAs (SO_x Emission Control Areas) of the North Sea and East Sea;
- 2020: The EU Marine Fuels Sulphur Directive obliges to use fuel with a sulphur content of not more than 0.5% m/m when sailing in territorial seas, exclusive economic zones, and pollution control zones of EU Member States;
- 2025: LNG fuelling infrastructure needs to be implemented in maritime ports that are part of the TEN-T core network under the clean power for transport strategy.

4.2.5. Final selection of cases

Table 28 summarizes the selected cases.

Table 28 Selection of cases

	Northern and Western Europe ECA	Southern and Eastern Europe
Car and passenger ferries	Stockholm (SE), Dover (UK)	Civitavecchia (IT)
Platform supply vessels	Kristiansand	
Cruise	Southampton (UK)	Civitavecchia (IT), Marseille-Fos (FR)
Container vessels	Antwerp (BE)	Marseille-Fos (FR), Constanza
General cargo/bulk	HaminaKotka (FI)	Cartagena

4.3. Case description

This section will present a detailed description for each of the cases in the form of fact sheets. First an overview will be presented on the state of play and the planned development for each of the segments within the different ports. This is followed by an overview of typical ships used in the different vessel segments. Finally, an overview of the LNG bunker infrastructure for each of the cases is presented.

4.3.1. State of play and planned development at the ports

This section presents a brief overview of the main characteristics of the ports included for each of the cases. The information in this paragraph is based on a detailed analysis of data from the ports and the interviews with representatives of the port authorities. For each port a fact sheet has been drafted containing detailed information.
These factsheets are presented in Annex B.

The section will provide details on:

- main characteristics of the involved segment in the port;
- layout of the port;
- current bunkering infrastructure (all fuel types);
- current and planned LNG bunkering infrastructure.

Table 29 provides a summary of the main characteristics of the ports included in the study. The table shows that the cases represent a wide range of the European ports.

Table 29 Main characteristics of the ports

Port	Volume freight millions of tons	Volume in Pax (1,000)	Port calls (seagoing vessels)	Growth rate freight volume until 2025 (annual %)[1]
Antwerp (BE)	199	-	14,009	*1.55%*
Cartagena (ES)	33	137	1,854	2–4%
Civitavecchia (IT)	8	3,600	3,200	*6%*
Constantza (RO)	43	65	4,772	*1.55%*
Dover (UK)	0.3	13,000	19,500	*1.55%*
HaminaKotka (FI)	15	-	3,400	1-2%
Kristiansand (NO)	0.7	1,300	2,423	3%
Marseille-Fos (FR)	78.5	2,463	15,487	1%
Southampton (UK)	35.8	1,800	10,016	*1.55%*
Stockholm (SE)	4	12,000	3,950	*1.55%*

1 When no specific growth rate is available from the port, growth was assumed the same as the assumed main growth of maritime trade in Europe (annual growth of 1.55%).

This diversity is also reflected in the size of the bunkering market. The Port of Antwerp is one of the largest bunkering ports in the world, due to its position as a deep sea hub. During the interviews, no reference was made to any unavailability of Low Sulpher Fuel Oil.

Table 30 presents an overview of the status of LNG infrastructure in the port. Interviews show that 6 out of 10 ports currently facilitate LNG bunkering in some form. In five cases, this involves truck–to-ship bunkering. In two cases (Antwerp and Cartagena) the tank truck can be loaded from storage facilities that are present in the port. For three other ports, the bunkering fuel comes directly from an import terminal into another port. All five ports mention that LNG bunkering is still only used in incidental cases. In one case, Stockholm, the LNG supplier (AGA–BominLinde) has invested in an LNG bunkering vessel. This vessel bunkers an LNG ferry ship on a daily basis. The port does not have a storage facility. The bunker vessel is supplied by trucks from a nearby LNG import terminal.

The maturity of plans for future investments in LNG differs strongly between the ports:

- The LNG terminal in Constantza is under construction.
- Four ports have plans in place for the development (or extension) of LNG bunkering infrastructure. The actual development will be considered in case of beneficial market developments.
- Two ports mention that in the near future a market and feasibility study for development of LNG bunkering infrastructure will be performed.
- One port mentions that LNG is currently not considered.

Table 30 Overview of LNG bunkering infrastructure in the ports

	Bunkering volume in Thousand (Million Tons of Oil Equivalent)	LNG Infrastructure in place	Plans for future development of LNG infrastructure
Antwerp (BE)	8,000-10,000	400 m^3 terminal in place for Inland Waterway Transport.	Plans have been developed for investment by the port of an LNG bunker vessel of 4,000 m^3. Development has been postponed and is dependent on LNG uptake.
Cartagena (ES)	5	Import terminal in location. Truck-to-ship infra in place.	Plans in place to facilitate shore-to-ship bunkering.
Civitavecchia (IT)	115	Truck-to-ship bunkering.	Plans in place for 100 m^3 storage tank. Possible acquisition of LNG vessel.
Constantza (RO)	120	None	Plans in place for a bunker station of 5,000 m^3. Planned LNG import terminal.
Dover (UK)	Unknown	None	None. Feasibility study planned.
HaminaKotka (FI)	Unknown	Tank truck	None. Feasibility study planned.
Kristiansand (NO)	300	Tank truck	Storage tank of 4,000 m^3. LNG barge of 1,000 m^3 for supply to smaller ports. LNG barge of 750 m^3 for supply local ships 750 m^3.
Marseille-Fos (FR)	500	No specific LNG bunkering infrastructure in place. The port however has 2 LNG import terminals that can facilitate bunkering vessels and bunkering trucks.	LNG development is dependent upon clarifications in French legislation: if LNG used as bunker fuel continues to be treated as a hazardous good, it will not be possible to install any LNG bunkering infrastructure in the Eastern basin of the port because it is located too close to the city center.
Southampton (UK)	Unknown	None	None.

	Bunkering volume in Thousand (Million Tons of Oil Equivalent)	LNG Infrastructure in place	Plans for future development of LNG infrastructure
Stockholm (SE)	300	Storage capacity: 20,000 m^3. Tank truck 80 m^3. Bunker vessel: 175 m^3.	Plans for development of a larger bunker vessel are in place.

4.3.2. State of play and planned development within the ship segments

Building on the information provided in the previous section, this section summarizes the main characteristics of the vessel segments used in the cases. More detailed findings are presented factsheets per ship type in Annex C.

Table 31 provides a summary of the main characteristics. The ship segments vary significantly both in ship size and in engine capacity. Therefore large differences in tank capacity are also observed.

Table 31 Main characteristics of the selected vessel types

	Ship size (gross tonnage in GT)	Cargo Capacity	Engine size in KW	Tank size m^3 LNG
Container vessel	15,000	1,000 TEU	14,772	700
Cruiseship	135,000	4,000 PAX	48,000	3,500
Ferry	57,565	2,800 pax + 1,775 lane meters for vehicles	20,400	200
General cargo vessel	14,000	11,000 tonnes	5,860	780
PSV	5,381	7,864 m^3 cargo space	7,332	233

The technical characteristics of the ships are a result of the differences in operational profiles (see Table 32). Important factors influencing the fuel consumption of a ship are:

- The operational and sailing hours of the vessel: operational hours are on average around 8,000 hours per year (330 days). Sailing hours however vary significantly. Cruise ships for instance are in the ports for about half of their total operating hours. This percentage is much lower for other ship types.
- Sailing speed: the average operating speed of vessels is highly dependent on its cargo’s time value or, in the case of ferries, on the need to have fixed daily schedules. Therefore, the sailing speed of passenger ships is on average higher than that of cargo vessels.

Together with the vessel’s ship and engine size, the operational profile results in significantly different bunkering volumes, especially when comparing the total volumes of the cruise vessels to the other vessel types.

Table 32 Overview of bunkering volumes and procedures for the selected vessel types

Ship type	Operational hours	Operational speed	Bunkering volume per year m³ LNG	Days between bunkering	Bunkering location
Ferry	6,450	22	38,000	1-2	Fixed
PSV	7,920	12-13	10,000	6	Variable
Cruise ship	8,000	16-18	90,824	14	Multiple ports on a fixed route
Container vessel	8,640	15-18	10,000	14	Multiple ports on different routes
General cargo vessel	6,000	10.5	10,000	30	Multiple ports on different routes

Table 32 shows differences in bunkering procedures between the selected vessel types:

- Ferries have a fixed route between two ports. Therefore they have a fixed bunkering location and refuel every 1 or 2 days.
- Cruise vessels also sail on a fixed route along different ports. The vessels have certain fixed ports which they use for bunkering (the choice for a port is partly based on the local bunkering prices).
- Short sea cargo vessels are often operating on the spot market, and therefore do not sail according to fixed routes. The bunkering location therefore can vary significantly from one contract to another.
- PSVs typically operate from one port. The operational range of PSVs is relative short and most of the time have a few key ports as bunker station. This makes it feasible to set up LNG bunkering in ports where PSVs often operate.

Finally, Table 31 summarizes the main effects interviewed ship operators perceive when switching to LNG (see for more information per stakeholder Annex C). These effects vary significantly:

- For ferries, effects on operations and safety are considered to be limited. Bunkering of LNG does not affect operations and are not considered to have significant effects on safety. The interviewed operator furthermore stated that switching to LNG reduced exhaust odors and noise, which are all beneficial effects for both the environment and passengers.
- For cruise ships there is no experience yet with LNG. The interviewed operator stated that LNG is not to be considered for retrofitting existing ships (scrubbers and MGO are preferred options). LNG is considered as an option for new build ships.
- Cargo vessel operators state that, in current circumstances, LNG uptake does have a significant impact on operations. LNG tanks need to be very limited in size in order to not affect the cargo space of the vessels. As an example, a containership operator stated that installing an LNG tank implies that one or more rows of containers might have to be sacrificed, for ships having the same dimensions. Furthermore, nowadays bunkering cannot be performed at the same time as

loading and unloading of goods. This is partly due to unavailability of bunkering vessels for ship-to-ship bunkering, and partly due to restrictions imposed by the ports.

Table 33 Main perceived effects of switching to LNG by vessel operators

	Safety effects	Operational effects
Containership	▪ The general crew needs to have basic training. Engine room and master deck staff require more elaborate certificates. ▪ Technically, bunkering can be performed at the same time with loading/unloading operations. But the respondent expects that port authorities will impose limitations on the number of areas in the port where LNG bunkering can be performed.	▪ Effect on storage capacity. Main restriction lies in space between first rows of containers and fuel tank. ▪ Time in port may be increased due to bunkering restrictions (this would depend on the type of bunkering chosen).
Cruise	▪ The general crew needs to have basic training. Engine room and master deck staff require more elaborate certificates.	None
Ferry	▪ The general crew needs to have basic training. Engine room and master deck staff require more elaborate certificates. ▪ Bunkering is performed away from other port activities, minimizing safety risk.	▪ No loss in cargo space perceived by the operator due to the location of the tanks. ▪ Bunkering performed within loading/unloading period in ports.
General cargo	▪ The general crew needs to have basic training. Engine room and master deck staff require more elaborate certificates. ▪ No additional safety risks perceived. ▪ Additional safety courses by crew are required.	▪ Effect on storage capacity, especially in case of medium or large tank size. ▪ Bunkering is performed in another location than loading/unloading. Because of the of the small tank size, effect on operations is limited (1 hour extra time in port).
PSV	▪ The general crew needs to have basic training. Engine room and master deck staff require more elaborate certificates.	n/a

4.3.3. Fueling infrastructure

Using the information on the state of play and developments at the ports and the ship characteristics, possible supply infrastructure options will be described in this section. The options considered are:

- truck-to-ship bunkering;
- ship-to-ship bunkering;
- shore-to-ship bunkering by pipeline.

For these options, the following aspects are listed:

- tank size of the bunker vehicle;
- ships per day: maximum number of ships bunkered per day;
- unique ships: Maximum number of unique ships bunkered per year (only for ferries);
- bunker movements per year (maximum);
- capacity per year: maximum bunker capacity per year.

Assumptions used for the calculations of the different options are presented in Table 34.

Table 34 Overview of assumptions used for calculating the LNG fuel infrastructure per port

Aspect	Figure	Source
Operational hours per day	24 hours possible. Days in action are based on operational days of ships bunkered.	Fact sheets
% of tank filled (of receiving vessel)	80%	DMA (2012)
Tank truck		
Capacity	80 m^3	DMA (2012)
Loading time	60 m^3/h	DMA (2012)
Loading preparation	1 hour	DMA (2012)
Bunkering time	60 m^3/h	DMA (2012)
Bunkering preparation	0.5 hour	DMA (2012)
Bunker vessel		
Capacity	Ranging from 175 m^3 to 10,000 m^3 (short sea tankers, suitable for bunkering) depending on the tank size of the ship type and demand in the port.	DMA (2012) and fact sheets
Loading time	Ranging from 300 m^3/h to 2,000 m^3/h depending on the tank size of the bunker vessel.	DMA (2012)
Loading preparation	0.5 hour for preparation and travel time depending on location of storage tank/import terminal.	Factsheets
Bunkering time	Ranging from 300 m^3/h to 2,000 m^3/h depending on the tank size of the ship.	DMA (2012)
Bunkering preparation	0.5-1 hour	DMA (2012)

Aspect	Figure	Source
Pipeline (shore-to-ship)		
Bunkering time	300 m^3/h	DMA (2012)
Bunkering preparation	0.5 hour	DMA (2012)

4.3.4. Main results per port

Stockholm – ferries-port ships

Stockholm is the first port in the world equipped to bunker an LNG powered large passenger ferry, and the outlook for further uptake looks positive. The supply infrastructure solutions connecting the *Linde* LNG terminal in Nynäshamn can be scaled up to accommodate growing demand for this type of fuel.

On the demand side, passenger throughput was stable at around 12 million for the period 2009–2013. Growth of passenger traffic is expected due to introduction of larger vessels in the port. This phenomenon was observed for traffic between Stockholm and Turku. Traffic increased significantly after introduction of the (large) LNG-fuelled ferry Viking Grace, operated by Viking Line.

Stockholm falls within the geographic scope of the Sulphur Emission Control Areas, as defined by Annex VI of the 1997 MARPOL Protocol regulation. Operators see LNG as a viable option to comply with the emission levels imposed by this protocol when it comes to newly built vessels. Today the port of Stockholm receives around 10 ferry calls/day, of which only one is LNG powered. Given the assumptions that: a) the current renewal rate for the ferry fleet is maintained, and b) the number of calls/day will not increase, our forecast is that at least three ferries will bunker LNG in Stockholm every day by 2020. This quantity could still be supplied with one bunkering vessel. However, investing in a second bunker vessel that would supply LNG between Nynäshamn and Stockholm could be a good investment for the future: the vessel would replace the rather slow and environmentally unfriendly truck traffic between Nynäshamn and Stockholm.

The following table presents an overview of the different supply options for Stockholm. The table makes a distinction between the number of vessels that can be bunkered by a bunkering vessel each day ("LNG-fuelled ships per day") and the number of unique ferries that can be bunkered by the bunkering vessel ("unique vessels").
The distinction between the two is time period between refuelling:

- for Option 1 refueling needs to take place every day because there is a restriction in the amount of LNG that can be bunkered by the bunkering vessel (tank is only partly filled);
- for Option 2 and 3, refueling can be performed once every two days, therefore doubling the number of unique ferries that can be bunkered).

Table 35 Supply options for LNG bunkering for the case of Stockholm

Subject	Value		
Bunker options			
Sourcing options	Direct import from the LNG import terminal in Nynäshamn.		
Bunkering possibilities	Ship-to-ship bunkering (Transport from LNG plant by tank trucks with daily capacity of 168 m^3 per day)		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	1 bunker vessel with capacity of 175 m^3 (currently active in the port)	1 bunker vessel with capacity of 500 m^3	1 bunker vessel with capacity of 1,000 m^3
LNG-fuelled ships per day	9 ferries	9 ferries	13 ferries
Unique ships	9 ferries (refuelling every day)	18 ferries (refuelling every two days)	26 ferries (refuelling every two days)
Bunker movements per year	2,700	2,700	3,900
Capacity per year	340,000 m^3	432,000 m^3	624,000 m^3
Qualitative assessment			
Storage capacity	The capacity of the current storage tank.		
Other infrastructure needed	Due to the fact that the tank is located in Nynäshamn and not in the port of Stockholm, tank trucks are needed to transport the LNG from the plant to the bunker vessel of *SeaGas*. Three tank trucks are needed to supply one bunker vessel. Hence in the case of larger vessels, a better option is to let the bunker vessel sail to the LNG plant to load directly from the tank there. In order to do that, jetties need to be built at the LNG plant. The permission to do this is already there.		

Dover: Car & passenger ferries

The Port of Dover has no LNG infrastructure currently in place or planned.

The port authority is applying for funding for a feasibility study together with the ports of Calais and Dunkerque.

The port's main traffic flow is represented by ferries connecting the UK with the continental mainland. The port has a significant amount of traffic performed by ships that are sailing at a fixed route that is 100% within SECA. Just as in the case of Stockholm, switching to LNG might be an economically viable option. Bunkering could be facilitated by an LNG bunker vessel that operates from the import terminal in Dunkerque. Given the short distance to the import terminal, it is most likely that bunkering will take place in the Port of Calais.

Table 36 Supply options for LNG bunkering for the case of Dover

Subject	Value		
Bunker options			
Sourcing options	Direct bunkering of the bunkering vessel in Dunkerque		
Bunkering possibilities	Ship-to-ship bunkering in Calais		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	1 bunker vessel with capacity of 175 m^3	1 bunker vessel with capacity of 500 m^3	1 bunker vessel with capacity of 1,000 m^3
LNG-fuelled ships per day	3 ferries	8 ferries	11 ferries
Unique ships	6 ferries (refueling every two days)	16 ferries (refueling every two days)	22 ferries (refueling every two days)
Bunker movements per year	900	2,400	3,300
Capacity per year	144,000 m^3	384,000 m^3	528,000 m^3
Qualitative assessment			
Storage capacity	No extra storage capacity is needed since bunkering is done with a bunker vessel directly from Dunkerque.		
Other infrastructure needed	No infrastructure needed.		

Civitavecchia: Car & passenger ferries and cruises

So far, Civitavecchia has only bunkered an LNG powered vessel once. No supply infrastructure is in place, but the port has plans to invest in a small storage tank and will consider the acquisition of an LNG bunkering vessel if demand for LNG will increase.

The port expects a significant increase in port traffic due to an increased demand in cruise vessels. Due to the relative large bunkering volumes per vessel and the requirement that the ship remains stationed at the Cruise terminal, ship-to-ship bunkering is considered to be the only option for these vessels.

The port of Civitavecchia does not fall under SECA, but many of the cruise lines sailing to the port are partly operating in the SECA area. Currently, cruise operators install scrubbers to comply with the SECA regulations. LNG is mainly considered as a cost-effective option for newly built vessels.

Under the present circumstances, switching to LNG is not considered economically viable for cruise operators sailing outside of SECA. For the situation in 2020, switching to LNG is considered to be a viable option for new build vessels by the interviewed ship operator.

Supplying bunker fuel to cruise ships requires investing in a considerably large bunkering vessel, because of large tank size cruise ships use. A possible short term strategy for the port could be to cater to LNG ferries with a small bunker vessel (750 or 1,000 m^3) and to accommodate cruise ships in the first years directly from La Spezia with a short sea LNG supply vessel.

Table 37 Supply options for LNG bunkering for the case of Civitavecchia

Subject	Value	
Bunker options		
Sourcing options	Supply via short sea supply vessel from import terminal in La Spezia, Marseilles or Barcelona. Local storage in a storage tank in Civitavecchia	
Bunkering possibilities	Ship-to-ship bunkering.	
Possible options	**Option 1**	**Option 2**
Bunker platform	1 bunker vessel with capacity of 1,000 m^3	1 bunker vessel with capacity of 3,000 m^3
LNG-fuelled ships per day	Ferries: 16	Ferries: 19 Cruises: 3.75
Unique ships	Ferries: 32 (refuelling every two days)	Ferries: 38 (refuelling every two days)
Bunker movements per year	Ferries: 4,800	Ferries: 5,700 Cruises: 1,370
Capacity per year	Ferries: 768,000 m^3	Ferries: 912,000 m^3 Cruises: 3,800,000 m^3
Qualitative assessment		
Storage capacity	Storage tank needed to store the LNG supplied from import terminals in other ports. It is assumed that this supply is done weekly. Size of the tank depends on the demand.	
Other infrastructure needed	A short sea LNG supply vessel that might also supply other ports coming from La Spezia, Marseilles or Barcelona.	

Southampton: Cruises

The port of Southampton has no LNG infrastructure in place and is not yet considering investing in LNG.

The main vessel type considered in Southampton is the cruise ship. As stated before, retrofitting cruise ships is considered to be a less viable option than installing scrubbers. Uptake is considered to be feasible for the 2025 situation for new built ships (only limited effect on available space).

As shown in the following infrastructure overview, fuelling cruise vessels will require investing in ship-to-ship bunkering infrastructure with ships of considerable size. Just as in Civitavecchia, a short term solution could be to accommodate cruise vessels in the short term directly from an import terminal by a short sea LNG supply vessel.

Table 38 Supply options for LNG bunkering for the case of Southampton

Subject	Value	
Bunker options		
Sourcing options	Supply from Grain terminal or Milfort terminals in the UK or from Zeebrugge or Dunkerque by short sea supply vessel.	
Bunkering possibilities	Ship-to-ship	
Possible options	**Option 1**	**Option 2**
Bunker platform	1 bunker vessel with capacity of 3,000 m^3	1 bunker vessel with capacity of 10,000 m^3
LNG-fuelled ships per day	3-4 cruises	5-6 cruises
Bunker movements per year	1,370	1,990
Capacity per year	3,800,000 m^3	5,550,000 m^3
Qualitative assessment		
Storage capacity	Storage tank needed to store the LNG supplied from import terminals in other ports. It is assumed that this supply is done weekly. Size of the tank depends on the demand.	
Other infrastructure needed	A short sea LNG supply vessel that might also supply other ports coming from one of the import terminals in the UK, Zeebrugge or Dunkerque.	

Marseille-Fos: Cruise ships and container vessels

Due to the presence of two LNG import terminals in Fos, LNG bunkering is possible by truck-to-ship bunkering. The port has currently no plans to invest in LNG bunkering. An important barrier perceived by the port authority for development is French legislation regarding hazardous goods. Under this legislation it is not permitted to bunker LNG in port basins situated close to residential areas.
The main ship types considered for the port are cruise ships and container vessels. As stated before, retrofitting cruise ships or container vessels is considered to be a less viable option than installing scrubbers. Uptake is considered feasible for newly built ships in the 2025 situation for (if effect on cargo space is limited).

Table 39 Supply options for LNG bunkering for the case of Marseille-Fos

Subject	Value		
Bunker options			
Sourcing options	Direct supply from the LNG import terminals in the port with bunker vessel or pipeline.		
Bunkering possibilities	Ship-to-ship or shore-to-ship (for containers)		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3	Shore-to-ship via a jetty and loading arm
Ships per day	Cruises: 3-4 Container vessels: 8-9	Cruises: 5-6 Container vessels: 12-13	Cruises: 2-3 Container vessels: 7-8
Bunker movements per year	Cruises: 1,370 Container vessels: 3,160	Cruises: 1,990 Container vessels: 4,550	Cruises: 890 Container vessels: 2,700
Capacity per year	Cruises: 3,800,000 m^3 Container vessels: 2,500,000 m^3	Cruises: 5,550,000 m^3 Container vessels: 3,600,000 m^3	Cruises: 2,500,000 m^3 Container vessels: 2,150,000 m^3
Qualitative assessment			
Storage capacity	Current import terminal.		
Other infrastructure needed	No other infrastructure needed.		

Constanta: Container vessels

As part of the LNG Masterplan, Constanta is currently gaining expertise in LNG. The port has plans for a bunker station of 5,000 m^3. Furthermore, there are plans to invest in an LNG import terminal that should be ready between 2020 and 2025.

The main markets for LNG uptake considered by Constanta are seagoing cargo vessels and Inland Navigation vessels. Switching to LNG is not considered viable for cargo ships that are currently sailing mainly in the Mediterranean area. Uptake is considered feasible for newly built ships in the future situation (if effect on cargo space is limited).

Table 40 Supply options for LNG bunkering for the case of Constanta

Subject	Value		
Bunker options			
Sourcing options	Current: Supply from import terminals in Greece (Revithoussa) or Turkey (Ereglisi) via short sea supply vessel or tank trucks. Future: Direct delivery from import terminal in port.		
Bunkering possibilities	Ship-to-ship and shore-to-ship		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3	Shore-to-ship via a jetty and loading arm
Ships per day	8-9 vessels	12-13 vessels	7-8 vessels
Bunker movements per year	3,160	4,550	2,700
Capacity per year	2,500,000 m^3	3,600,000 m^3	2,150,000 m^3
Qualitative assessment			
Storage capacity	When the import terminal is in place, no extra storage capacity is needed. For the current situation a storage tank is needed which can handle the weekly supply from Greece or Turkey.		
Other infrastructure needed	A short sea LNG supply vessel coming from Greece and Turkey in the current situation.		

Antwerp: Container vessels

Bunkering of LNG is currently possible in the port of Antwerp for inland navigation vessels. Plans for investing in a maritime bunkering vessel have been developed, but are currently postponed. LNG bunkering might become feasible from 2016 onwards on an incidental basis from the LNG bunkering vessels that Shell or GDF Suez will charter in Rotterdam (Shell) and Zeebrugge (GDF Suez). Shell intends to use its vessel to facilitate the wider region.

Antwerp could potentially supply seagoing cargo vessels as well as inland navigation vessels with LNG. Because of the large size of the bunkering market, potential uptake might be significant. The port however will compete with other ports, such as Rotterdam and Zeebrugge, which also have LNG import terminals in the port.

Although the port is in SECA, switching to LNG is not considered viable for cargo ships that are currently sailing in Europe by the interviewed cargo operator. On the short term, ships are mainly switching to MGO. Uptake is considered to be feasible for newly built ships in the 2025 situation (if effect on cargo space is limited).

Table 41 Supply options for LNG bunkering for the case of Antwerp

Subject	Value		
Bunker options			
Sourcing options	Supply from Zeebrugge or Rotterdam by bunker vessel.		
Bunkering possibilities	Ship-to-ship bunkering		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3	
Ships per day	6-7 vessels	11-12 vessels	
Bunker movements per year	2,420	4,100	
Capacity per year	1,900,000 m^3	3,250,000 m^3	
Qualitative assessment			
Storage capacity	No extra storage capacity is needed since bunkering is done with a bunker vessel directly from Zeebrugge or Rotterdam.		
Other infrastructure needed	A short sea LNG supply vessel coming from Zeebrugge or Rotterdam.		

Kristiansand: Platform & Supply vessels

LNG bunkering takes place on an incidental basis in Kristiansand by tank-to-ship bunkering directly from the import terminal in the same port. The port has planned to build two local storage tanks and, in the more distant future, also a bunkering vessel to provide ship-to-ship bunkering services and supply smaller ports in the region with LNG.

The bunkering market of Kristiansand is relatively large for the size of the port. Theport accommodates both cargo vessels as well as PSVs. The market for PSVs is especially interesting, since one of its largest client groups are Norwegian state owned companies who impose high environment protection requirements through their contracts. LNG uptake for this vessel type will therefore be relatively high.

Table 42 Supply options for LNG bunkering for the case of Kristiansand

Subject	Value		
Bunker options			
	Supply from LNG terminal in Øra (Fredriksstad, Norway or Fredrikshavn (Denmark).		
Bunkering possibilities	Truck-to-ship (short term) and ship-to-ship		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	3 tank trucks with capacity of 80 m^3	1 bunker vessel with capacity of 500 m^3	1 bunker vessel with capacity of 1,000 m^3
Ships per day	2 vessels	9-10 vessels	11-12 vessels
Bunker movements per year	730	3,020	3,800
Capacity per year	130,000 m^3	560,000 m^3	710,000 m^3
Qualitative assessment			
Storage capacity	Storage tank needed to store the LNG supplied from import terminals in other ports. It is assumed that this supply is done weekly. Size of the tank depends on the demand.		
Other infrastructure needed	A short sea LNG supply vessel that might also supply other ports coming from Fredrikshavn.		

HaminaKotka: General cargo & bulk

Currently there is no LNG infrastructure in place in the port, but in 2018 an LNG import terminal will be in operation. The terminal will initially facilitate land-based demand. The port has applied for TEN-T funding to investigate maritime bunkering options.

The main shipping activity in HaminaKotka consists of dry bulk transport.
The representative of the port authority considers it to be likely that LNG uptake for this vessel type will be rather slow.

Table 43 Supply options for LNG bunkering for the case of HaminaKotka

Subject	Value		
Bunker options			
Sourcing options	Current: supply from Sweden (Nynasham). Future: supply from Finland (4 terminals planned) or Estonia (4 terminals planned) via short sea supply vessel. Possibly supply by the planned LNG import terminal in the port.		
Bunkering possibilities	Ship-to-ship and shore-to-ship		
Possible options	**Option 1**	**Option 2**	**Option 3**
Bunker platform	1 Bunker vessel with capacity of 1,000 m^3	1 Bunker vessel with capacity of 3,000 m^3	Shore-to-ship via a jetty and loading arm
Ships per day	5-6 vessels	9-10 vessels	9-10 vessels
Bunker movements per year	1,560	2,740	3,350
Capacity per year	970,000 m^3	1,710,000 m^3	2,090,000 m^3
Qualitative assessment			
Storage capacity	Storage tank needed to store the LNG supplied from import terminals in other ports. It is assumed that this supply is done weekly. Size of the tank depends on the demand.		
Other infrastructure needed	A short sea LNG supply vessel that might also supply other ports coming from one of the import terminals in Nynäshamn, Finland or Estonia.		

Cartagena: General cargo & bulk

Because of the presence of an LNG import terminal in the port of Cartagena, LNG bunkering can already be performed from trucks. The port has plans to develop a shore-to-ship bunkering facility on the site of the terminal.

Cruise ships calling at the port will most likely not be willing to bunker at a location other than the cruise terminal and will therefore not be suitable for shore-to-ship bunkering. The main clients for shore-to-ship bunkering would therefore be cargo vessels. The current bunkering market for cargo is relative small in 2015, but could increase significantly in 2025 due to the relative high growth expectancy (for instance in container traffic). As shown in the table below, supplying cargo vessels by truck-to-ship bunkering is not considered to be a good option. Filling a medium-sized short sea vessel requires at least three tank truck loads, which would imply either a significant investment in tank trucks or a significantly longer port call for the cargo vessel.

Switching to LNG is not considered viable for cargo ships that are currently sailing mainly in the Mediterranean area. Uptake is considered feasible for newly built ships in the 2025 situation (only limited effect on cargo space).

Table 44 Supply options for LNG bunkering for the case of Cartagena

Subject	Value	
Bunker options		
Sourcing options	Direct delivery from import terminal in port.	
Bunkering possibilities	Truck-to-ship or shore-to-ship	
Possible options	**Option 1**	**Option 2**
Bunker platform	3 tank trucks with capacity of 80 m^3	Shore-to-ship via a jetty and loading arm
Ships per day	1 vessels	9-10 vessels
Bunker movements per year	280	3,350
Capacity per year	170,000 m^3	2,090,000 m^3
Qualitative assessment		
Storage capacity	Current import terminal.	
Other infrastructure needed	No other infrastructure needed.	

5. Cost-benefit analysis

5.1. Introduction

This chapter describes the financial and social cost-benefit analyses for several LNG scenarios with different ship types, bunkering methods and ports for the period 2020-2030. The financial cost-benefit analyses thereby take the end-user perspective (ship operator). The methodology used for the cost-benefit analyses (CBA) is presented, along with the results and a sensitivity analysis. These results will be used to provide general advice for the shipping industry's stakeholders on suitable solutions.

5.2. Design of CBA

Two types of cost-benefit analyses are performed for the scenarios defined in Chapter 4:

1. Financial cost-benefit analysis for the business case of LNG as bunkering fuel.
2. Social cost-benefit analysis for the welfare analysis of LNG as bunkering fuel.

The latter will include also non-financial effects such as environmental effects, while the former will focus on investment costs and financial benefits of introducing LNG as bunkering fuel in the case ports considered.

5.2.1. Baseline and alternative scenarios

The costs and benefits of LNG as bunkering fuel are presented in comparison to two baseline scenarios. In one baseline scenario the ship type under consideration is assumed to use HFO in combination with a scrubber and a second baseline scenario in which it is assumed to use MGO. Both baseline scenarios assume continuous low sulphur emissions. This is considered to be a good approximation to reality from 2020 onwards, when a limitation of sulphur content in fuel is imposed on all ships sailing in EU waters (the maximum sulphur content in ECAs will be 0.10%, in other territorial seas, EEZ, pollution control areas it will be 0.50%) as per the provisions of the Sulphur Directive. In addition to this, favouring our assumption, all ships globally outside ECAs will face MARPOL Annex VI similar sulphur cap of 0.50% m/m, also after 2020 (unless it is decided in 2018 to postpone the implementation date by 5 years, to 2025).

For the MGO baseline, it is assumed that the prices of distillates with 0.50% and 0.10% sulphur content will have approximate bunker prices. In support of this assumption the prices for Low Sulphur Fuel Oils (of heavier blends) at 0.5% are assumed to become close to that of MDO, in a future context of lower sulphur fuels availability in the bunker market. Taking into account the uncertainties in driving the oil fuel price in the forthcoming years, together with the historically attractive energy price differential for LNG, the assumption is warranted.

If prices of 0.50% fuels are lower than those of 0.10% fuels, however, this second assumption may result, of course, in overestimated benefits of using LNG for ships whose operational profile largely falls outside ECAs. The particular business case would, in any case, always have to be carefully considered.

The baseline scenarios are compared to an alternative scenario in which LNG is used as bunkering fuel and a LNG-fuelled ship is built. An overview of the baselines and scenarios for the selected vessels and ports is given in Table 45.

Table 45 Overview of case studies

Case study	Type of vessel	Fuel used in baseline scenarios	Fuel used in alternative scenarios	Bunkering options in alternative scenarios	Additional LNG infrastructure in alternative scenarios
Stockholm	Car and passenger ferries	MGO HFO+ scrubber	LNG	TTS/STS	Option 1: Tank trucks Option 2 & 3: Bunkering vessel Jetty at import terminal
Dover	Car and passenger ferries	MGO HFO + scrubber	LNG	STS	Bunkering vessel Jetty at import terminal
Civitavecchia	Car and passenger ferries	MGO HFO + scrubber	LNG	STS	Bunkering vessel, Jetty at import terminal, short sea supply vessel, storage tank
Civitavecchia	Cruise vessels	MGO HFO + scrubber	LNG	STS	Bunkering vessel, Jetty at import terminal, short sea supply vessel, storage tank
Kristiansand	Platform supply vessels	MGO HFO + scrubber	LNG	TTS/STS	Option 1: Tank trucks, Option 2 & 3: Bunkering vessel, storage tanks short sea supply vessel
Southampton	Cruises	MGO HFO + scrubber	LNG	STS	Bunkering vessel, storage tank, short sea supply vessel
Marseille	Cruises & container vessels	MGO HFO + scrubber	LNG	STS/PTS	Bunkering vessel, pipelines
Antwerp	Container vessels	MGO HFO + scrubber	LNG	STS	Bunkering vessel
Constanta	Container vessels	MGO HFO + scrubber	LNG	STS/PTS	Bunkering vessel, pipelines, storage tanks
HaminaKotka	General cargo/bulk	MGO HFO + scrubber	LNG	STS/PTS	Bunkering vessel, pipelines, storage tanks

Case study	Type of vessel	Fuel used in baseline scenarios	Fuel used in alternative scenarios	Bunkering options in alternative scenarios	Additional LNG infrastructure in alternative scenarios
Cartagena	General cargo/bulk	MGO HFO + scrubber	LNG	PTS	Pipelines

5.2.2. Financial CBA

The financial cost-benefit analysis determines whether LNG as fuel is financially attractive from the point of view of the end-user, which is the ship operator in this case. The financial costs, such as investment and operational costs, are compared to the benefits from the investments to calculate the net present value and pay-back period. This is done by discounting the costs and benefits for 2030 with 2020 as the starting year. The financial discount factor used in this analysis is 10%. This is the average weighted average cost of capital (WACC) for the different ship types, which is calculated based on the assumption that:

- banks are only willing to finance the value of a conventional (non-LNG-fuelled) vessel since there is uncertainty about the second hand-price of LNG-fuelled vessels;
- 70% of the value of a conventional (non-LNG-fuelled) vessel is financed with outside capital and 30% of the value of a conventional vessel plus the incremental costs for an LNG-fuelled vessel with equity financing;
- the low-risk interest rate for financing with outside capital amounts to approximately 2%[34] and the risk mark-up to 3%[35];
- the expected internal rate of return (IRR) for the equity financing of the ship owners lies in the range of 15-20%[36].

The costs and benefits which are analysed are presented in Table 46.

Table 46 Cost and benefits in the financial CBA

LNG ship	
1. Additional capital expenditure on new built LNG-fuelled ship or on retrofit ship	Quantified
2. Additional non-fuel operational expenditures on LNG-fuelled ship	Saving on lubrication oil expenditures for ferries quantified
Fuel cost difference	Quantified
Difference wage cost technical personnel	PM[37]
Difference safety measures	PM
Evaporation of LNG	PM

34 2.03% is the annualized forward rate for the period 2020-2030 derived from the June 2015 zero coupon interest rate curve (end of month) as published by De Nederlandsche Bank (DNB, 2015).
The first 20 years of this zero coupon interest rate curve were derived by bootstrapping the Euro swap rates (Bloomberg tickers EUSA1 Curncy to EUSA20 Curncy).

35 Personal communication with EIB (2015).

36 For an IRR of 15% the WACC for the different ship types ranges from 8.4 to 10% and for an IRR of 20% from 10.1 to 12.5%.

37 Pro memorie; effect will not be quanitified.

The results of the financial CBA of LNG-fuelled vessels are presented using two indicators, the financial net present value (FNPV) and the pay-back period. The first is calculated by deducting the sum of discounted expected investment and operating costs from the discounted expected revenues. The second is an indicator that shows the amount of time needed for the costs to be paid back by the benefits.

A positive FNPV means that the present value of the benefits are higher than the present value of the costs in the period under consideration, i.e. 2020-2030 with the year 2020 as base year. In the cost-benefit calculations, the additional investment costs of LNG-fuelled ships are spread over a 10 year period (2020-2029), annuitizing the investment costs. A positive FNPV goes along with a pay-back time of less than 11 years. A case in which the FNPV is positive is considered to be a positive business case[38].

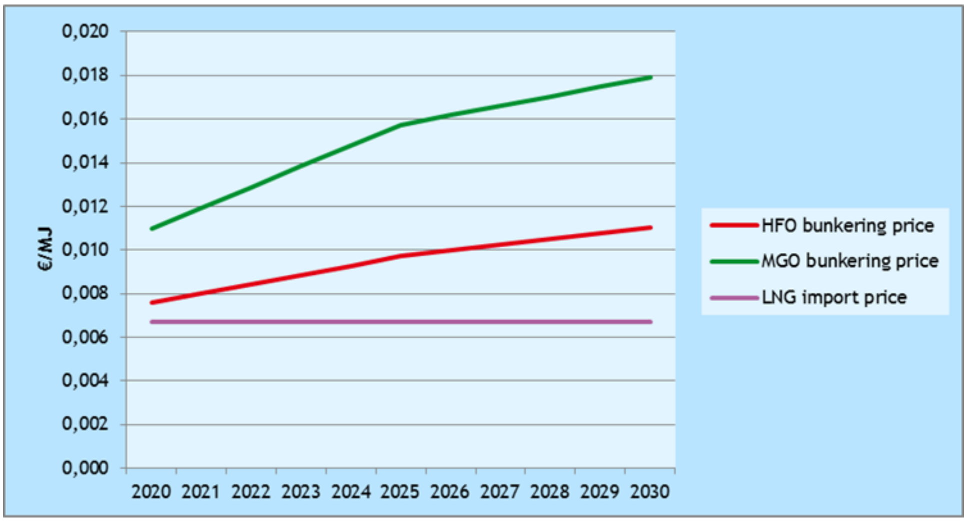
As the CBA is carried out from the end-user perspective, additional costs and benefits for one LNG-fuelled vessel are calculated from a financial and social perspective.
The scenarios are built in such a way that this port is the main port for bunkering the different types of vessels. Thus assuming that bunkering only happens in this port due to lack of data on amount of times the types of vessel bunker in a specific port.
In addition, placing the LNG infrastructure in a certain port allows types of vessels to bunker LNG other than the reference vessel investigated.

Fuel cost difference

The difference in fuel costs between LNG and conventional marine fuel (HFO or MGO) are very crucial for the results of the cost-benefit analyses.

In Figure 35 the HFO and MGO bunkering prices together with the LNG import prices that are used in the cost-benefit analysis are depicted (see Section 2.3.2 for more details).

Figure 35 HFO and MGO bunkering prices and LNG import prices utilised in the CBA



38 Results are based on 2015 prices.

The LNG bunkering prices are calculated per case (port/infrastructure option), by adding a mark-up to the LNG import price (based on the results of Chapter 3). The mark-up is thereby determined by dividing the annuitized investment and the annual operational costs of the LNG bunkering infrastructure (e.g. bunker vessels or tank trucks) by the maximum annual LNG bunkering capacity of this infrastructure. In the sensitivity analysis a higher mark-up is considered, accounting for the case that the LNG bunkering infrastructure may not be fully used.

Regarding the LNG import price and the HFO and MGO bunkering prices, it is, for simplicity reasons, assumed that prices are uniform across European ports. The HFO and MGO bunkering prices may therefore be underestimated for some, especially smaller ports.

In the sensitivity analysis, an LNG import price that is 25% lower and 25% higher than the LNG import price as depicted in Figure 35 is considered, accounting for the uncertainty regarding the future LNG import price.

Financial policies and discounts

There are several policies in place that support the installation of LNG bunkering infrastructure, such as EU subsidy within the TEN-T policy, which can be used for research purposes such as feasibility studies and to partly cover the construction costs of LNG terminals. An example is the co-funding of 261,000 EUR to convert an existing vessel into a LNG bunkering vessel (NVG, 2013). Another funding opportunity is the Connecting Europe Facility (CEF-fund) (EC, 2012a) or the European Energy Program for Recovery (for storage and regasification facilities for LNG) (EC, 2009).

In addition, national policies provide financial incentives for LNG bunkering, such as the NO_x fund in Norway which allows investors of an LNG-fuelled ship to apply for monetary support for investments that decrease the NO_x emissions in Norway. A member of the fund can get up to 75% of investments for such measures (DMA, 2012). In some port authorities in Europe, like Rotterdam and Antwerp, port-specific emission regulations have been established that give a discount in port dues to ship owners who use clean fuels for their vessels (i.e. the environmental ship index (ESI) programme) (Wang & Notteboom, 2013). Another example of national policies regarding LNG is the differentiation of port dues by sulphur content of the fuel used and the NO_x emissions from the engines, which happens in 20 to 25 of the bigger ports in Sweden (CNSS, 2015). The addition of financial policies as part of the costs and benefits depends on the scenario.

Note that in the cost-benefit analyses subsidies are not explicitly taken into account. If in the period 2020-2030 there will be subsidies in place that reduce the LNG bunkering infrastructure costs, this could lead to a reduced LNG bunker price. If there will also be subsidies in place that reduce the additional costs of purchasing an LNG-fuelled ship or the conversion of a ship into an LNG-fuelled ship, this would both have a positive impact on the ship owners business case.

5.2.3. Social CBA

The social cost-benefit analysis determines whether LNG as fuel is desirable given the welfare effects from the point of view of the society as a whole. This includes both financial and non-financial effects, which are quantified, discounted and compared to the baseline scenario to determine the overall welfare effect.

The social discount rate used in the social CBA is 3% (EC, 2014b). The effects that are taken into account in this analysis are listed in Table 47.

Table 47 Cost and benefits in the social CBA

LNG ship	
1. Additional capital expenditure on new built LNG-fuelled ship or on retrofit ship	Quantified
2. Additional operational expenditures on LNG-fuelled ship	Saving on lubrication oil expenditures for ferries quantified
Fuel cost difference	Quantified
Other	
3. Stranded assets MGO bunkering	PM
4. Difference wage cost technical personnel	PM
5. Difference safety measures	PM
6. Evaporation of LNG	PM
7. Emissions (CO_2, Methane, SO_x, NO_x, PM)	Quantified
8. Innovation/competitiveness	Qualitative

Innovation and competitiveness

The construction of LNG bunkering infrastructure can affect the EU’s position in innovation and competitiveness. As LNG in shipping is a new market and a relative new technology, large-scaled implementation can trigger innovations and first mover advantages for the European shipping industry. Export of new technologies will result in increased economic output, employment and welfare in the European Commission. These benefits will be expressed qualitatively.

Valuing change in emissions

The differences in emissions from using LNG as bunkering fuel is calculated and valued at their shadow prices to determine the effect of switching to LNG bunkering fuel on social welfare, using the values from Table 48.

Table 48 Shadow prices of emissions and emission factors

Type of emission	Emissions MGO (g/MJ)	Emissions HFO + scrubber (g/MJ)	Emissions LNG (g/MJ)	Shadow price (EUR_{2015}/t emission)
CO_2	75.2	76.0	56.6	36
NO_x	2.25	2.21	0.29	10,734
SO_2	0.23	0.24	0.0	10,299
PM_{10}	0.02	0.04	0.0037	25,164
CH_4	0.001	0.002	1.02	696

Source: (IMO, 2014), (CE Delft, 2010), Clean North Sea Shipping (CNSS, 2015).

Note that the shadow prices of the air pollutants are not ship emission specific and may therefore overestimate the impact of the emissions. In the sensitivity analysis, lower shadow prices for the air pollutants are therefore considered.

Emissions associated with the different fuels do differ not only when burned on board a ship but regarding the upstream production and transport chain of the fuels. These differences have not been considered in the cost-benefit analysis.

5.3. Results CBAs

5.3.1. Results per case study

For the interested reader, the results of the financial and the social CBAs of the different cases are described in detail in Annex D.

5.3.2. Overview of results and conclusions

In this section an overview of the results of the CBAs and of the sensitivity analyses is presented and conclusions are drawn based on these analyses.

Results financial CBAs

In Table 56 and Table 45 an overview of the results of the financial CBAs is given by means of one indicator, i.e. the pay-back time. Table 56 gives the pay-back times of the CBAs for the MGO baseline, whereas Table 45 for the HFO+scrubber baseline.

Knowing the pay-back time allows to draw conclusions on the second indicator, i.e. the net present value as well, however only on the sign of the net present value – a pay-back time of less than 11 years is associated with a positive NPV in this analysis. For the absolute values of the net present values please see Annex D.

In the financial cost-benefit analyses, two factors are crucial: the additional CAPEX for the LNG-fuelled vessel and the change of the fuel costs due to difference of the bunkering prices between LNG and HFO or MGO.

The capital investment for LNG-fuelled vessels is larger than for vessels using HFO with a scrubber or MGO.

For most of the bunkering methods, the LNG bunkering price is lower than the HFO and the MGO price with the price difference between LNG and MGO being larger than between LNG and HFO. In the third row (‘Mark-up on 2030 LNG import price’) of Table 56 and Table 45, the mark-up on top of the LNG import price which determines the LNG bunkering price is given for the different infrastructure options. For some options a range is given, when the same bunkering method has been considered in different ports. Here the mark-up differs between ports due to port specific factors (e.g. distance to import terminal) and due to ship type specific factors (e.g. annual LNG bunkering capacity). From Table 56 and Table 45 it can be concluded that the mark-up on top of the LNG import price differs between the bunkering methods in the sense that Truck-to-ship, a combination of trucks + Ship to ship bunkering, and shore-to-ship bunkering are relatively costly bunkering methods.

Ship to ship bunkering is associated with relatively lower infrastructure costs and thus lower LNG bunkering prices and the scale of the infrastructure has an impact on the LNG bunkering prices.

The financial net present value is positive in most cases with MGO as reference fuel, except in the case of Shore-to-ship bunkering in Constanta and HaminaKotka (see Table 56 for pay-back times of less than 11 years).

The financial NPV is negative for several infrastructure options when considering the HFO & scrubber baseline (see Table 56 for pay-back times of more than 11 years): Truck + Ship to ship bunkering in Stockholm, Truck-to-ship bunkering in Kristiansand, Ship to Ship bunkering of container vessels in Marseille, Constanta, and Antwerp, Ship to Ship bunkering of ferries with a very small bunkering vessel in Dover, and Shore-to-ship bunkering in Constanta and HaminaKotka.

Table 49 Results of the financial CBAs for the different cases - MGO baseline

		Mark-up on 2030 LNG price	Pay-back time											
			Stockholm	Dover/Calais	Civitavecchia	Civitavecchia	Southampto	Marseille	Marseille	Antwerp	Constanta	HaminaKotka	Cartagena	Kristiansand
			Ferry			**Cruise**			**Container vessel**			**General cargo**		**PSV**
Ship-to-ship	175 m^3 bunker vessel	23%		6										
	500 m^3 bunker vessel	13%-16%		6										5
	1,000 m^3 bunker vessel	11-15%	6	6	6							5		5
	2,000 m^3 bunker vessel	13%	6											
	3,000 m^3 bunker vessel	8%-16%			6	5	5	5	7	7	8	5		
	10,000 m^3 bunker vessel	6%-10%					5	5	7	7	8			
Truck-to-ship	80 m^3 tank trucks	40%												7
Truck + STS	80 m^3 tank trucks and 175 m^3 bunker vessel	45%	8											
Shore-to-ship		6%-380%							7		X*	X*	4	

*Investment that does not pay off.

Table 50 Results for the financial CBAs for the different cases - HFO+scrubber baseline

		Mark-up on 2030 LNG price	Pay-back time											
			Stockholm	Dover/Calais	Civitavecchia	Civitavecchia	Southampton	Marseille	Marseille	Antwerp	Constanta	HaminaKotkah	Cartagena	Kristiansand
			Ferry			**Cruise**			**Container vessel**			**General cargo**		**PSV**
Ship-to-ship	175 m^3 bunker vessel	23%		12										
	500 m^3 bunker vessel	13%-16%		10										9
	1,000 m^3 bunker vessel	11-15%	9	9	10							8		9
	2,000 m^3 bunker vessel	13%	10											
	3,000 m^3 bunker vessel	8%-16%			10	8	8	9	12	12	12	7		
	10,000 m^3 bunker vessel	6%-10%					8	9	12	12	12			
Truck-to-ship	80 m^3 tank trucks	40%												18
Truck + STS	80 m^3 tank trucks and 175 m^3 bunker vessel	45%	24											
Shore-to-ship		6%-380%							12		X*	X*	6	

*Investment that does not pay off.

In addition, a difference between types of vessels can be identified. Comparing the shortest pay-back period per ship type, a pattern shows. The pay-back period for cargo vessels is the shortest (MGO baseline: 4 years, HFO baseline: 6 years) and the pay-back period for container vessels is the longest (MGO baseline: 7 years, HFO baseline: 11 years. The pay-back period for platform supply vessels, ferries, and cruise vessels are similar (MGO baseline: 5-6 years, HFO baseline: 8-9 years) and lie in between the pay-back period for cargo and container vessels. This is related to the technical specification of the typical vessel such as annual bunkering volume and size of the engine, which leads to differences in additional capital investments and bunkering costs for the new built LNG-fuelled vessel.

Overall it can be conclude that LNG is, in general, a viable option if MGO was used instead of LNG and a bunkering method other than shore-to-ship is available in ports. If HFO and a scrubber were used instead of LNG, the viability of LNG depends on the ship type and the bunkering method offered in the ports, with large-scale ship-to-ship bunkering being the most promising option.

Results social CBAs

LNG is relatively more beneficial when compared to MGO than to HFO+scrubber. The social net present values, i.e. if the benefits from reduced emissions are taken into account, are positive for each of the cases, independent of the baseline considered.

Results sensitivity analyses

To account for the uncertainty of several assumptions that underlie the cost-benefit analyses as presented above, cost-benefit calculations with alternative values for the following five parameters have been carried out:

1. LNG import price: 25% lower/higher than in base case.
2. Financial discount factor: 5% instead of 10%.
3. Annual use of port LNG capacity: 50% instead of 100%.
4. Investment costs of scrubbers: 50% lower than in base case.
5. Shadow prices of NO_x, SO_2 and PM: 50% lower than in base case.

An overview of the results of the base case (first column) and the sensitivity analyses in terms of the sign of the NPV of the financial CBA is presented in Table 51. Note that thereby only those infrastructure options per port case are given that showed the highest NPV for the HFO & scrubber baseline. This is because the results for the MGO baseline are, in general, more positive and would show less sensitivity to a change of the above parameters in terms of the sign of the NPV.

If the LNG import price was 25% higher than in the base case, then the NPV would be negative for all infrastructure options taken into account.

If the LNG import price was 25% lower than in the base case of if the financial discount rate was 5% instead of 10%, then the NPV would be positive for all infrastructure options taken into account.

Decreasing the annual use of the LNG bunkering capacity in a port with 50% leads to higher LNG bunkering prices and provides a lower NPV for all port cases, turning some of the cases into negative business cases.

Decreasing the scrubber costs with 50% leads to higher additional investment costs for an LNG-fuelled vessel compared to an HFO-fuelled vessel equipped with a scrubber, leading to a lower NPV and turning several of the considered cases into negative business cases.

Lowering the shadow prices of NO_x, SO_2, and PM with 50% leads to a lower social NPV for all the case ports. However, none of the cases that featured a positive NPV in the base case of the social cost-benefit analyses now features a negative NPV.

Table 51 Overview results sensitivity analysis (sign of NPV)

Port	Base case	Higher LNG import price	Lower LNG import price	Lower financial discount rate	Lower usage of LNG bunkeringcapacity	Lower scrubber costs
Stockholm – ferry (Option 2)	+	-	+	+	-	-
Dover – ferry (Option 3)	+	-	+	+	-	-
Civitavecchia – ferry (Option 2)	0	-	+	+	-	-
Civitavecchia – cruise (Option 2)	+	-	+	+	-	-
Southampton – cruise (Option 2)	+	-	+	+	0	0
Kristiansand – platform supply vessel (Option 3)	0	-	+	+	-	0
Marseille – cruise (Option 2)	+	-	+	+	+	-
Marseille – container vessel (Option 3)	-	-	+	+	-	-
Antwerp – container vessel (Option 2)	-	-	+	+	-	-
Constanta – container vessel (Option 2)	-	-	+	+	-	-
HaminaKotka – cargo vessel (Option 2)	+	-	+	+	+	+
Cartagena – cargo vessel (Option 1)	+	-	+	+	+	+

An important remark is that the price difference between LNG bunker fuel and HFO or MGO mainly determines the fuel expenditure difference between an LNG-fuelled ship and a HFO or MGO-fuelled ship. Fuel expenditure savings have to be sufficiently high to compensate for the higher investment costs of an LNG-fuelled ship. Therefore, the relative LNG bunker price is a very crucial factor on the results of the CBA of LNG-fuelled vessels.

The bunker prices of HFO/MGO/MDO have historically developed in line with the crude oil price and since mid-2014, the bunker prices have been falling together with the crude oil price. If EU LNG import prices are not linked to the crude oil price, then the relative price of LNG bunker fuel will rise, discouraging the uptake of LNG-fuelled ships.

The sensitivity analysis of a higher LNG import price reflects the same effect as the drop in crude oil prices. The CBA include the valuation of the difference between LNG and marine fuel use and it seems that this is an important factor of determining the LNG as fuel is a good business case. The sensitivity analysis on a higher LNG import price shows that for all types of vessels negative results are presented. Therefore, it is expected that if the oil prices continue to drop, the business case for LNG-fuelled vessels will become negative due to small differences between the LNG price and HFO or MGO price. It is also possible to have LNG prices which are higher than HFO or MGO prices, resulting in no financial benefits from transferring to LNG as bunker fuel. The possibility of transitioning to LNG as marine fuel thus highly depends on the (crude) oil price developments.

Due to the recent drop in oil price, a concern is raised as to whether cheap oil combined with scrubbers and SCR would be a preferred option compared to LNG. The effect of oil drop will have a limited duration and it is anticipated that the price of liquid fuels will be higher than for natural gas in the foreseeable future. Therefore, the current low oil price will not have a long term negative impact on the deployment of LNG as a fuel (DNV-GL, 2015c).

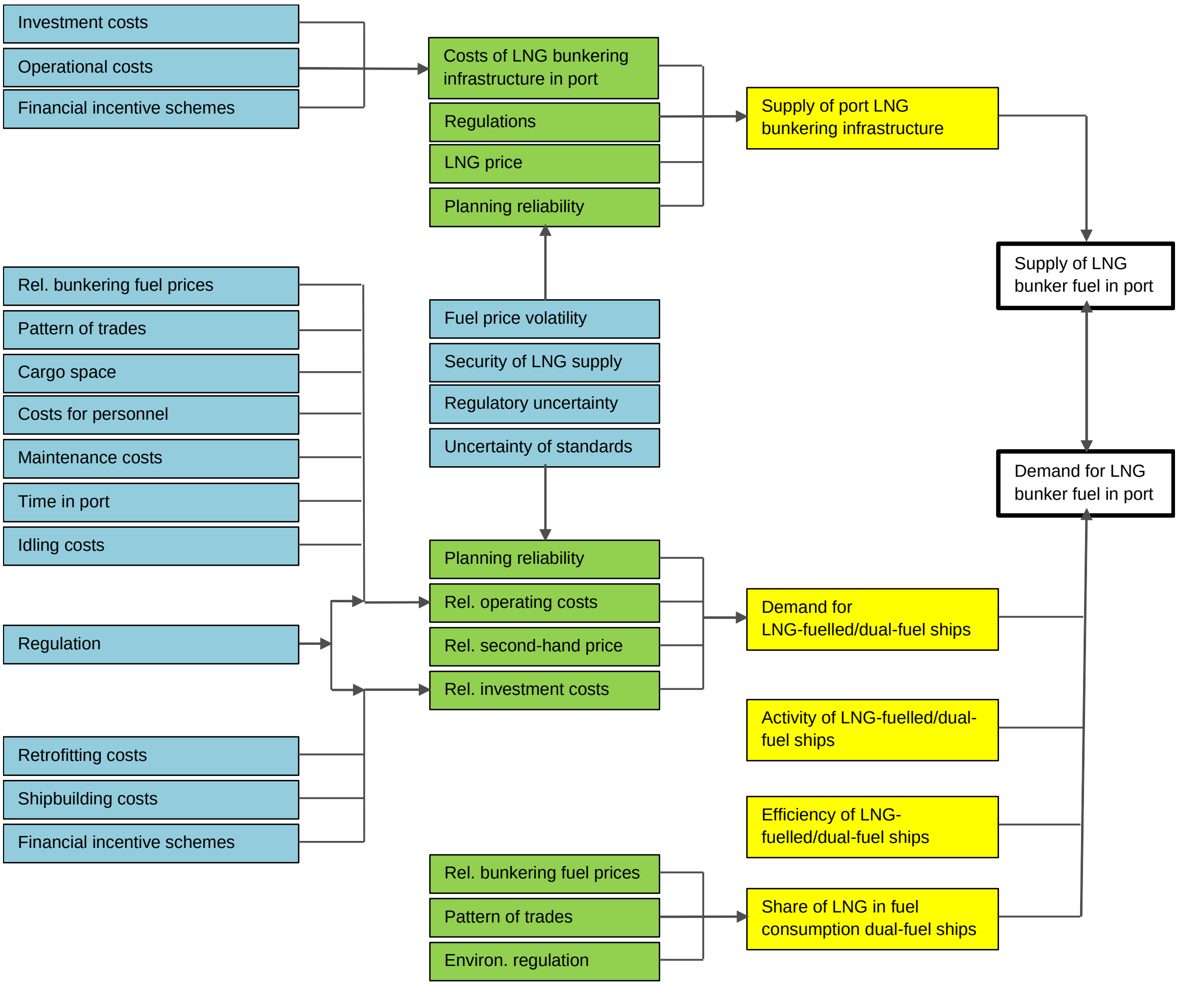
6. Analysis of the future LNG market

6.1. Introduction

This chapter provides a qualitative and quantitative outlook of the development of the LNG bunkering market until 2030.

The basis for the outlook is the model of supply and demand that was developed in Chapter 2, and which is reproduced in Figure 36. This model identifies the drivers and barriers to the development of the LNG bunkering market.

Figure 36 Factors that determine the supply and the demand for LNG bunker fuel in ports



Section 6.2 discusses the regulatory developments, infrastructure investments and economic developments that are relevant for the model through to 2030. Section 6.3 develops building blocks for scenarios and identifies relevant sources for their quantification. Section 6.4 describes the scenarios and presents the quantitative estimates of supply and demand of LNG as a bunker fuel.

6.2. Regulatory developments and infrastructure investments

In the next decade, some of the current barriers to the establishment of an LNG bunkering fuel market in the EU can be expected to be overcome. Initiatives to harmonise standards and regulations are already underway, led, in part, by EMSA. The EU Alternative Fuels Infrastructure Directive will lead to the establishment of more LNG bunkering supply infrastructure in ports. More information about the costs and benefits of LNG-fuelled ships will become available from the existing/ordered LNG-fuelled ships.

The number of LNG import terminals and bunker fuel facilities in ports is currently increasing. As mentioned in Chapter 2, in 2015 (as by April 2015), there have been 23 LNG import terminals in EU countries with a nominal annual regasification capacity of 200 billion m^3 in terms of natural gas (IEA, 2015). GLE (Gas LNG Europe) reports (GIE, 2015b) that in the EU LNG import terminals of around 20 billion m^3 nominal annual regasification capacity are under construction and that another 145 billion m^3 have been planned. However, most of this capacity can be expected to be used for the conventional natural gas consumers like power plants, industry, and households.

In Europe, LNG is currently available as bunker fuel for maritime shipping at seven EU sea ports in, Belgium, Germany, the Netherlands, Denmark and Sweden (GIE, 2015b). According to the World Port Climate Initiative (WPCI, 2015a) LNG bunkering infrastructure is planned in another 21 EU ports located in Belgium, Denmark, Estonia, Finland, France, Germany, the Netherlands, Spain and Sweden.

What remains as the **biggest hurdle** for the establishment of an LNG bunkering market in the EU is the level and uncertainty regarding the actual **LNG bunkering price** and the relative price compared to the other bunkering fuels. Will the relative LNG price be sufficiently low for ship owners to have a positive business case when investing in an LNG-fuelled ship and thus generating LNG demand and will it be sufficiently high for the bunkering fuel supplier to have a positive business case on his part?

If the crude oil price remains low or will fall even more, the LNG price will be relatively high compared to the HFO, MDO, and MGO price which have been highly correlated to the crude oil price in the past. Oil-linked LNG price contracts would then be an attractive option for ship owners, but LNG suppliers may then face a negative business case.

Additional environmental regulation, like the establishment of an NO_x Emission Control Area in the North Sea and the Baltic can lead to a higher demand for LNG-fuelled ships, just as cost decreases of LNG-fuelled engines due to learning effects and economies of scale. This however can only be expected to lead to a marginal decline of LNG bunker prices, since LNG import prices will not be affected.

For the LNG bunkering fuel supply side, financial support could contribute to reduce the financial risk, as well as long term contracts between ship owners and the bunker fuel supplier. These contracts however are only conceivable for owners of ships with a dedicated gas engine and liner trades and ferries for which the ship owner knows for sure that his ship calls the port on a regular basis.

6.3. Building blocks for scenarios

As discussed in Chapter 2, the main barrier to the development of the LNG market is uncertainty. There are different types of uncertainty, each of which is addressed in the scenario development:

- Uncertainty about future fuel prices which comprise of uncertainty about gas and oil prices, and uncertainty about bunkering options in ports, which can have a significant influence on LNG bunkering prices in ports. The CBAs in Chapter 5[39] show that higher LNG prices (of lower prices of petroleum fuels) will result in business cases turning negative, and that the same is true for some bunkering options (especially bunkering by tank trucks and in some cases by a jetty and loading arm). In the development of the scenarios, the different prices are taken into account by using a relatively low LNG price in and the best bunkering option the maximum scenario, the base case LNG price with the second-best bunkering option in the medium scenario and a relatively high LNG price in the low scenario.
- Uncertainty about the availability of LNG. It is assumed that by 2025, the Alternative Fuels Infrastructure Directive (EC, 2014a) will be fully implemented and that LNG will be available in all TEN-T core ports. This assumption is made in all scenarios.
- Uncertainty about the technology itself, standardisation, second hand-prices of LNG ships, and further environmental regulation are treated in combination, as there is no information available about their individual quantitative impacts on supply and demand. Instead, it is assumed that because of these remaining uncertainties, 30, 60 or 90% of the potential market will not shift to LNG.

The scenarios have been developed for cargo ships and for ro-ro, ro-pax, ferries and cruise ships. Other ship types are not included, such as fishing vessels, research, dredging, yachts, etc. The reason for excluding these ship types is that they have a different cost-structure and demand is driven by other factors than included in this analysis. To the extent that these ships will also use LNG (and there have been reports about trailing suction hopper dredgers with dual-fuel engines and LNG tanks)[40], the quantitative estimates presented in this chapter can be regarded as lower estimates.

Below, first each scenario is described and then the quantitative estimates of supply and demand of LNG is presented.

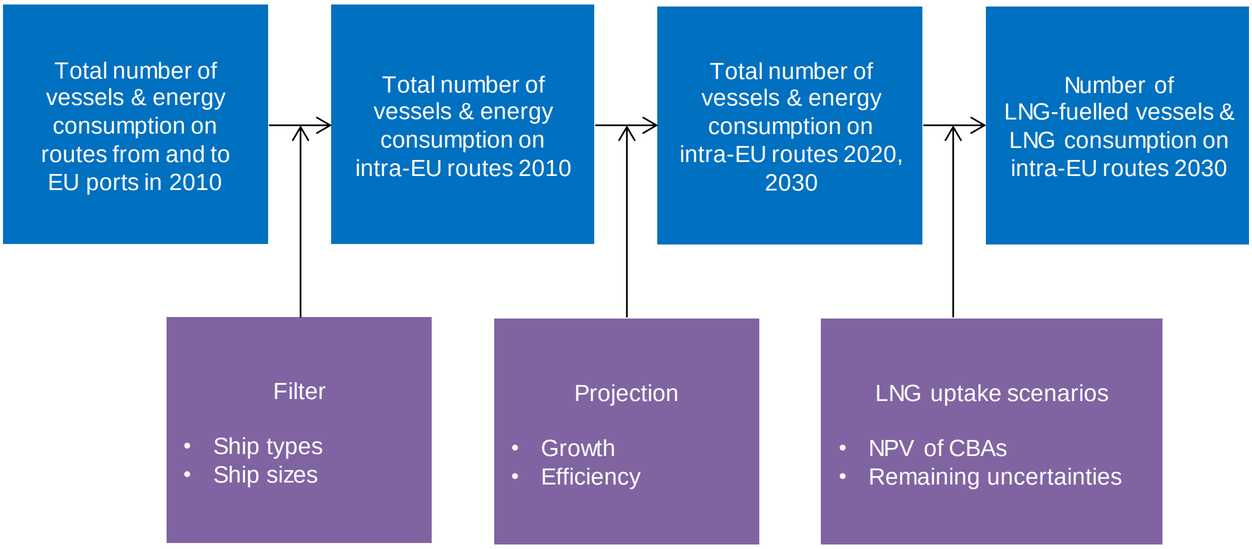
39 Based on the fuel price assumptions in Table 8.

40 Royal IHC is building two LNG powered trailing suction hopper dredgers for DEME, to become operational from 2016. www.ihcmerwede.com/about-royal-ihc/media/news/article/royal-ihc-secures-order-to-supply-worlds-first-lng-low-emission-tshds-for-deme/.

Quantification of the baseline scenario

The quantification of the scenarios (see Figure 37) combines a constant baseline scenario of energy use by ships sailing between EU ports with different projections of the share of LNG in the total fuel use.

Figure 37 Quantification of the scenarios



The baseline scenario focuses on ships sailing between EU ports. The fuel use and the number of ships in 2010 have been taken from Ricardo-AEA et al. (2013). It is assumed that all ferries, ro-ro and service vessels sail between EU ports. For the other ship types, it is assumed that all ships below 5000 GT sail between EU ports, and that larger ships are oceangoing ships, which are assumed not to use LNG.[41] Emissions from ships sailing between EU ports represent 24% of the emissions from all ships calling at EU ports (so emissions on voyages to and from EU ports). This is lower than the estimate of CE Delft et al. (CE Delft, 2009) that intra-EU voyages account for 36% of total voyages. The fact that the current estimate is lower can be explained because the estimated emissions are from ships that sail exclusively between EU ports, and do not include intra-EU legs of voyages of ocean going vessels.

The 2010 data are projected forward using growth factors for short sea shipping from COWI et al. (COWI, et al., 2015)[42]. These factors are expressed in tonnes, but assuming that the average cargo haul remains constant, they are applicable to transport work as well. It is assumed that in this period the fleet average efficiency will improve as in the BAU scenarios from the 3rd IMO GHG Study (IMO, 2014).

[41] We have compared the resulting number of ships with the number of ships reported in DMA (2012) to sail more than half of the time within the North Sea and Baltic SECAs and find the number of ships in our base case to be plausible.

[42] GDP growth assumptions in this study are taken from the European Central Bank and are +1.5% for the period 2015-2017 and +1.7% for the period 2017-2020 (baseline values). The demand in short sea shipping is correlated with economic growth measured through GDP. In the baseline, the increase in short sea shipping demand is 1.4% per year. In the scenario without GDP growth, the authors have calculated that the annual increase in short sea shipping demand is 0.95%. In the scenario with GDP growth, the annual demand increases with 1.55%. these annual growth rates are used in the calculations of the scenarios.

Furthermore, it is assumed that 3% of the existing fleet is retired in any year, and that the first LNG ships are introduced to the market in 2020.

The number of ships and fuel consumption baseline are presented in Table 52.

Table 52 Number of total (LNG- and non-LNG-fuelled) coastal ships and total fuel consumption (PJ) for the central growth scenario

		Number of ships		Fuel consumption	
		2020	**2030**	**2020**	**2030**
Oil tanker	<5,000 GT	330	380	5.1	6
Chemical tanker	<5,000 GT	600	690	28.3	33.8
LPG carrier	<5,000 GT	150	170	8.8	10.5
LNG carrier		10	10	4.4	5.3
Other tanker	<5,000 GT	60	70	1.6	1.9
Bulker	<5,000 GT	150	170	4.5	5.4
General cargo	<5,000 GT	3,690	4,240	90.3	107.9
Other dry	<5,000 GT	170	200	4.5	5.4
Container vessel	<5,000 GT	70	80	4.4	5.2
Vehicle carrier	<5,000 GT	100	120	17.4	20.8
RoRo	All	450	520	95.3	113.8
Ferries	All	1090	1090	264.8	275.3
Cruise ships	<5,000 GT	50	50	1	1
Yachts	<5,000 GT	570	570	10	10.3
Offshore	All	860	860	25.2	26.2
Service vessel	All	1,620	1,620	29.7	30.9
Fishing	All	390	390	5.6	5.9
Miscellaneous	All	110	110	2.3	2.3
Total		**13,450**	**11,310**	**603.2**	**667.9**

6.4. Scenarios for the use of LNG as a bunker fuel

Based on the base case that has been quantified in Section 6.3, the share of LNG in the fuel mix is calculated in four steps:

1. Identify the ships for which the CBAs of using LNG are positive, taking into account the scenario-specific fuel prices and bunkering options, and assuming that dry bulk carriers and tankers have the same CBA results as general cargo ships.
2. Take into account the uncertainty about standardisation, second hand-prices of LNG ships, and further environmental regulation by assuming that 100%, 60% and 20% of the eligible ships will indeed use LNG.
3. Calculate the fuel consumption of the new ships of these types in 2030, as well as the scenario-dependent share of existing ships to which LNG will be retrofitted by 2030.
4. Estimate the number of LNG ships and their LNG consumption in each scenario.

One of these assumptions results in an overestimation of LNG demand, viz. which is not taken into account that new ships are more energy efficient than existing ships, because of the EEDI regulation. However, the other assumptions result in an underestimation of demand, viz. that ocean going vessels will not use LNG and that intra-EU voyages exclude voyages between EU ports and Norwegian ports.

Below, 3 scenarios are described in which the assumptions are either very favourable for the development of the LNG market (the maximum scenario), moderately favourable (the medium scenario) or rather unfavourable (the low scenario).

Maximum scenario

The maximum scenario assumes that the circumstances for the use of LNG as a bunker fuel are favourable. It takes the most positive outlook on the economic conditions (and hence the largest increase in transport work). Because of the positive economic outlook, it is assumed that the remaining uncertainties will be overcome to a larger extent than in the other scenarios by more experience with the use of LNG as a bunker fuel.

The scenario is built on a relatively low LNG import price (25% below the base price), which implicitly assumes that the security of supply of LNG to the European market will be good. It also implies that ports will invest in the cheapest bunkering option, which often has a larger scale and thus requires a more optimistic outlook on demand. The full scale development of ship-to-ship bunkering infrastructure in ports means that the LNG bunkering price is low and also that there is only a minimal impact on ships' time in port and on idling costs.

With regards to the unquantified uncertainties, it is assumed that standards are fully harmonised so that ships can bunker without problems in any TEN-T core port.
The uncertainty about second hand-prices is assumed to be reduced by the fact that other world regions also make a shift to LNG (especially in ECAs) and that the date of entry into force of the global 0.50% m/m sulphur content in marine fuel is kept at 2020. Because of the financial benefits of LNG, yards will have experience with building LNG ships and the additional capital expenditures of LNG ships will reduce.

The reduced uncertainty results in 70 or 40% of the new buildings of ship types for which the NPV of an LNG-fuelled ship is positive in at least one of the CBAs under the assumptions mentioned above will be an LNG ship. In addition, it is assumed that 3% of the existing fleet will retrofit an LNG installation.

Medium scenario

The scenario is built on the base-price of LNG imports and baseline forecasts on economic growth and transport demand growth. It is assumed that under these conditions, ports and bunker fuel suppliers will generally choose for a medium-scale bunkering option, which will result in slightly higher bunkering costs than in the maximum scenario. Still, most ports and fuel suppliers will invest in bunkering ships, which means that there is only a minimal impact on ships' time in port and on idling costs.

With regards to the unquantified uncertainties, it is assumed that standards are harmonised so that ships can bunker without problems in any TEN-T core port.
The uncertainty about second hand-prices is assumed to be reduced by the fact that

other world regions also make a shift to LNG (especially in ECAs) and that the date of entry into force of the global 0.50% m/m sulphur content in marine fuel is kept at 2020. Because of the financial benefits of LNG, yards will have experience with building LNG ships and the additional capital expenditures of LNG ships will reduce.

The remaining uncertainty results in 70, 40 or 10% of the new buildings of ship types for which at least one of the CBAs is positive under the assumptions mentioned above will be an LNG ship. In this scenario, and in contrast to the maximum scenario, it is not assumed that there will be a noticeable demand for retrofitting LNG to existing ships.

Low scenario

The low scenario assumes that the circumstances for the use of LNG as a bunker fuel are not favourable. It builds upon a negative outlook on the economic conditions with a low growth of short sea shipping transport. Because of the negative economic outlook, it is assumed that the remaining uncertainties will be overcome to a lower degree than in the other scenarios because fewer ship owners, equipment manufacturers, fuel suppliers and ports will gain experience with the use of LNG as a bunker fuel.

The scenario is built on a relatively high LNG import price. Because of the unfavourable conditions, ports and fuel suppliers will invest only in small-scale bunkering options in order to comply with the EU Alternative Fuels Infrastructure Directive. In a significant number of ports, LNG will be supplied by tank trucks which has a negative impact on the time ships need to stay in the port, because bunkering may not always be possible simultaneously with cargo handling. This means that the LNG bunkering price is less favourable and in most CBAs, the NPV of an LNG-fuelled vessel is negative.

In this scenario, LNG will only be an attractive option for ships that frequent specific ports, so that fuel suppliers and shipping companies can cooperate to reduce the uncertainty of supply and demand, e.g. by entering in contractual arrangements about the minimum demand and maximum price of LNG. Hence, it is assumed that in this scenario, only some ferries and PSVs will use LNG.

The remaining uncertainty results in 40 or 10% of the new ferries and PSVs will be an LNG ship. In this scenario, no noticeable demand for retrofitting LNG to existing ships is expected.

Table 53 Overview of the different assumptions per scenario

	Low scenario	Medium scenario	Maximum scenario
Share of 2020 fleet annually replaced by new builds	3%	3%	3%
Share of relevant existing fleet that chooses for an LNG retrofit	0%	0%	3%
Uptake scenarios of relevant fleet (due to uncertainty)	10%, 40%	10%, 40%,70%	40%,70%
Growth factor (cargo transport work)	0.95% p.a.	1.4% p.a.	1.55% p.a.
Growth factor (passenger transport)	0%	0%	0%
Annual GDP growth	No economic growth	Until 2017: 1.5% From 2018: 1.7%	Until 2017: 1.65% From 2018: 1.87%
Average fleet energy efficiency improvement compared to 2010	2020: 3% 2030: 11%	2020: 3% 2030: 11%	2020: 3% 2030: 11%
Choice of relevant vessel types based on…	Only vessels that can be expected not to sail to ports outside EU	One of the CBAs regarding the HFO& scrubber baseline has to be positive given the base case LNG import price (see Figure 35)	One of the CBAs regarding the HFO& scrubber baseline has to be positive given that the LNG import price is 25% lower than the base case price (see Figure 35)

6.5. Quantification of the scenarios

If the criteria as specified in the last row of Table 53 are applied, the following ship types are assumed to potentially become LNG-fuelled:

- low scenario: RoRo vessels, ferries, offshore and service vessels;
- medium scenario: all ship types except container vessels, fishing vessels, yachts, and miscellaneous;
- maximum scenario: all ship types except fishing vessels, yachts, miscellaneous.

The estimated number of LNG-fuelled ships and the fuel consumption of these ships is summarised in Table 54 for 2030. The Table also provides an estimation of the emission reductions of CO_2, NO_x, SO_x and PM. The estimates have been calculated using the emission factors of the Third IMO GHG Study 2014, which are summarized in Table 55.

Table 54 Estimated number of LNG-fuelled ships and their LNG consumption in 2030

	Low scenario	Medium scenario	Maximum scenario
Number of vessels	120-500	370–2,600	3,200-5,500
Share in fleet*	1–5%	3–20%	30–50%
LNG consumption (PJ)	10–50	20-140	180-310
Share of total fuel consumption*	2–10%	3–20%	30–50%
LNG consumption (kt)	250–1,000	400 -2,800	3,700–6,300
Related CO_2 emission reduction (kt)	100-400	150-1,100	1,400-2,400
Related NO_x emission reduction (t)	200-800	350-2,300	3,000-5,100
Related SO_x emission reduction (t)	0.3-1.2	0.5-3.2	4.2-7.2
Related PM emission reduction (t)	0.2-0.9	0.4-2.6	3.4-5.9

* Fleet/total fuel consumption of intra-EU fleet + cruise vessels.

In the low scenario 1 to 5%, in the medium scenario 3 to 20%, and in the maximum scenario 30 to 50% of the vessels of the intra-EU fleet (+cruise vessels) are expected to be LNG-fuelled in 2030. In terms of fuel consumption, in the low scenario 2 to 10%, in the medium scenario 3 to 20%, and in the maximum scenario 30 to 50% of the fuel consumed by the intra-EU fleet (+cruise vessels) are expected to be LNG.

Table 55 Emission factors 2030 (g/g fuel)

	LNG	HFO/MGO
CO_2	2.8	3.2
NO_x	0.1	0.8
SO_x	0	0.001
PM	0.00018	0.00097

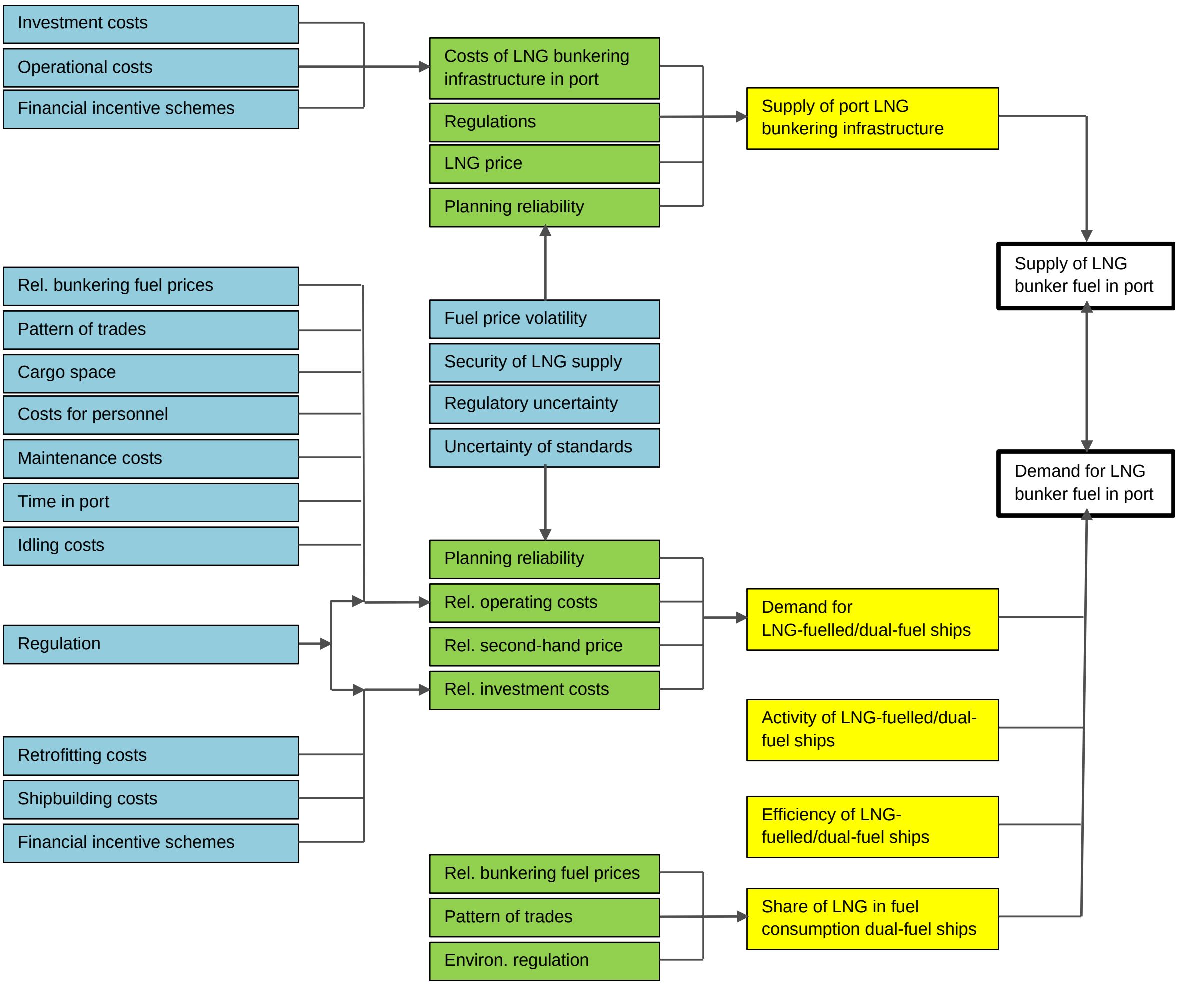
Source: Third IMO GHG Study, 2014.

7. Conclusions

As stated in Chapter 1, the objective of this study is to provide a market overview and estimations on LNG, and to assess the hindrances that prevent a quick, gradual deployment of LNG as a bunker fuel.

The study has developed a model for the LNG bunkering fuel market, which is reproduced below. The model shows that the main drivers for the use of LNG are the environmental regulation, especially with regards to the sulphur content of fuel, and the price difference between LNG and other fuels. The main barriers are uncertainty about the availability of LNG in ports, about technical and safety standards, and about the second hand-price of LNG ships.

Figure 38 Factors that determine the supply and the demand for LNG bunker fuel in ports



The major uncertainties that are currently holding back demand for LNG as a bunker fuel are the uncertainty about the fuel price (contrary to conventional maritime fuels, there is no public price information on LNG bunkering price) and future price developments, uncertainty about the availability of LNG in ports, uncertainty about the second hand-price of an LNG ship, and a range of factors that stem from a lack of experience with the use of LNG as a bunker fuel, such as the required time in port for bunkering, maintenance, cargo space, standardization, et cetera.

Some of these uncertainties are likely to be reduced considerably in the coming decade. By 2025, LNG will be available in all EU TEN-T core ports, as the Alternative Fuels Infrastructure Directive will be implemented. Possibly, a fuel price or price benchmark will become available once LNG is available in more ports. With the number of LNG ships increasing, there will be more experience with LNG, reducing the associated uncertainties. The remaining uncertainties are the fuel price and the second hand-price.

What is not shown in the model, is that the LNG bunkering market is a segment in a much larger market for LNG, which, in turn, is linked to natural gas markets on the one hand and to markets for other liquid fuels on the other. Currently, the natural gas market is much larger in Europe than the LNG market, and the LNG bunkering market is very small compared to the European LNG market.

In the last decades, the LNG prices have been different in different world regions, with the highest prices being paid in Asia. Since 2008, with shale gas becoming available in large quantities in North America, American LNG prices have been the lowest in the world. European prices have fluctuated between Asian and North American prices. Most price projections, including the ones used in this report, assume this situation to continue in the next decades.

The study has analysed the costs and benefits of LNG ships of in ten different ports in Europe under a range of assumptions on LNG prices and bunkering options. The focus of the case studies has been on ships that are engaged in intra-EU trades, because the fuel supply risk for these ships will be low once the Alternative Fuels Infrastructure Directive will have been implemented. For all ships, LNG has lower end-user costs than using MGO, and in many cases, LNG is more cost-effective than HFO in combination with a scrubber (the scrubber is needed to comply with the EU Marine Fuels Sulphur Directive after 2020). The two main cost items are the additional investments in LNG engines, tanks and piping, and the reduced cost of the fuel. The pay-back times of investments in LNG tanks, piping and engines range from 6 years for a general cargo ship in a port with relatively low LNG bunker prices (because of the availability of LNG in the port and an investment in a supply ship) to 12 years for container ships which have relatively large engines and therefore require higher investments. In most cases, the pay-back time is between 8 and 10 years.

The examples provided above demonstrate the sensitivity of the results to the bunkering options. In fact, when bunkering is done by tank-trucks or by shore infrastructure, the NPV of the CBA is hardly ever positive. In all the examples provided, the reference case was a HFO-fuelled ship with a scrubber. If MGO is used as a reference fuel, the pay-back time is typically 3 to 5 years shorter. Other important factors are the difference between the LNG price and the prices of other fuels, the costs of a scrubber and the cost of capital.

The CBA results are very sensitive to the relative fuel prices. If LNG prices are 25% higher than projected by the World Bank (or, conversely, if petroleum fuel prices are 25% lower), all cases are negative. Note that the current bunker prices (September 2015) do not resemble the World Bank projections but are closer to a situation where the price difference between LNG and petroleum fuels is 25% smaller. Hence, with current fuel prices, LNG is not the most economically viable options in any case studied in this report.

In order to project the total demand in EU ports for LNG as a bunker fuel, this study has developed three scenarios. All scenarios share the common assumptions that by 2025, LNG will be available in all TEN-T core ports because of the implementation of the EU Alternative Fuels Infrastructure Directive and that from 2020 onwards the EU Marine Fuels Sulphur Directive will require ships sailing to EU ports to use low sulphur fuels or a scrubber with equivalent emissions. The scenarios have different assumptions on the drivers of demand for LNG bunker fuel (economic growth, transport demand, LNG import prices, bunkering options), and on the barriers (uncertainty standards, uncertainty second hand-prices). Table 56 provides an overview of the assumptions.

Table 56 LNG Bunkering Market Scenarios

	Maximum scenario	Medium scenario	Low scenario
Economic growth	high	medium	low
Transport demand growth Fleet growth	1.55% p.a.	1.40% p.a.	0.95% p.a.
LNG import price relative to HFO and MGO	25% below base case	Base case	25% above base case
Preferred LNG bunkering option	Large-scale supply vessels in most TEN-T core ports	Medium-scale supply vessels in most TEN-T core ports	Medium-scale supply vessels in specific ports
Uncertainty about technical and safety standards	Low (full harmonization)	Low (full harmonization)	Medium (partial harmonization)
Uncertainty about second hand-price of LNG ships	Low (implementation of global low Sulphur requirements by 2020; LNG ships in other ECAs)	Medium (implementation of global low Sulphur requirements by 2020)	High (implementation of global low Sulphur requirements by 2025; LNG ships in other ECAs)
Uncertainty about technology	Low	Medium	High
Ship types for which LNG is an attractive option	Ships on intra-EU voyages	Ships on intra-EU voyages	Vessels that sail on specific routes, e.g.

	Maximum scenario	Medium scenario	Low scenario
			ferries, platform supply vessels
Number of LNG ships (2030)	3,200-5,500	370–2,600	120-500
LNG Bunker Demand (Million tonnes, 2030)	3.7–6.3	0.4 -2.8	0.25–1
Related NO_x emission reduction (t)	3,000-5,100	350-2,300	200-800
Related SO_x emission reduction (t)	4.2-7.2	0.5-3.2	0.3-1.2
Related PM emission reduction (t)	3.4-5.9	0.4-2.6	0.2-0.9

Under these scenarios, the LNG bunkering market is projected to range from about 0.25 million tonnes in 2020 to 6 million tonnes. The former projection assumes a low economic growth rate, high LNG import prices, remaining uncertainty about demand resulting in bunker fuel suppliers opting for relatively small-scale LNG bunkering options. As a result, LNG-fuelled ships will only be cost-effective in ports where there is a high local demand, and only for ships that visit these ports frequently. It is expected that under these conditions, ferries and platform supply vessels will consider LNG, but other ship types will not.

The high projection assumes a higher economic growth (and hence a larger share of new ships in the fleet), a lower LNG import price. As a result, LNG-fuelled ships are very cost-effective and fuel suppliers will invest in larger scale bunkering options. Many ships of different ship types will convert to LNG. Note that the current fuel prices (September 2015) reflect the assumptions in the low scenario.

8. References

ABP, 2014. *Southampton port profile,* s.l.: Associated British Ports (ABP).

Acorn Petroleum Services, 2013. *Free resources for the upstream oil & gas industry : North Sea Fields.* [Online]
Available at: http://www.acorn-ps.com/web/page/oilgas/nsfields.htm
[Accessed 2015].

Antwerp Port Authority, 2013. *Antwerp, Your port of choice : Containers,* Antwerp: Port of Antwerp.

Ashcroft and Associates, 2013. Cruise Insight world's top cruise ports. *Cruise Insight,* Issue Autumn, pp. 50-55.

Cars, H., 2013. *LNG in the ports of Stockholm,* Stockholm: Stockholm Stad.

CE Delft, TNO and ECN, 2013. *Natural gas in transport : an assessment of different routes,* Delft: CE Delft.

CE Delft, 2009. *Technical support for European action to reducing Greenhouse Gas Emissions from international maritime transport,* Delft: CE Delft.

CE Delft, 2010. *Shadow Prices Handbook : Valuation and weighting of emissions and environmental impacts,* Delft: CE Delft.

CE Delft, 2015. *Scrubbers - An economic and ecological assessment,* Delft: CE Delft.

Clean Baltic Sea Shipping, 2013. *Task 5.6 Bunkering of ships that use liquefied natural gas or dual fuel at Klaipeda state seaport,* sl: Clean Baltic Sea Shipping.

CNSS, 2013. *LNG fuelled ships as a contribution to clean air in harbours,* sl: Clean North Sea Shipping.

CNSS, 2015. *Differentiated port and fairway dues.* [Online]
Available at: http://cleantech.cnss.no/policies-and-instruments/voluntary-instruments/clean-shipping-index/
[Accessed 2015].

Constanza Port , 2015. *The traffic of goods - over 55.6 million tonnes in 2014.* [Online]
Available at:
http://www.portofconstantza.com/apmc/portal/vizstire.do?method=showNews&bifa=true&id_stire=12995&tip_stire=1
[Accessed 2015].

COWI, VITO & CENIT, 2015. *Analysis of recent trends in EU shipping and analysis and policy support to improve the competitiveness of short sea shipping in the EU,* Brussels: COWI Belgium.

CRS, 2015. *U.S. Natural Gas Exports : New Opportunities, Uncertain Outcomes,* Washington DC: Congressional Research Service (CRS).

DGC, 2012. *LNG - Status in Denmark. Technology and potential,* Horsholm: Danish Gas Technology Centre (DGC).

DLR, et al., 2014. *LNG as an alternative fuel for the operation of ships and heavy-duty vehicles,* Berlin: Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR).

DMA, 2012. *North European LNG Infrastructure Project: A feasibility study for an LNG filling station infrastructure and test of recommendations, full report,* Copenhagen: Danish Maritime Authority (DMA).

DNB, 2015. *Rentes.* [Online]
Available at: https://www.statistics.dnb.nl/financiele-markten/rentes/index.jsp
[Geopend juli 2015].

DNV GL; PWC, not yet published. *Study on the completion of an EU framework on LNG-fuelled ships (...) fuel provision infrastructure, L.1: Analysis and evaluation of identified gaps (...) remaining aspects for completing an EU-wide framework for marine LNG distribution, bunkering and use,* s.l.: DNV GL.

DNV GL, 2014a. *LNG Fleet as of March 2014 : Sailing ships and orderbook.* [Online]
Available at: http://www.slideshare.net/blikom/world-lng-fueled-fleet-as-of-march-2014
[Geopend 2015].

DNV GL, 2014b. *LNG as ship fuel : the future-today,* Hamburg: DNV GL - Maritime.

DNV GL, 2014c. *Liquefied Natural Gas (LNG) Bunkering Study,* sl: DNV GL.

DNV GL, 2015a. *DNV GL – LNG fuelled vessels : Ship list – Vessels in operation and vessels on order.* [Online]
Available at: https://www.dnvgl.com/Images/2015-07-01%20World%20LNG%20fuelled%20fleet_tcm8-5550.pdf
[Accessed 2015].

DNV GL, 2015b. *In focus-LNG as ship fuel : Latest devopments and projects in the LNG industry,* Hamburg: DNV GL Maritime.

DNV-GL, 2015c. *LOT 1 Position Paper: Implications of drop in oil price on LNG uptake,* Antwerp: DNV-GL.

EC, 2009. *European Energy Programme for Recovery: Regulation (EC) No 663/2009 of the European Parliament and of the Council of 13 July 2009 establishing a programme to aid economic recovery by granting Community financial assistance to projects in the field of ener,* Brussels: European Commission.

EC, 2012a. *Connecting Europe : the energy infrastructure for tomorrow,* Brussels: European Commission (EC).

EC, 2012. *Directive 2012/33/EU of the European Parliament and of the Council of 21 November 2012 amending Council Directive 1999/32/EC as regards the sulphur content of marine fuels,* Brussels: European Commission.

EC, 2013a. *Regulation (EU) No 1315/2013 of the European Parliament and of the Council of 11 December 2013 on Union guidelines for the development of the trans-European transport network and repealing Decision No 661/2010/EU Text with EEA relevance ,* Brussels: European Commission.

EC, 2013b. *Communication from the Commission to the European parliament , the Council, the European economic and social committee and the Committee of the regions Clean Power for Transport: A European alternative fuels strategy (COM (2013) 17 final),* Brussels: European Commission.

EC, 2014a. *Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure Text with EEA relevance,* Brussels: European Commission.

EC, 2014b. *Guide to Cost-Benefit Analysis of Investment Projects. Economic appraisal tool for Cohesion Policy 2014-2020,* Brussels: European Commission (EC).

EEA, 2013. *The impact of international shipping on European air quality and climate forcing,* Copenhagen: European Environmental Agency.

EIB, 2015. *WACC* [Interview] (14 July 2015).

Enagas , 2013. *LNG Trucking : A First Step to the Development of LNG for Fuel for Transportation,* s.l.: s.n.

Eurogas, 2014. *2014 statistical report,* Brussels: Eurogas.

Eurostat, 2015. *Maritime ports freight and passenger statistics.* [Online]
Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Maritime_ports_freight_and_passenger_statistics
[Accessed 2015].

EY, 2014. *Competing for LNG demand : the pricing structure debate,* S.l. : Ernst & Young Global Limited (EY).

GDF Suez, 2014. *Demand for LNG as Fuel in Marine Applications. Presentation at NAMEPA Annual Conference October 29, 2014.* s.l., GDF Suez.

Germanischer Lloyd, 2011. *Costs and benefits of LNG as ship fuel for container vessels : Key results from a GL and MAN joint study,* Hamburg: Germanischer Lloyd.

Germanischer Lloyd, 2013. *European Maritime Safety Agency (EMSA) : Study on Standards and rules for bunkering of gas-fuelled Ships,* Hamburg: Germanischer Lloyd SE (GL).

GIE, 2015a. *Small Scale LNG map.* [Online]
Available at: http://www.gie.eu/index.php/maps-data/gle-sslng-map
[Accessed 2015].

GIE, 2015b. *LNG map : GIE LNG Map Dataset in Excel-format.* [Online]
Available at:
http://www.gie.eu/download/maps/2015/2015%20GLE%20LNG%20Map%20database.xlsx
[Accessed 2015].

IEA; OECD; Eurostat, 2005. *Energy Statistics Manual,* Paris Cedex: OECD/IEA.

IEA, 2015. *Natural Gas Information 2015.* Paris: International Energy Agency (IEA)/OECD.

IGU, 2015. *World LNG Report - 2015 Edition,* Fornebu: International Gas Union (IGU).

IMO, 2010. *Reduction of GHG emissions from ships : Marginal abatement costs and cost-effectiveness of energy-efficiency measures,* sl: IMO, Institute of Marine Engineering , Science and Technology (IMaREST).

IMO, 2014. *Third IMO Greenhouse Gas Study 2014 : Safe, secure and efficient shipping on clean oceans,* London: International Maritime Organization (IMO).

IMO, 2015. *International Convention for the Safety of Life at Sea (SOLAS), 1974 : Adoption: 1 November 1974; Entry into force: 25 May 1980.* [Online]
Available at: http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx
[Accessed 2015].

Kleven, 2011. *Viking -Princess BN 347.* Ulsteinvik: Kleven Maritime AS.

Lloyd's Register and UCL, 2014. *Global Marine fuel trends 2030,* London: Lloyd's Register and UCL Energy Institute.

Lloyds Register, 2012. *LNG-fuelled deep sea shipping: The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025,* London: Lloyds Register.

Maersk Broker, 2015. *Container Market- Weekly report.* [Online]
Available at: http://www.soefart.dk/app/doc/Container_Market.pdf
[Accessed 2015].

Marseille Fos Port, 2015. *Regular lInes April 2015,* Marseille Cedex: Maseille Fos Port.

Natgas, 2015. *Gas Pricing.* [Online]
Available at: http://natgas.info/gas-information/what-is-natural-gas/gas-pricing-contracts
[Accessed 2015].

NVG, 2013. *TEN-T Project Supports Swedish LNG Floating-Bunker Feasibility Trial.* [Online]
Available at: http://www.ngvglobal.com/blog/ten-t-project-supports-swedish-lng-floating-bunker-feasibility-trial-0111
[Accessed 2015].

Oxford Institute for Energy Studies, 2014. *The prospects for natural gas as a transportation fuel in Europe,* sl: Oxford Institute for Energy Studies.

Petromedia Ltd., 2015. *Bunkerworld.* [Online]
Available at: http://www.bunkerworld.com/
[Accessed 28 may 2015].

Platts, McGraw Hill Financial, 2015. *LNG Daily.* [Online]
Available at: http://ceproject.cedelft.eu/projecten/LNG-fuelled-ships-and-fuel-infrastructure-Lot-3-LNG-market-development-in-the-EU-/Documents/Literatuur/Platts_2015_lngdaily.pdf
[Geopend 2015].

Ports of Stockholm Group, 2013. *Ports of Stockholm : annual report 2013,* Stockholm: Ports of Stockholm.

Rotterdam Port Authorities, 2014. *Top 20 European Container Ports,* Rotterdam: Port od Rotterdam.

SMTF, 2010. *LNG ship to ship bunkering procedure,* Udevalla: Swedish Marine Technology Forum.

SSPA, 2012. *Feasibility study on LNG fuelled short sea and coastal shipping in the wider Caribbean region,* Goteborg: SSPA Sweden AB.

TNO ; MARINTEK ; TML ; ISL, 2015. *GHG Emission reduction potential of EU-related maritime transport and iets impacts,* s.l.: s.n.

U.S. Energy Information Administration, 2015. *Natural Gas, Data : Henry Hub Natural Gas Spot Price.* [Online]
Available at: http://www.eia.gov/dnav/ng/hist/rngwhhdm.htm
[Accessed 2015].

USGS, 2014. *Supporting Data for the U.S. Geological Survey 2012 World Assessment of Undiscovered Oil and Gas Resources,* s.l.: U.S. Geological Survey (USGS).

Vlaamse Havencommissie, Grand Port Maritime de Marseille, 2014. *Maritieme overslag in Europese havens: Frankrijk - Marseille-Fos, haven van Marsellie-Fos.* [Online]
Available at: http://www.vlaamsehavencommissie.be/vhc/page/maritieme-overslag-europese-havens-frankrijk-marseille-fos
[Accessed 2015].

Wang, S. & Notteboom, T., 2013. LNG as a ship fuel: perspectives and challenges. *Port Technology International,* Issue 60.

Wärtsila, 2015. *LNG Conservation for Marine Engines,* Copenhagen: Wärtsila.

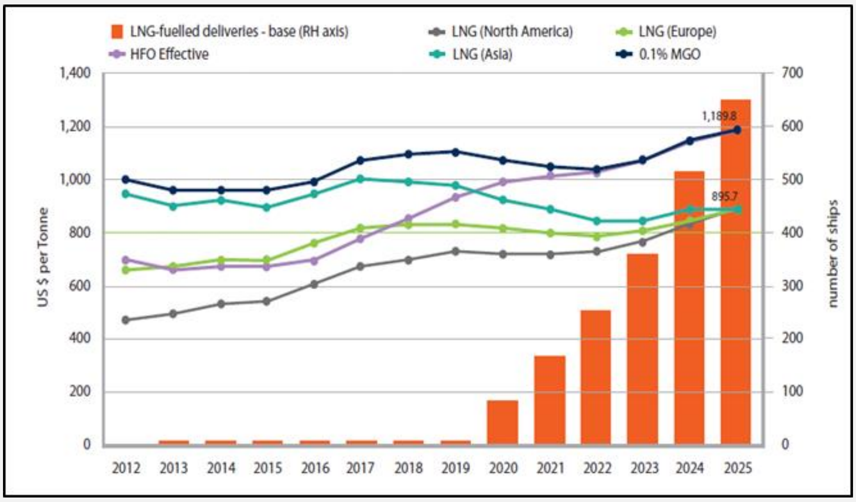
World Bank, 2014. *Commodities Price Forecast (nominal US dollars).* [Online]
Available at: http://siteresources.worldbank.org/INTPROSPECTS/Resources/334934-1304428586133/Price_Forecast_20140717.pdf
[Geopend 2015].

WPCI, 2015a. *LNG fuelled vessels.* [Online]
Available at: http://www.lngbunkering.org/lng/
[Accessed 2015].

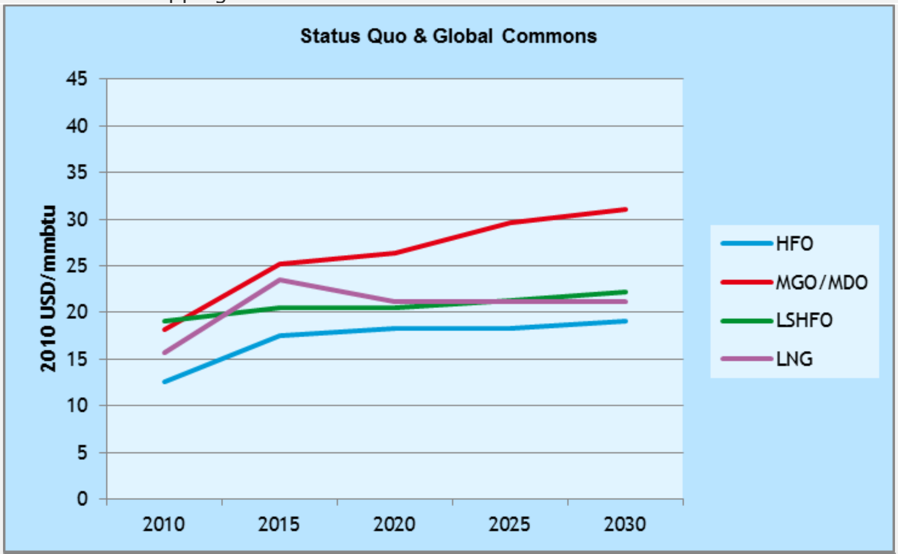
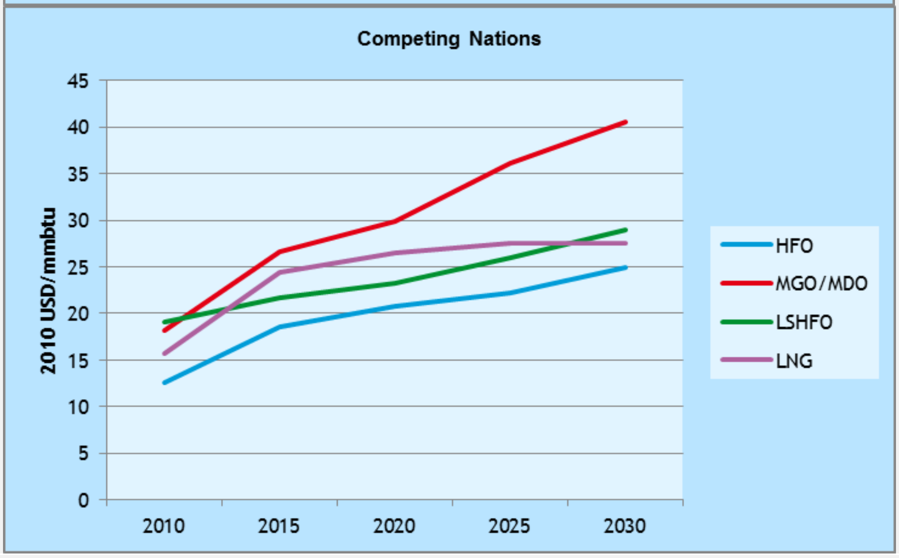
WPCI, 2015b. *LNG fuelled vessels : Funding for LNG infrastructure in the EU.* [Online]
Available at: http://www.lngbunkering.org/lng/bunkering/funding-lng-infrastructure/eu-funding
[Accessed 2015].

Annex A Literature sheets

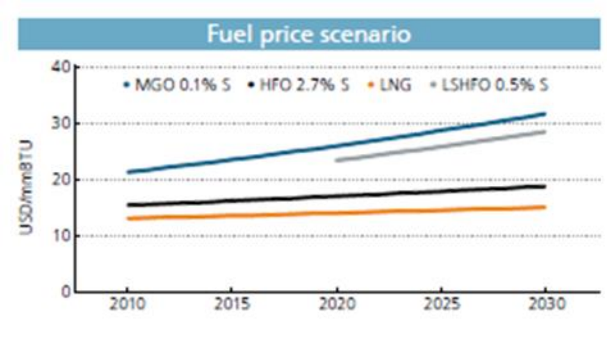
A.1 Bunkering fuel price projections

Paper identifier	**Lloyd's Register Group, 2012, LNG-fuelled deep sea shipping The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025**
Brief description	Bunkering fuel price forecasts until 2025 for three scenarios (base, low, high)
Geographical scope	World
Sectoral scope	Deep sea shipping
Price projection	Base case price projection: 
Price projection method	Base case price projection: For the HFO, MDO/MGO price forecasts, Lloyd's Register (2012) has taken the 2012 price levels as a starting point and have applied the year-on-year changes of the crude oil price projection to these prices. Regarding the LNG bunker price projection, the starting point is the 2012 US Henry Hub spot gas price. For the Asian 2012 LNG price it is assumed that it is double the Henry Hub price and for the European 2012 LNG Price that it is 70% higher than the Henry Hub price. For the LNG bunkering price forecast until 2025, a combination of the annual changes of the Henry Hub natural gas price forecast and the annual changes of the HFO-price forecast have been applied to the 2012 LNG prices. The rationale behind this is that future LNG bunker prices are assumed to be increasingly influenced by other fuel option prices as the 2020 global sulphur limits are being approached. The regional LNG bunkering prices are assumed to converge, so that in 2025 there is one global LNG bunkering price. Low case scenario: A 25% increase in forecast LNG bunker prices used in the base case model. High case scenario: A 25% decrease on the forecast LNG bunker prices used in the base case model.
Drivers	Environmental regulations

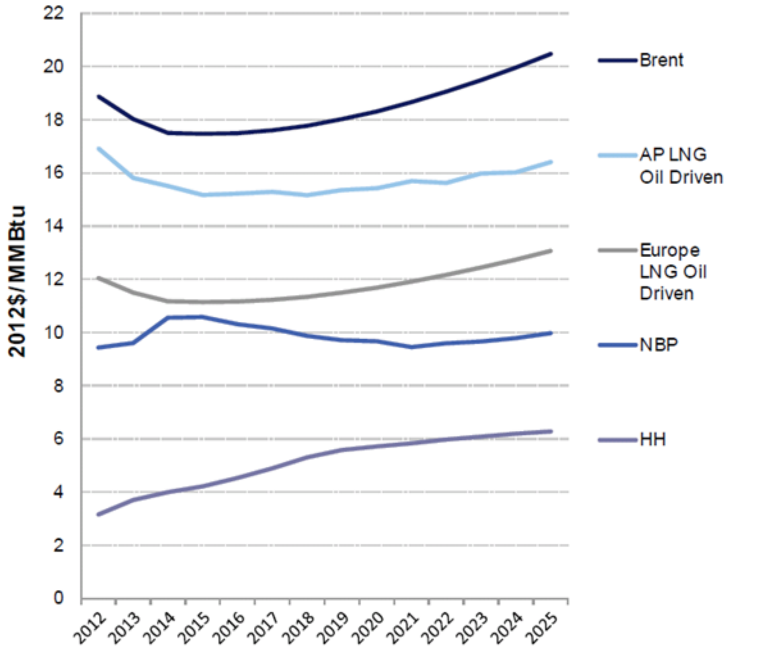
Paper identifier	Lloyd's Register Group, 2012, LNG-fuelled deep sea shipping The outlook for LNG bunker and LNG-fuelled newbuild demand up to 2025
Barriers	▪ Shipping companies consider LNG-fuelled engines as a long term term option (>10 years) ▪ Bunkering infrastructure: gas providers and bunker suppliers are unwilling tot invest until there is sufficient demand ▪ Shipping companies unwilling to invest because of lack of infrastructure

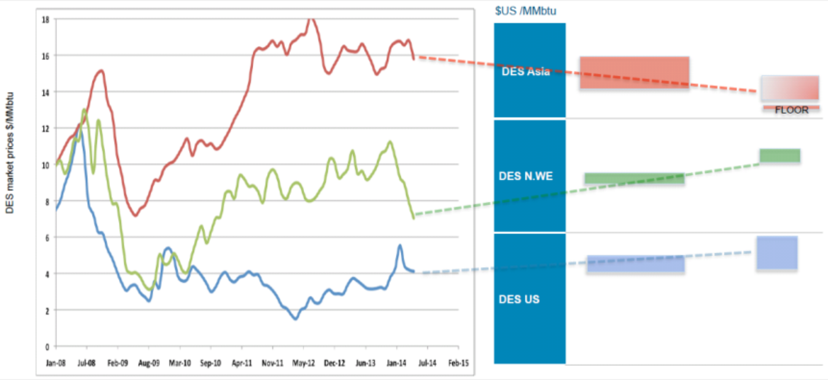
Paper identifier	Lloyd's Register Marine & UCL Energy Institute, Global Marine Fuel Trends 2030 (2014)
Brief description	Market overview and trend study of all marine fuel trends, including the uptake of LNG, Three scenarios (BaU, globalization, localization)
Geographical scope	Global
Sectoral scope	Commercial shipping
Price projection	
Price projection method	Lloyd's Register and UCL (2014) take the DECC crude oil and gas price projections as starting point for their bunkering fuel price forecast. For the period up to 2020, it is assumed that the historical relationship of MGO, LSHFO and HFO-prices and the crude oil price will still be valid, whereas for the period after

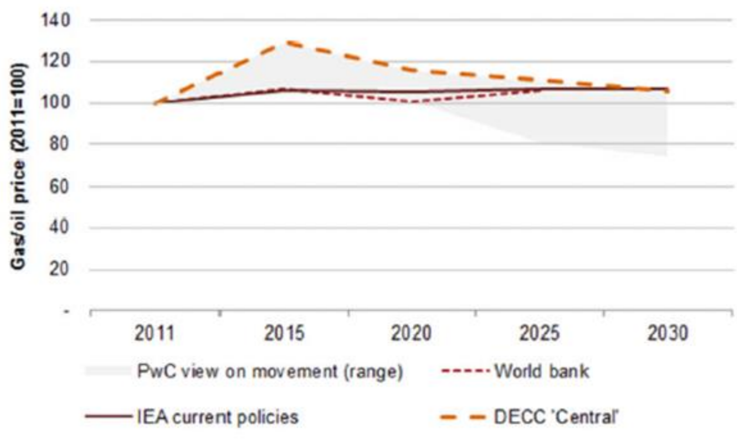
Paper identifier	**Lloyd's Register Marine & UCL Energy Institute, Global Marine Fuel Trends 2030 (2014)**
	2020, the prices of MGO, LSHFO and HFO are assumed to be mainly determined by environmental regulation. The future LNG price is determined based on the DECC gas price projection, a cost estimate of the required LNG import infrastructure, and an estimate of the annual amount of LNG consumed.
Drivers	Regulation: ECAs, Energy Efficiency Requirements (EEDI) and Carbon policies. Exogenous drivers: consumption, production, fuel, policy.
Barriers	

Paper identifier	**Germanischer Lloyd (2011) Costs and benefits of LNG as ship fuel for container vessels**
Brief description	The study assumes costs for key technologies when applied to five differently sized container vessels and predicts their benefits in comparison to a reference vessel which uses marine fuel oil required by existing and upcoming regulations depending on time and location of its operation. I.e., the reference vessel uses MGO when inside an ECA by 2015 or within EU ports.
Geographical scope	World
Sectoral scope	Shipping
Price projection	Bunkering fuel price projection until 2030: 
Price projection method	Germanischer Lloyd (GL, 2011) expects the bunkering fuel prices to continuously increase, due to increasing oil and gas production costs and expects MGO and LSHFO-prices to increase faster than HFO and LNG, due to a stronger increase in demand. GL takes the actual 2010 bunkering fuel prices as starting point which amount to 21.2 USD/mmbtu for 0.1% S MGO, to 15.3 USD/mmbtu for HFO, and 13 USD/mmbtu for LNG, including small-scale distribution costs of 4 USD/mmbtu.
Drivers	-
Barriers	Supply infrastructure not widely available.

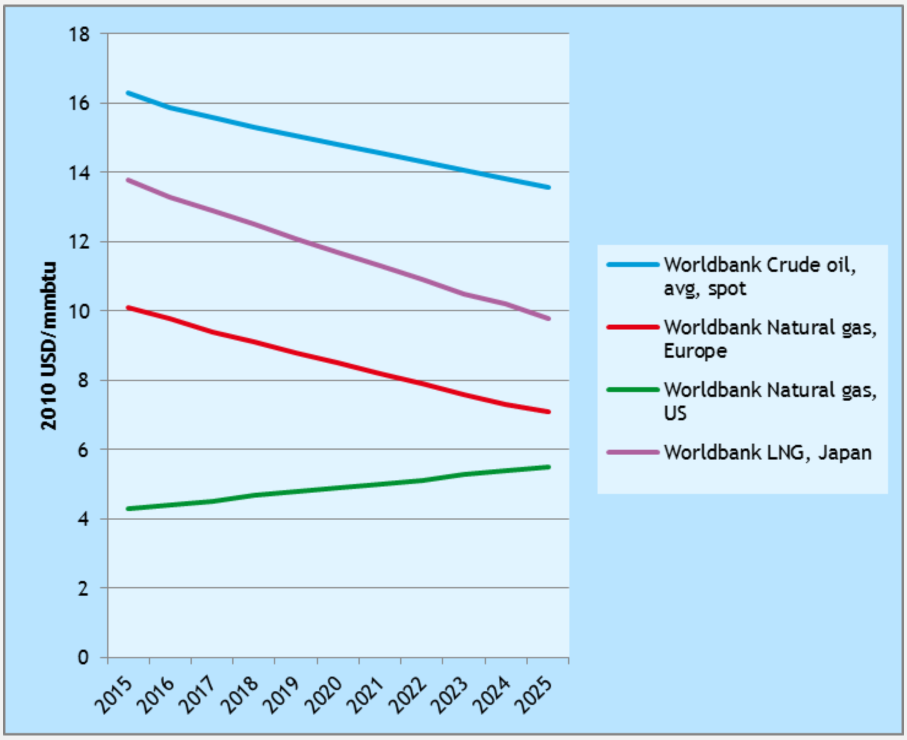
A.2 LNG price projections (including Europe)

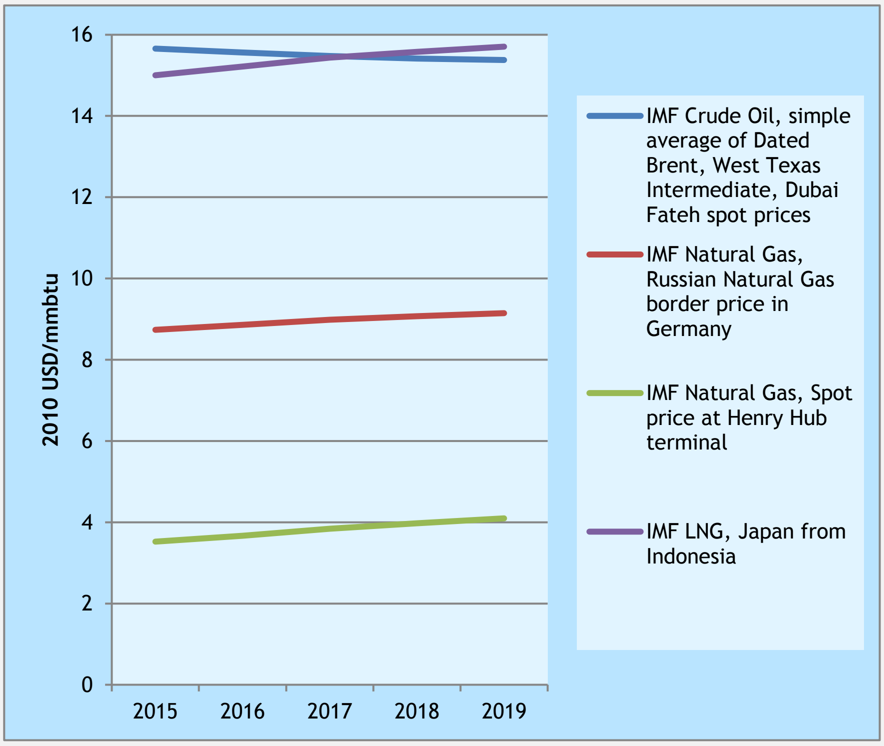
Paper identifier	Adamcheck, 2013, LNG as a marine fuel
Brief description	Complete market overview, drivers, barriers and projection of future LNG use
Geographical scope	World
Sectoral scope	Marine
Price projection	 **Figure 11. Natural Gas & Oil Benchmark Projection**
Price projection method	Not specified.
Drivers	▪ Low price – future uncertain ▪ Opportunities to meet NO_x requirements – increasing over time, dependent on timing sulphur requirement
Barriers	▪ Required investments for ships : more shipboard storage ▪ Required investments for fuel handling systems and bunker facilities ▪ Development of new safety regulations ▪ LNG availability

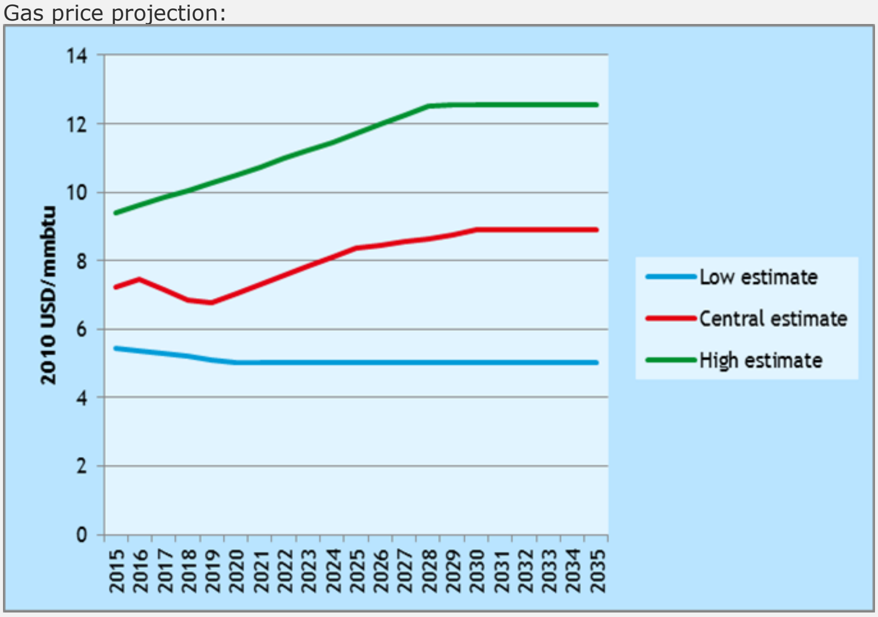
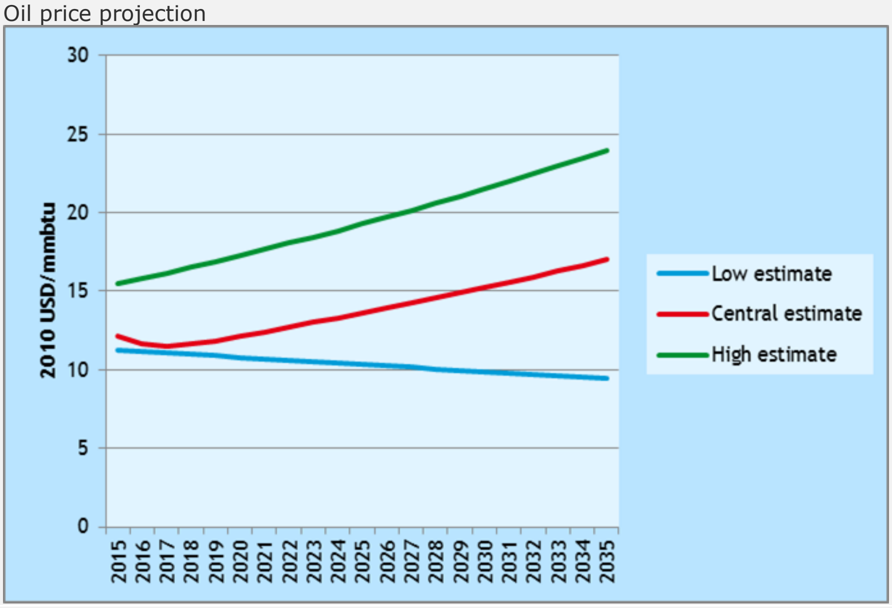
Paper identifier	Clingendael Energy, 2014, Current outlook for Global LNG to 2030 and European LNG prospects
Brief description	LNG price projection for 2017 and 2020 (DES market prices per region)
Geographical scope	Global
Sectoral scope	Total LNG market
Price projection	
Price projection method	Trends and assumptions around demand and supply. Regional LNG pricing unlikely tot fall significantly but narrowing to a certain extent. Assumptions: ▪ Oil price: oil price $ 100/bbl; no shocks ▪ LNG demand: strong demand from Asia, slow return of nuclear Japan, BaU Europe, new growing pockets of demand through FSRU start ups ▪ LNG supply: production in service uninterrupted; new production Australia 2017; US new production startup from Q1 2016
Drivers	▪ Growth from Asia ▪ 'Good' supply demand balance in Europe
Barriers	▪ Buyers more challenging to service ▪ Supply capacity is mostly late and over budget

Paper identifier	**Pwc, The Economic impact of small-scale LNG, 2013**
Brief description	Analysis of economic impact of small-scale LNG in transport sector in NL
Geographical scope	Netherlands
Sectoral scope	Transport sector: short sea shipping, inland shipping and road transport (deep sea shipping is excluded)
Price projection	▪ High prices until 2015, no new supply is foreseen. After 2015 strong supply growth, uncertainty on development: US LNG exports; development of facilities; uncertain demand; future: declines due to additional LNG tankers, less demand from Asia (Japanese return to nuclear energy) and more supply Figure 4.6: Gas price relative to price of oil (projections)[14]  Source: IEA, World Bank, DECC, PwC analysis
Price projection method	Uses projections of IEA, Worldbank and Decc (not forecasts but projections).
Drivers	Four key drivers: ▪ Policy (local, national, international) ▪ Availability of alternatives ▪ Fuel price differential (MGO, HFO, Diesel) ▪ Growth of transport sector
Barriers	▪ Long depreciation period of ships ▪ Uncertainties around investment costs, operational performance and LNG price may hinder uptake ▪ Retrofit not possible for all ship types ▪ Lack of infrastructure ▪ High initial investment, no best practises ▪ Using European/Russian natural gas not cost-effective

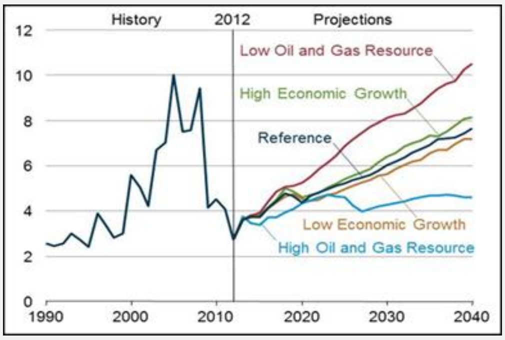
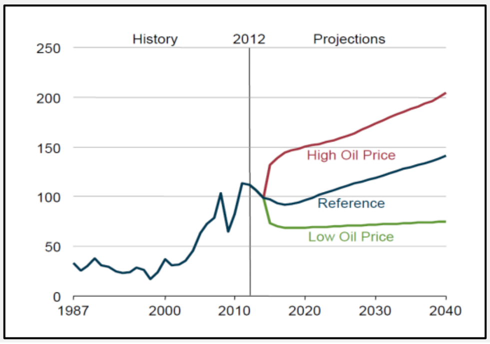
A.3 Natural gas and oil price projections

Paper identifier	World Bank Commodities Price Forecast, July 2014
Brief description	Forecast of commodity prices
Geographical scope	World
Sectoral scope	-
Price projection	
Price projection method	-
Drivers	-
Barriers	-

Paper identifier	**IMF World Economic Outlook, October 2014**
Brief description	Forecast of commodity prices
Geographical scope	World
Sectoral scope	-
Price projection	
Price projection method	-
Drivers	-
Barriers	-

Paper identifier	DECC Fossil Fuel Price Projections (September 2014)
Brief description	Forecast of gas prices for three scenarios
Geographical scope	UK
Sectoral scope	-
Price projection	Gas price projection:  Oil price projection 
Price projection method	Three scenarios (low, central, high estimate) based on assumptions around liberalisation, market fundamentals and contracting/pricing arrangements. 1. Gas price projection Central projection: 2014-2015 – based on forward curve. 2016-2019 – an average of external forecasts. 2020-2024 – linear interpolation 2025-2030 – linkage to US price (Henry Hub) 2030-2035 – flat-lined Low projection: 2014 – based on historical error from forecasting short term prices using forward curve

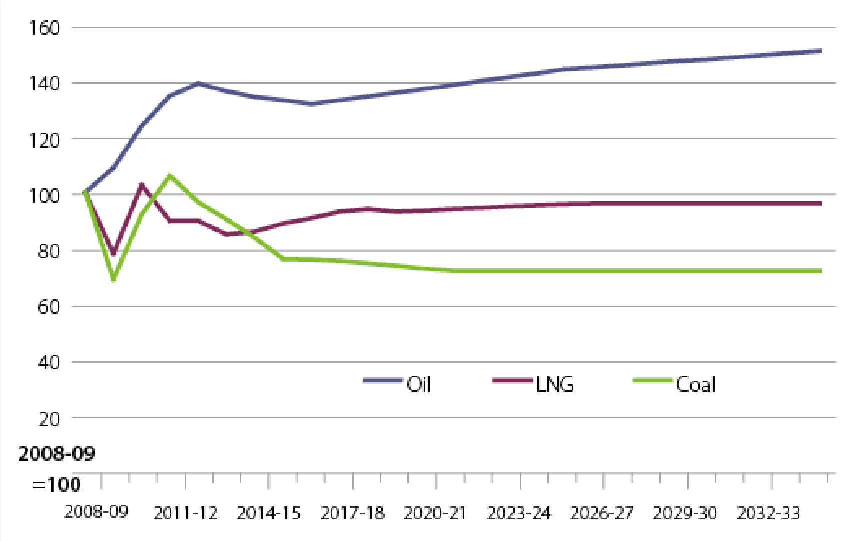
Paper identifier	DECC Fossil Fuel Price Projections (September 2014)
	2015-2019 – linear interpolation 2020-2035 – low estimate of long-run marginal cost of supply High projection: 2014 – based on historical error from forecasting short term prices using forward curve 2015-2029 – oil-linked prices 2030-2035 – flat-lined 2. Oil price projections Central projection: 2014 based on futures curve. 2015-2020 average of external forecasts. 2035 based on the long term (2035) central projections of the IEA and EIA. 2021-2034 interpolation between the 2020 and 2035 values. High projection (zero supply growth): 2014 based on historical error from forecasting short term prices using futures curve 2035 based on DECC modelling of the impact of zero supply growth 2014-2035 2015-2034 interpolation between the 2014 and 2035 values Central projection (LRMC price floor): 2014 based on historical error from forecasting short term prices using futures curve 2035 based on estimates of Long Run Marginal Cost of non-OPEC production 2015-2034 interpolation between the 2014 and 2035 values
Drivers	-
Barriers	-

Paper identifier	EIA, Annual Energy Outlook 2014
Brief description	Crude oil and natural gas price projections until 2040
Geographical scope	Global, US.
Sectoral scope	
Price projection	Natural gas price projection:  Crude oil price projection: 
Price projection method	-
Drivers	▪ Economic growth ▪ Scale of oil and gas resources
Barriers	-

Paper identifier	Mishra, 2012, Forecasting Natural Gas Price – Time Series and Nonparametric Approach
Brief description	Paper aims to estimate a forecast of the natural gas price using different econometric techniques.
Geographical scope	World
Sectoral scope	-
Price projection	Natural gas price is forecasted using the US Crude Oil price and Gold average price as independent variables. No projection of future prices, but methods to simulate historical prices.
Price projection method	Nonparametric techniques viz. Alternating Contitional Expectation (ACE) and ARIMA. Time series data from 1976 to 2011 are used as input parameters.
Drivers	-
Barriers	-

Paper identifier	What drives natural gas prices? – a structural VAR approach, 2013, Sebastian Nick and Stefan Thoenes, EWI
Brief description	Historical gas price is modelled, not projected.
Geographical scope	Germany
Sectoral scope	Natural gas market
Price projection	In the short run prices are affected by abnormal temperatures and supply shocks; in the long run price developments are tied to crude oil and coal prices.
Price projection method	VAR model
Drivers	-
Barriers	-

Paper identifier	Melling (Carnegie Endowment), 2010, natural gas pricing and its future Europe as the battleground
Brief description	The purpose of this study is to document and understand the dynamics of the unfolding gas contracting crisis in Europe, and to anticipate how the fallout from this crisis would impact LNG markets. Which pricing system will prevail? Indexed or hub/spot prices?
Geographical scope	Europe
Sectoral scope	Gas sector: pricing structures of LNG and natural gas
Price projection	Depends on pricing method and scarcity
Price projection method	-
Drivers	▪ Increasing demand from Asia, Middle East and Latin America
Barriers	-

Paper identifier	**Bureau of Resources and Energy Economics, 2011, Australian Energy Projections to 2034-2035**
Brief description	Forecast of Australian energy demand and fuel mix using the E4cast model
Geographical scope	Australia
Sectoral scope	Energy sector
Price projection	
Price projection method	Based on BREE assumptions, using a model: ▪ Long-term energy price profiles will hinge on a number of factors, including demand, investment in new supply capacity, costs of production, and technology ▪ Oil price indexed prices for LNG are assumed. In Asia indexing is still dominant
Drivers	-
Barriers	-

A.4 Studies on the LNG bunkering fuel market (not including a price projection)

Paper identifier	Wang & Notteboom, 2013, LNG as a ship fuel: perspectives and challenges, Port Technology, 60: 1-3
Brief description	Meta study on 33 published studies on the use of LNG as a ship fuel: understand challenges and perspectives, focus on most important drivers and barriers
Geographical scope	World (not specified)
Sectoral scope	Shipping
Price projection	-
Price projection method	-
Drivers	Economic viability: ▪ Low price of LNG ▪ Lower maintenance costs compared tot oil engines ▪ ETS and other taxation costs ▪ ECA's SO_x **limits** and NO_x Tier III standards
Barriers	Gaps in the regulatory framework: ▪ No international standards, in 2013 an ISO framework was expected in 2014 ▪ No safety code, expected in 2014 ▪ In EU use of LNG is prohibited on inland waterways, because of safety, EU started permit process Economic viability: ▪ Costs for converting ships ▪ Uncertainty about development of **LNG price** Technical viability: ▪ Size of LNG fuel tanks ▪ CH4 emissions reduces overall environmental performance ▪ Safety risks Availability of **infrastructure** : ▪ Lack of infrastructure and incentives for investments Public social awareness Alternative options to reach environmental targets

Paper identifier	Mikkelsen, 2012, Drivers influencing the choice of fuel and the implication of choosing LNG, presentation for the German Norwegian Chamber of Commerce – Bergen
Brief description	Presentation of a research on which technologies are most likely to be adopted by the shipping industry in 2020 to meet environmental standards and to deal with higher fuel prices
Geographical scope	World
Sectoral scope	Shipping
Price projection	▪ Four scenarios for 2020: between 30 and 110% of HFO-price, depending on economic growth and regulatory and stakeholder pressure
Price projection method	▪ Relative fuel prices are assumed (scenarios)
Drivers	▪ Regulatory requirements on EEDI and SO_x – getting more important in more regions - New regulations after 2020 ▪ Reduces NO_x and CO_2
Barriers	▪ Investment costs for shipping companies (retrotfit, requires larger fuel tanks) – technology costs decrease with more installations ▪ Limited infrastructure ▪ Availability of alternatives to meet environmental standards

Paper identifier	DNV, 2012, Shipping 2020
Brief description	The purpose has been to share our views on technology uptake towards 2020 and beyond, and to stimulate discussions about likely options for the industry
Geographical scope	World
Sectoral scope	Shipping
Price projection	▪ See Mikkelsen, 2012
Price projection method	▪ See Mikkelsen, 2012
Drivers	▪ Demand for seaborne transport – driven by economic growth ▪ Environmental regulations: also beyond 2020 ▪ Fuel costs – also beyond 2020
Barriers	▪ See Mikkelsen, 2012

Paper identifier	LNG as marine fuel: challenges to be overcome, n.d. Semolinos, Olsen, Giacose, Total
Brief description	The purpose of this paper is to provide an overview of the challenges and possibilities ahead for the development of LNG as marine fuel
Geographical scope	World
Sectoral scope	Shipping and heavy-duty transportation
Price projection	-
Price projection method	-
Drivers	▪ IMO Regulations ▪ EU regulations (LNG as a preferred fuel) ▪ Willingness of countries to reduce their dependence of oil imports
Barriers	▪ Demand: Lack of infrastructure for LNG retailing ▪ Supply: Limited number of LNG-fuelled vehicles ▪ Safety requirements increase complexity of supply chain, ship design and operations ▪ Uncertainty about prices ▪ Regulatory framework

Paper identifier	Herzik, ASPECTS OF USING LNG AS A MARINE FUEL, 2012, Journal of KONES Powertrain and Transport, Vol. 19, No. 2
Brief description	The paper presents a probe of LNG usage analysis as a marine fuel. More focused on technical requirements for LNG bunkering
Geographical scope	World
Sectoral scope	Marine
Price projection	-
Price projection method	-
Drivers	-
Barriers	▪ Bunkering is a problem ▪ Not enough ships have the possibility to be bunkered with LNG

Paper identifier	Feasibility Study on LNG-fuelled Short Sea and Coastal Shipping in the Wider Caribbean Region, SSPA, 2012
Brief description	Full market analysis on the possibilities for the use of LNG in the Caribbean
Geographical scope	Caribbean
Sectoral scope	Shipping
Price projection	▪ Natural gases comes out as the favourable source of energy
Price projection method	Based on Ashworth (2012) and Moniz E.J. et al (2011)
Drivers	▪ Future expand of the WCR ECAs
Barriers	▪ Physical infrastructure ▪ Regulative gaps ▪ Lack of technical standards ▪ Lack of safety regulations ▪ Training and education requirements ▪ Public awareness (relatively unimportant) ▪ Investments and operational costs for adaption to LNG

Paper identifier	DGC, LNG - Status in Denmark, 2012
Brief description	A status report including a technology description and an evaluation of the potential of small-scale LNG in Denmark.
Geographical scope	Denmark
Sectoral scope	Ship, truck, individuals, backup
Price projection	-
Price projection method	-
Drivers	▪ Emission regulations ▪ For new ships: usability
Barriers	▪ Energy requirements for liquefaction, especially for small-scale plants ▪ Lack of public support for small-scale projects

Paper identifier	Bunkering of Liquefied Natural Gas-fuelled Marine Vessels in North America, American Bureau of Shipping, ND
Brief description	ABS collects all value information from different sources about the possibilities for successful, safe growth of LNG use as a fuel in North America. Goal is to assist LNG stakeholders in implementing the existing and planned regulatory framework for LNG bunkering
Geographical scope	North America
Sectoral scope	Marine shipping
Price projection	-
Price projection method	-
Drivers	▪ Increasingly stricter air emissions – this driver becomes increasingly important as more stringent regulations come into force (SO_x in 2020 or 2025 and NO_x in 2016 in ECAs) ▪ Favourable financial conditions for the use of natural gas instead of liquid fuel (shale gas)
Barriers	▪ Hazards because of chemical characteristics of LNG (flammable), prevention, training, and safety regulations required

Paper identifier	Bunkering, infrastructure, storage, and processing of LNG, Jürgen Harperscheidt, 2011, Ship and Offshore
Brief description	Paper describes technical options for LNG shipping and infrastructure
Geographical scope	World
Sectoral scope	Shipping
Price projection	-
Price projection method	-
Drivers	▪ Future environmental regulations
Barriers	▪ Challenges: safe storage and processing of liquefied gas ▪ Bunker infrastructure, procedure and equipment ▪ Low density: LNG takes up roughly twice the volume of fuel oil for the same energy content ▪ Investments in infrastructure may be too high for bunkering activities only

Paper identifier	LNG as an alternative fuel for the operation of ships and heavy-duty vehicles, 2014, Deutsches Zentrum für Luft- und Raumfahrt
Brief description	
Geographical scope	Germany
Sectoral scope	Transport sector
Price projection	-
Price projection method	-
Drivers	▪ Extended operating range in comparison with CNG ▪ Stricter emission standards: this is a main driver, without this perspective there will be no incentive to invest ▪ Simplifies exhaust gas after treatment measures ▪ Decrease in fuel costs – low LNG costs compared to other fuels ▪ A modernization of the framework for bunkering procedures may lead to increased interest ▪ Decrease in greenhouse gas emissions ▪ The existing LNG infrastructure for a specific mode may act as a driver for preferential utilisation of LNG in other modes(?) ▪ Increases security of energy supply ▪ Technology is available on the market; engine technology not an obstacle; four bunkering techniques available ▪ Lower fuel costs compared to other fuels ▪ Regulations: according to the COM (2013) AFID, draft EU member states are obliged to establish an LNG fuelling station in in the TNE-T seaports and inland ports by 31-12-2030; blue corridors project
Barriers	▪ GHG emissions reductions limited by using fossil LNG, only with RE methane(?) ▪ Lack of infrastructure – under investigation (LNG in Baltic Sea Ports; Costa) ▪ Lack of ships and vehicles at present ▪ Lack of incentives to invest in additional infrastructure ▪ National regulations may hinder investments in infrastructure ▪ Lower energy density than diesel (but higher than CNG or methanol) ▪ Lack of regulatory framework (not recognized as a fuel; bunkering process not covered in technical report; no common port rules; no crew training regulation; no international standards; no guidelines measuring sulphur component; safe sampling, etc.): standardization required (expected in 2016) ▪ Demand (ship operators): no benefits from investment; uncertainty about procedures; diesel oil seems better alternative till problems are solved ▪ Supply (infrastructure): only investments if demand increases; hindered by (the lack of) (inter)national regulations

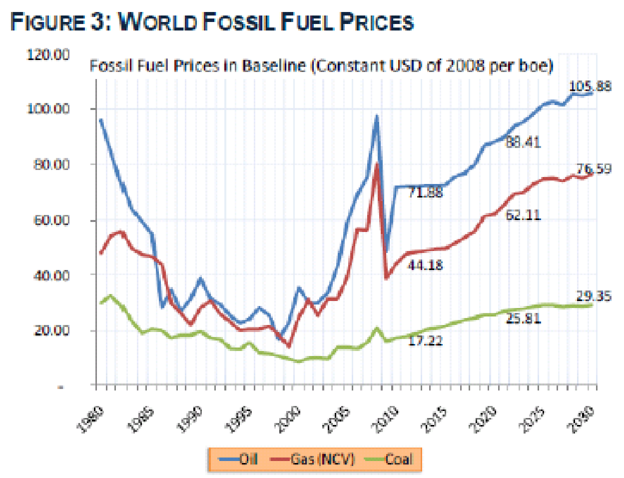
Paper identifier	**European Commission, Actions toward a comprehensive EU framework on LNG for shipping, 2013**
Brief description	Overview of current status of the opportunities of the use of LNG for shipping; research agenda
Geographical scope	EU
Sectoral scope	Shipping
Price projection	▪ Prices may drop if a viable spot market for LNG establishes
Price projection method	-
Drivers	▪ Supply: funding for infrastructure available
Barriers	▪ Demand: Lack of appropriate bunker facilities along the shipping routes ▪ Demand: No LNG supply at preferred ports ▪ Demand: no harmonised bunkering procedures ▪ Supply: diverging regulations ▪ Negative public perception about dangers ▪ Supply: empty order books European shipbuilders reduce R&D

Paper identifier	**Liquefied Natural Gas as a Marine Fuel, NEPI (National Energy Policy Institute, 2013**
Brief description	A Closer Look at TOTE’s Containership Projects, business case of an early adopter
Geographical scope	USA
Sectoral scope	Shipping
Price projection	▪ Relative price to other fuels is improving till 2035
Price projection method	▪ From EIA
Drivers	▪ Demand: new rules by the International Maritime Organization and the US EPA ◦ Black carbon emissions ◦ Underwater noise ◦ Climate change ▪ Demand: positive business case – savings in operation costs are larger than investment costs ▪ Demand: In US price of gas is less volatile, because it’s a domestic fuel
Barriers	▪ Demand: costs – high costs for conversion; new ships 15-20% more expensive – pay-back time > 10 years ▪ Demand: lack of infrastructure – users have to invest (first mover disadvantage) ▪ Possible decrease in cargo space ▪ Costs of production, including costs of required infrastructure doubles the cost of LNG compared to natural gas ▪ Regulatory hurdles ▪ High time spent outside ECA – less incentives

Paper identifier	DNV-GL; LNG-fuelled ships status and Drivers; 2014; presentation
Brief description	Overview of drivers of uptake of LNG as fuel; status for ships and availability of techniques, focus on a few drivers
Geographical scope	Global, focus on EU
Sectoral scope	Ships
Price projection	-
Price projection method	-
Drivers	▪ Demand: environmental regulations; increasingly important because of more stringent SO_x, NO_x limits in future (2015-2025), new ECAs? ▪ Demand: cost of fuel: stable gas price whilst prices for alternative fuel are higher and rising/more volatile ▪ NO_x fund In Norway (companies pay NO_x tax, used for LNG investments)
Barriers	-

Paper identifier	Ocean Shipping Consultants Haskoning UK, 2013, LNG as a Bunker Fuel: Future Demand Options & Port Design Options
Brief description	Overview of current (2013) and future status of LNG bunkering Liquefaction capacity by region Case studies calculations for different types of vessels Current bunkering market
Geographical scope	Global
Sectoral scope	Bunkering
Price projection	Two scenarios: 80% and 60% of HFO
Price projection method	Only scenario analysis, no projection
Drivers	▪ Opportunity to reduce bunker and emission costs ▪ EC plans to develop LNG bunkering facilities in all TECN ports by 2020 (drives demand) ▪ Focus on lower operating costs (drives demand) ▪ Rapid rise in bunker fuel costs (drives demand) ▪ Environmental awareness cruise ship passengers (drives demand) ▪ Supply of cheap natural gas in US, becoming increasingly important (drives demand) ▪ New ECAs (drives demand) ▪ Technical developments for supply infrastructure (drives supply)
Barriers	▪ Regulations and guidelines are under construction (IGC code; IGF code) ▪ Limited infrastructure mainly for ships without fixed itineraries

Paper identifier	Oxford Institute for Energy Studies, 2014, The Prospects for Natural Gas as a transport fuel in Europe
Brief description	Study on the opportunities for the use of natural gas, including LNG, as a transport fuel, including shipping. Country reports
Geographical scope	EU27
Sectoral scope	Transport
Price projection	-
Price projection method	-
Drivers	▪ Lower vehicle tax rates ▪ EU policies ▪ Demand for vehicle kilometres ▪ Economic situation ▪ Comply with regulations ▪ Improve cost-effectiveness through improved fuel efficiency
Barriers	▪ Inertia ▪ Higher operational and investment costs ▪ Chicken and act: demand or supply first?

Paper identifier	**TNO, 2014, Global potential of small-scale LNG distribution**
Brief description	Primary objective: determine the potential global market volumes for small-scale LNG in the period 2015-2025, so complete market review
Geographical scope	Global
Sectoral scope	Transport (sea and land)
Price projection	 Figure 11: World fossil fuel prices. Source: EU, 2009.
Price projection method	No bunkering fuel price estimations , but Primes reference scenario forecast of oil, gas and coal prices included.
Drivers	▪ Stringent environmental requirements ▪ Rising energy demand for marine bunkers until 2035, though stabilization marine in Europe till 2025 (derived from ExxonMobil) ▪ EU: large share of ECA demand in 2025 ▪ More demand lower sulphur fuel → higher oil prices ▪ Market is large ▪ Growth rate at emerging economies
Barriers	▪ Long pay-back period for infrastructure investors ▪ Currently: low price differential, increases pay-back time ▪ Current surplus in transport capacity in some ship transport segments ▪ High methane emissions

Paper identifier	DNV, 2013, LNG Bunkering in Australia: infrastructure and regulations
Brief description	Research on current status and future needs for infrastructure and regulations in Australian ports, so focus on few drivers
Geographical scope	Australia
Sectoral scope	-
Price projection	-
Price projection method	-
Drivers	▪ Availability of LNG in Australia, currently very dependent of imported marine fuel ▪ Less CO_2 emissions and less tax to pay ▪ Pressure from society ▪ Less risk to the environment in case of a marine casualty ▪ Knowledge available ▪ IMO's global sulphur cap ▪ International standards available ▪ No legal barriers ▪ Attractive pay-back periods possible ▪ Availability of LNG terminals ▪ Interest from Asia (relevant for Australia)
Barriers	▪ Lack of regulatory framework for shore-based and ship-to-ship bunkering ▪ Lack of infrastructure ▪ Right pricing structure should be established ▪ No financial incentive for shipping company if charterer pays for fuel costs

A.5 General LNG market projections

Paper identifier	A Comparative Study of Liquefied Natural Gas: An Overview, 2014, Khan Meon et al, Research Journal of Applied Sciences, Engineering and Technology
Brief description	The main objective of the study is to highlight the current data for reviewers on LNG world market, mainly on LNG production, supply, demand, price and new development of LNG plants.
Geographical scope	World
Sectoral scope	Total (L)NG market
Price projection	▪ Highlights an increase in demand, supply and trade
Price projection method	-
Drivers	-
Barriers	-

Paper identifier	Alaska Natural gas transportation projects, 2013, LNG market overview look at supply and demand
Brief description	Overview of supply and demand in different regions, no focus on Europe, and pricing systems
Geographical scope	World
Sectoral scope	LNG
Price projection	Depends on pricing method (oil-linked, gas-on-gas, hub priced)
Price projection method	-
Drivers	▪ New capacity in Australia ▪ Canada and Russia (trying) entering the market ▪ Demand growth China
Barriers	▪ Export barriers USA ▪ Japan tries to find cheaper energy sources

Paper identifier	International Gas Union, World LNG Report 2014 Edition
Brief description	Overview of global LNG market in 2014, facts and figures around demand, supply and prices
Geographical scope	Global
Sectoral scope	LNG
Price projection	-
Price projection method	-
Drivers	-
Barriers	▪ Supply constrained until 2015

Paper identifier	**S. Kamalakannan, 2012, Drivers for demand of LNG in a growing global market**
Brief description	This paper lists the driving factors for the growing global LNG market and how traded LNG volumes have doubled over the last decade with several new countries joining the LNG market.
Geographical scope	Global
Sectoral scope	LNG sector
Price projection	-
Price projection method	-
Drivers	▪ Drivers for the recent growth of the LNG market ▪ Economic growth and demand for energy ▪ Cleaner than alternatives ▪ Widely applicable ▪ Consumer prefers a wider energy mix ▪ Deregulation in several key markets ▪ Lower prices due to lower liquefaction costs caused by technological improvements ▪ Lower construction costs for vessels → lower shipping costs ▪ Domestic gas production in many areas insufficient to meet demand ▪ Carbon penalties in Europe
Barriers	-

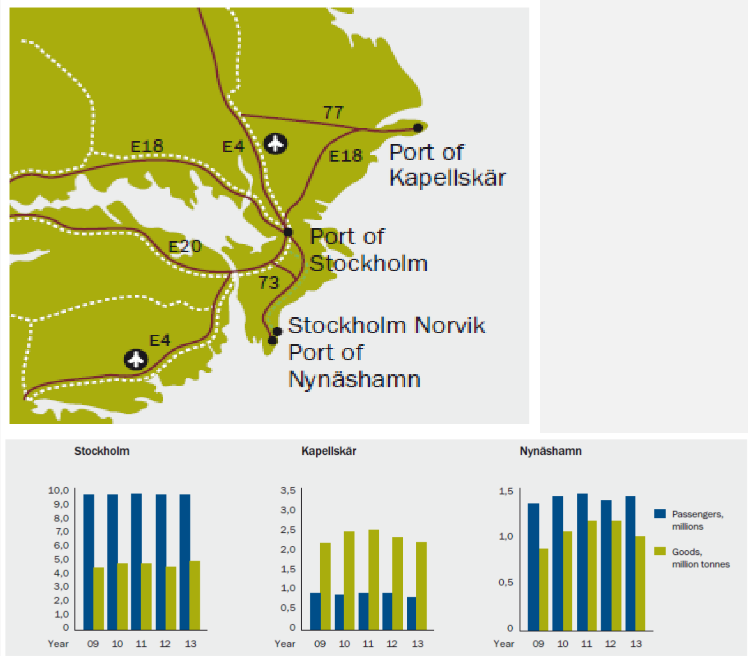
Annex B Factsheets on LNG infrastructure development in the selected ports

B.1 Port of Stockholm

<table>
<tr><th>Topic</th><th>Value</th></tr>
<tr><td colspan="2">Port activity flows</td></tr>
<tr><td>Throughput 2014</td><td>Freight:
▪ 4 million-ton of goods
▪ 51,000 containers per year

Passengers:
12 million passengers, out of which:
▪ Ferries:
  ▫ Europe: 7.5 million
  ▫ National: 4 million
▪ International cruises: 485,000</td></tr>
<tr><td>Ships 2013 (number)</td><td>International cruise vessels: 300
Ferry traffic: aprox. 10 calls every day (passengers and goods)</td></tr>
<tr><td>Origin/ Destinations</td><td>International cruise vessels: worldwide
Ferry traffic:
▪ National (mainly to the Stockholm archipelago)
▪ The Baltic Sea (11 ports) and other European destinations, Russia</td></tr>
<tr><td>Typical ship types used</td><td>Ropax ferry: ISABELLA (Viking Line)
▪ operates between Helsinki - Mariehamn - Stockholm
▪ 35,492 (2,420 passengers)
▪ Completed: 1992-05 by Brodogradiliste Industrija "Split", Split, Croatia
▪ Dimensions: loa: 171.5 m beam: 28.2 m draught: 6.25 m
▪ Main engine(s): 4, Pielstick 12PC2 6V-400e diesels.
▪ Power: 23,780 kW
▪ Speed: 21.5 knots

LNG powered: Viking Grace (see Viking Line factsheet).</td></tr>
<tr><td>Expected developments until 2025</td><td>Main trends in the market:
▪ Growing number of passengers
▪ Larger ships. Pier length may prove to be a hard constraint for the port of Stockholm
▪ Increase in goods transport volumes:
  ▫ the Swedish Transport Administration: 80% increase in the Baltic Sea by 2050
  ▫ The city of Stockholm is expanding, leading to an increase in the demand for goods</td></tr>
<tr><td>Large operators (vessel owners):</td><td>▪ Viking Line
▪ FinnLink
▪ Tallink Silja
▪ DFDS
▪ Polferries
▪ StenaLine</td></tr>
<tr><td colspan="2">Port infrastructure and facilities</td></tr>
<tr><td>Quay usage</td><td>The port of Stockholm group includes three locations:
▪ Stockholm:
  ▫ international cruise ships
  ▫ ferry traffic for goods and passengers
  ▫ containers</td></tr>
</table>

Topic	Value
	▫ bulk goods: oil, coal, sand, cement, fuel pallets ▪ Kapellskär: ▫ RoRo and passenger traffic ▪ Nynäshamn: ▫ RoRo ferry and passenger port Future development plans: ▪ passenger traffic: increase quay capacity for the Port of Stockholm (Frihamnen) and the Port of Nynäshamn ▪ freight traffic: plans are in place to build a new freight port, Stockholm Norvik **Ports of Stockholm: location and activity profile**  Source: Ports of Stockhom – Annual Report (2013).
Current bunkering infrastructure	Total bunker quantity : 300,000 MTOE ▪ Main method: 1 bunker barge pushed by a tugboat ▪ Trucks ▪ A few small bunker vessels
Current LNG bunkering infrastructure	Stockholm is the first port in the world with an infrastructure to provide liquefied natural gas to a large passenger ferry. Storage capacity: 8,900, metric tonnes = 20,000 m^3 Tank trucks: ▪ 3 tank trucks/day, 1,095 tank trucks/year ▪ Truck capacity = 25 metric tonnes = 56 m3 Bunker vessels: Seagas (77 metric tons = 175 m^3). The vessel is owned by Linde
Planned LNG infrastructure	The LNG plant in Nynäshamn has the required permits to build a 2nd terminal, but such a project is not justified given existing demand levels.
Policy issues	
Port in SECA (2015)	Yes
Other relevant issues	**Education:** training and standards for the personnel on shore handling LNG. **Infrastructure**: a higher demand for other on-shore small-scale LNG applications (heavy goods shipping, inland waterways vessels) might also reflect in an increased

Topic	Value
	demand for LNG in maritime shipping. **Financial support**: The current LNG infrastructure was partly financed through EU/national government subsidies.

B.2 Port of Dover

Topic	Value
Port activity flows	
Throughput 2014	Ferries (RoRo): 13 million passengers ▪ 5 million vehicles - 50% lorries, 50% tourist vehicles ▪ Value of goods: 130 billion EUR Cruise : ▪ 250,000 passengers ▪ UK 2nd busiest cruise port General cargo ▪ Fresh produce: 300,000 tons ; 9,000 container movements
Ships 2013 (number)	Total number of calls: 19,500 out of which: ▪ cruise calls: 140 ▪ general cargo: 150
Origin/ Destinations	Ferries: 2 destinations in France ▪ Dover-Calais: 80% of the traffic, ▪ Dover-Dunkerque: 20% of the traffic Cruises: Baltic Sea, Mediterranean Sea. Fresh products: West Africa, Costa Rica, Columbia.
Typical ship types used	Ferries: ▪ Spirit of Britain (P&O) □ Capacity: 2,000 passengers, 180 lorries or 1,059 cars □ Length: 210 m □ Gross tonnage: 47,592 □ Engines: 4 x MAN 7L 48/60 Diesels □ Speed: 22 knots
Expected developments until 2025	Growth rate: ▪ Freight volumes brought in by ferries have been enjoying a steady annual increase of 10% for the past 2 years ▪ This growth is expected to continue at the same pace for the years to come, and stabilize at around 5% per annum in the longer term ▪ Current projections point to an 40%increase in freight volume by 2030 Main trends in the market: ▪ Opportunities: economic conditions are improving, which translates into sustained ferry traffic growth. An increase in the size of the ships is also observed. ▪ Threats: congestion on connections to inland ports. ▪ Development plans: □ Traffic management improvement project (port centric distribution) □ Remove the cargo operation from the ferry terminal and move it to the western docs. The expected effects are: better utilization of the ferry terminal, and capacity increase for the cargo terminal □ Water regeneration project meant to make Dover a more attractive destination
Large operators (vessel owners):	Ferries: P&O ferries, Myferrylink, DSDS General cargo: Africa Express Line, Seatrade
Port infrastructure and facilities	
Quay usage	Ferry: 7 operational berths General cargo: 1 berth Cruise: 2 terminals that can accommodate up to 3 ships at the time Marina: 400 yacht berths
Current bunkering infrastructure	1 bunker barge Total current bunkering volume of port is not available.
Current LNG	No LNG bunkering infrastructure is installed.

Topic	Value
bunkering infrastructure	
Planned LNG infrastructure	Together with the ports of Dunkerque and Calais, the port of Dover submitted to the European Union TEN-T body a request for financial support for the completion of a study which should investigate what is the optimal level of LNG infrastructure the three ports should provide. LNG infrastructure plans in the port of Dover are dependent on the outcome of the above mentioned study. However, the most likely options are: truck-to-ship and/or ship-to-ship bunkering.
Policy issues	
Port in SECA (2015)	Yes. Longer routes may lose traffic because of the emission restrictions. Dover is not in this situation because the routes of most of the vessels calling in Dover only include very short SECA segments.
Other relevant issues	Main driver: EU emissions reductions target 2020.

B.3 Port of Civitavecchia

Topic	Value
Port activity flows	
Throughput 2014	**Passengers**: Cruise ships: 2.1 million passengers (1st port in Europe) Ferry: 1.5 million passengers **Freight**: ▪ Containers: 64,000 TEU ▪ Coal: 5 million tons ▪ Other goods: vehicles, vegetables
Ships 2013 (number)	Cruise ships: 1,000 calls Ferry: 1,500 calls: Bulk cargo (dry, liquid) & containers: 700 calls
Origin/ Destinations	Cruise ships: worldwide. Rome is one of the top cruise destinations. Ferries: ▪ Europe: Italy, Spain ▪ Africa: Tunisia, Alegeria Transshipment traffic: Italy, Spain, France
Typical ship types used	**Cruise ships**: Costa Favolosa, Norwegian Epic, Royal Carribean Costa Favolosa (Costa Crociera) ▪ 7–17 day cruises: the Mediterranean Sea, Northern Europe, South America ▪ 3,800 passengers ▪ Completed: 2011 ▪ Dimensions: loa: 290.2 m beam: 35.5 m draught: 8.3 m ▪ Main engine(s): 6, Wartsila W12V46C diesel electric ▪ Total power: 75,600 kW ▪ Speed (max/average): 18.5/12.3 knots **Ferries (RoRo Pax)**: Excellent, MB Janas, MB Eurostar Roma, MB Cruise Roma Excellent (operator: Grandi Navi Veloci, owner: Grimaldi Group): ▪ Completed: 1998 ▪ Routes: Civitavecchia – Tunis, Genoa - Porto Torres, Palermo-Tunis ▪ 2,253 passengers ▪ 760 cars ▪ Lane meters: 2,250 ▪ Dimensions: loa: 201.2 m, beam: 28 m, draught: 6.65 m ▪ Gross tonnage: 39,739 ▪ Main engine(s): 4, Wartsila 8L46A ▪ Total power: 28,960 kW ▪ Speed (average): 24 knots
Expected developments until 2025	Growth rate: 6% growth per year (until 2020) to 5.5 million passengers: ▪ Cruise ships: 3 million–cruise ▪ Ferries: 2.5 million Another goal of the port is to attract higher goods flows, thus contributing to the increase of occupied labour in the region. The plans that are put in place to support this ambition are: ▪ A new basin is built in the north of the current port. This new area will be used to cater for container, general cargo and oil products. The planned investment amounts to 500 million EUR, drawn from both public (200 million EUR) and private (300

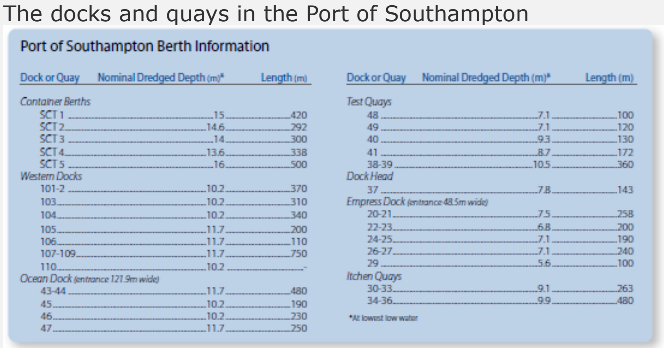
Topic	Value
	million EUR) sources. ▪ A second container terminal with a capacity of 1,000,000 TEU, to be operated by Evergreen China Shipping company. **Cruise ships** Giant vessels, larger than 280 m and with a depth of 8-10 m are expected. Civitavecchia is well equipped to handle this type of ships: the piers are up to 600 m long and 16 m deep. **Ferries** The port has 2 new piers to service these ships and 3 new piers are planned for the future. New ferry terminal planned for 2017. **Multi-modal infrastructure** Investments have been made in the connection to the road and railways network. As a result, it only takes 40 min to get from Civitavecchia to Rome, and also to the Fiumicino airport. Necessary future developments include the construction of a highway to the industrial centers in the north and center of Italy (Umbria, Tuscany).
Large operators (vessel owners):	**Cruise ships:** MSC, Carnival, Costa Crociere, Norwegian Cruise Line, Holland America Line, AIDA Cruises, Princes Cruises, TUI Cruises **Ferries:** Grimaldi Group, Grandi Navi Veloci, CIM
Port infrastructure and facilities	
Quay usage	30 operational piers. Port 22 is a temporary energy pier
Current bunkering infrastructure	Bunker quantity: 2011: 120,866 tons HFO (above 380) 2012: 137,516 tons HFO (above 380) 2013: 118,212 tons HFO (above 380) 2014: 114,986 ▪ Marine Gas oil 0.1 MGO: 15% - 14,914 tons ▪ HFO (above 380): 85% - 100,072 tons HFO (above) 380 ▪ HFO180: negligible percentage The main bunkering method is ship-to-ship bunkering. 4 ships are available: ▪ Duba 1 ▪ Duba - capacity: 500 m3 ▪ Big Duba ▪ Magic Duba - capacity: 2,000 m3. Magic Duba is provided with a double shell tank and it is the newest ship of the group – it was put in service 2 years ago. Trucks with a capacity of less than 30 m^3 are only used for special cases.
Current LNG bunkering infrastructure	There a currently no LNG powered ships operating in the Mediterranean Sea, and therefore no infrastructure in place.
Planned LNG infrastructure	A pilot project for an 100 m^3 (45 tons) LNG storage terminal has recently been submitted to the EU body INEA (TEN-T network) for funding. This capacity was chosen because in Italy it is considerably easier to obtain the environmental permits for capacities below 50 tons, than for those above this value. This terminal would be used to supply: a) HGVs operating in the port, and b) ships:

Topic	Value
	truck-to-ship bunkering. The LNG would be procured from EGON (Marseille, Barcelona). The plan is to build the bunkering station in an area close to the energetic quay of the port of Civitavecchia (at the moment under construction). Should this capacity prove to be insufficient for observed demand, the terminal can be scaled up to 5,000 m^3 capacity (similarly to the LNG terminal in Antwerp). The Italian Navy recently retrofitted a barge from oil to LNG against a competitive cost of 20,000. The retrofit operation was executed on 4 engines: 2 main and 2 auxiliary, with a total installed power of 1 MW. The ship can sail for 24h on LNG, with the main constraint being the size of the storage tank - 5 m^3.
Policy issues	
Port in SECA (2015)	No
Other relevant issues	In May 2014 a onetime truck-to-ship bunkering operation took place for a tug boat to be used in Karsto, Norway. The stopover proved that the port had all permits in place to execute an LNG bunkering operation. EU regulations stimulate the adoption of LNG as marine fuel. LNG adoption and the development of associated port infrastructure should be developed in sequential 'small steps'. Retrofit operations are not interesting for engine OEMs, as these would delay the sale of new engines.

B.4 Port of Southampton

Topic	Value
Port activity flows	
Throughput 2013	**Total 35.8 mln ton s (2013 figures)** ▪ liquid bulk: 24 million ton ▪ dry bulk: 1.6 million ton ▪ Container: 8.1 million ton ▪ RoRo : 1.7 million ton **Main trade flows:** ▪ Containers: 2nd largest container terminal in the UK - 1.5 million TEU (20 feet equivalent) ▪ Cruise: largest cruise handling port in the UK - 1.8 million passengers ▪ Cars: 1st by volume in the UK for light/commercial/new car models handles. Over 790,000 units handled in 2014 **Other traffic categories:** ▪ Dry bulk: animal feed, grain, fresh produce, fertilizer, recycled metal, salt, recycled glass ▪ Liquid bulk: oil and oil related products
Ships 2013 (number)	**9,572 cargo calls out of which:** ▪ Liquid bulk: 1,775 ▪ Dry bulk: 10 ▪ Containers: 668 ▪ General cargo: 6,013, including 1,200 calls made by car carriers **444 cruise calls in 2014** ▪ Mainly European routes ▪ 10% of the calls are call-in, the rest are turnaround cruises (the cruise begins and ends in Southampton)
Origin/Destinations	**Cruises:** ▪ The majority of cruise routes are within Europe: Eastern and Western Mediterranean Sea, Baltic Sea, Finland, Russia ▪ The remaining cruises are transatlantic **Container traffic**: 80% of the traffic is directed towards the Far East, while the remaining volumes come from transatlantic routes **Car traffic**: ▪ Within Europe: Mediterranean, Baltic Sea, Germany, France ▪ Deep-sea: wordwide (USA, Asia, Africa, the Middle East, Australia)
Typical ship types used	Cruise ships capacity varies between 1,500 and 3,500 passengers. Ex. Queen Elizabeth. Owner: Carnival Corporation. Operator: Cunard Line: ▪ Capacity: 2,547 passengers ▪ Length: 294 m ▪ Gross Tonnage: 90,901 ▪ Installed power: 64,000 kW produced by: 4 × MaK 12VM43C and 2 × MaK 8M43C

Topic	Value
Expected developments until 2025	**Growth rate:** No specific growth rate is available with the port. Assumed was that growth was the same as the assumed main growth of maritime trade in Europe (annual growth of 1.55%). **Main trends in the market:** ▪ Continuing growth in the container market. 2014 marked the inauguration of a new container terminal: quay length: 500 m; annual operational capacity: 3,000,000 TEU. Increase in the size of ships, rather than in the number of calls. ▪ Passenger traffic: beyond 2 million until 2025. All 4 cruise terminals are being upgraded: the work on 2 of the terminals will be ready in 2015, the other two will be delivered in 2016. ▪ Vehicles traffic is expected to grow to more than 1,000,000 units/year.
Large operators (vessel owners):	**Containers**: G6 alliance, MSC, Ocean Three **Cars**: Wallenius Wilmhelmsen, Hoegh Autoliners, NYK Line, UECC, Eukor, Grimaldi Lines **Cruises**: Cunard, P&O Cruises, Royal Carribean, Celebrity Cruises, MSC, Fred. Olsen and Saga
Port infrastructure and facilities	
Quay usage	Port estate: 726 acres 43 docks & quays The docks and quays in the Port of Southampton



Port of Southampton Berth Information

Dock or Quay	Nominal Dredged Depth (m)*	Length (m)	Dock or Quay	Nominal Dredged Depth (m)*	Length (m)
Container Berths			*Test Quays*		
SCT 1	15	420	48	7.1	100
SCT 2	14.6	292	49	7.1	120
SCT 3	14	300	40	9.3	130
SCT 4	13.6	338	41	8.7	172
SCT 5	16	500	38-39	10.5	360
Western Docks			*Dock Head*		
101-2	10.2	370	37	7.8	143
103	10.2	310	*Empress Dock (entrance 48.5m wide)*		
104	10.2	340	20-21	7.5	258
105	11.7	200	22-23	6.8	200
106	11.7	110	24-25	7.1	190
107-109	11.7	750	26-27	7.1	240
110	10.2	-	29	5.6	100
Ocean Dock (entrance 121.9m wide)			*Itchen Quays*		
43-44	11.7	480	30-33	9.1	263
45	10.2	190	34-36	9.9	480
46	10.2	230			
47	11.7	250			

*At lowest low water

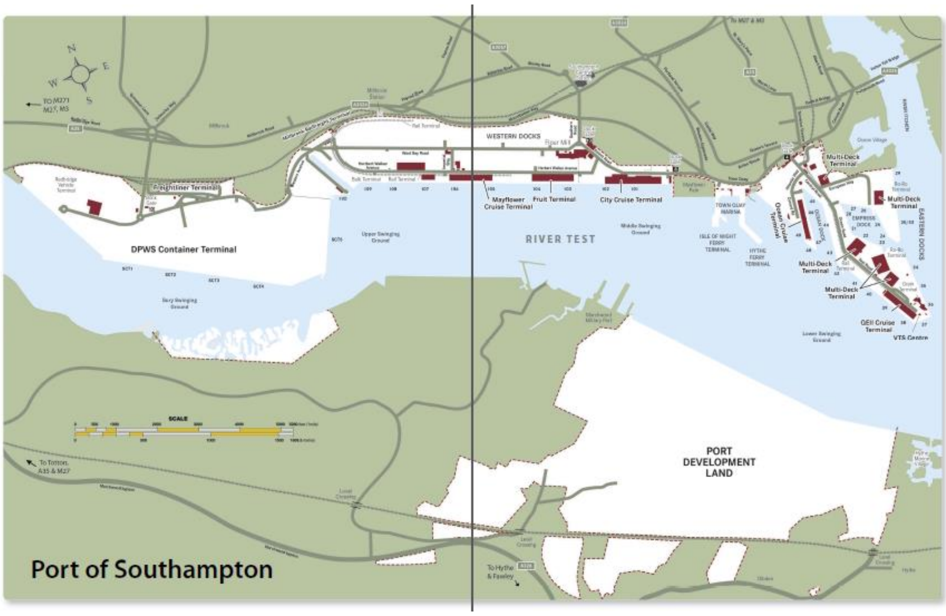
Topic	Value
	Source: ABP – Associated British Ports (ABP, 2014), Southampton Port Profile.

Current bunkering infrastructure	Bunkering infrastructure:
	▪ Whitaker Tankers: 4 barges with a capacity between:
	  ▫ HFO: 2,000–6,000 m3
	  ▫ MGO: 300–1,900 m3
	▪ Bunker trucks
	
	Information on the total bunkering demand was not available at the port

Current LNG bunkering infrastructure	No LNG bunkering infrastructure is in place.
Planned LNG infrastructure	The port is currently not looking into plans to develop LNG infrastructure. It is considered that LNG developments will be market led. So far, no significant level of interest in this fuel option was expressed by operators, with the exceptions of: ▪ UECC (United European Car Carriers) who is currently building two dual fuelled LNG car and truck carriers. The ships should be bunkered in Zeebruge (Belgium. ▪ AIDA Cruises who expressed an interest in a new LNG powered vessel. In general, the interest of the cruise sector in LNG is limited. Most of the operators in this vessel segment opt for scrubbers, in order to comply to the newly introduced restrictions on sulphur oxide emissions.
Policy issues	
Port in SECA	Yes

Topic	Value
(2015)	
Other relevant issues	Implications of the new SECA regime on the cruise vessels segment: ▪ Older cruise vessels had to reconsider their itinerary. LNG is mainly considered for new vessels. Reconversion investments are considered impossible to recover during the remaining lifetime of the vessel. In addition, cruise operators also have to refrain from passing on the additional costs to the customers through price increases, because it is anticipated that such a move would have a dampening effect on demand. ▪ An unleveled playing field was created in the Irish sea, because some ports are included in the ECA region, while others are not. ▪ A reduction in the type of offered itineraries is expected. Alternative cruise formats might also appear: eg. 'fly' cruises – for a cruise in the Mediterranean Sea on an old ship, an operator might chose to fly passengers from Northern Europe to the ship. But it should be assessed what the effects of the SECA regulation on this market are after at least 5 years since it was applied. Southampton is mainly a deep sea trade port. At present, most operators invest in dual fuel solutions and scrubbers. If LNG is more widely adopted by operators, we will adapt. New technologies have to be proven in terms of safety risks and environmental impact. We can benefit from the cooperation with other European ports, as knowledge can be easily transferred. What the government can do to support the evolution of LNG bunkering in ports is: ▪ Make implementation easier in terms of: planning, permits, etc. ▪ Issue guidance on what is expected that port installations should provide.

Figure 39 Southampton Port Map



Source: ABP – Associated British Ports (2014), Southampton Port Profile.

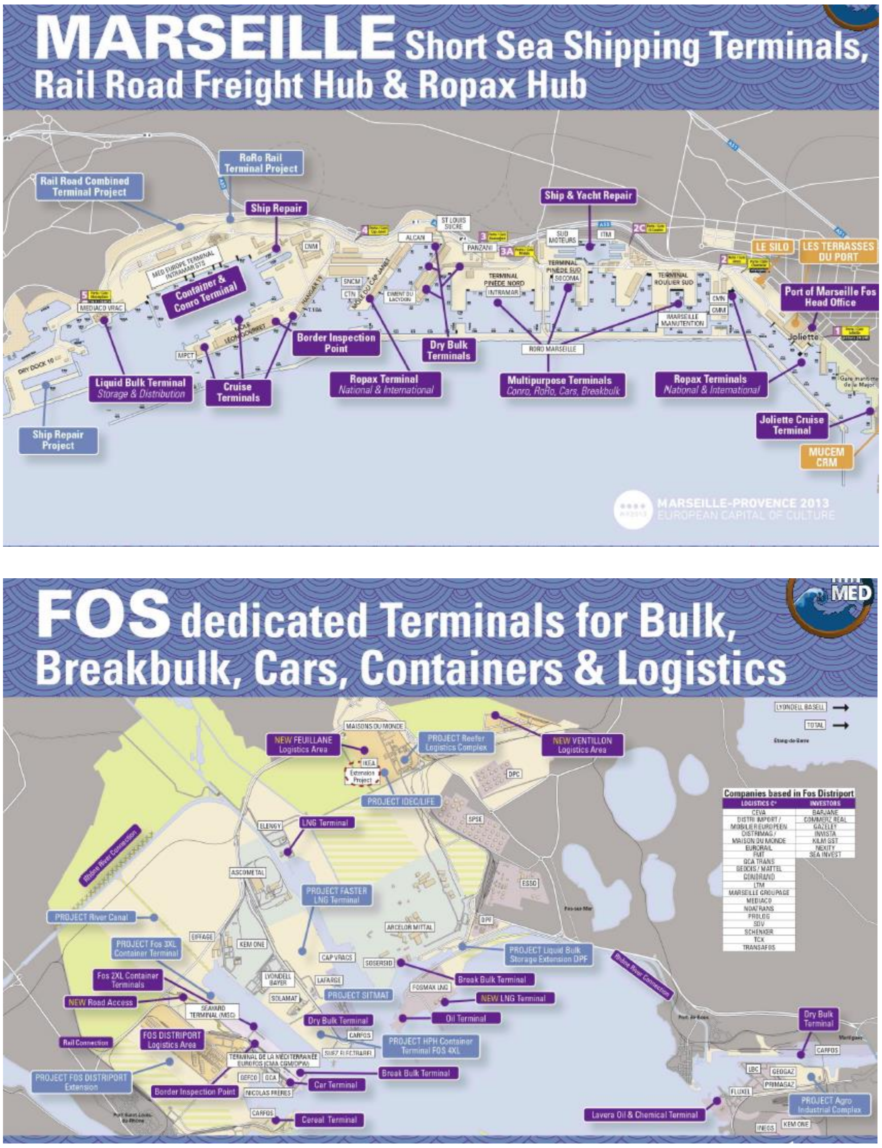
B.5 Port of Marseille-Fos

Topic	Value
Port activity	
Throughput 2014	**Cargo**: 78.5 million ton ▪ Liquid bulk: 47.3 million ton ▪ Dry bulk: 13.4 million ton ▪ Containers: 11.2 million ton ▪ RoRo: 3.7 million ton ▪ Other general cargo: 2.8 million ton **Passengers**: 2.46 million
Ship calls 2014 (number)	15,487 (vs. 2013: -1%): out of which 491 cruise calls Geographic distribution for relevant traffic segments: Eastern basin: 3,600 ship calls Western basin: 4,600 sea ship calls, 2500 river ship calls
Origin/ Destinations	Worldwide network

Topic	Value
	 Source: Regular lines April 2015. (Marseille Fos Port, 2015)
Typical ship types used	Car ferries: Mediterranean. Gross tonnage: 21,317. Net tonnage: 12,045. Containers: Miriam Borchard. Gross tonnage: 7,852. Net tonnage: 3,363. Containers: BF Caroda. Gross tonnage: 9990. Net tonnage: 6,006. Solid bulk: Priceless Seas. Gross tonnage: 24,196. Net tonnage: 12,223. Liquid bulk: Minerva Grace. Gross tonnage: 30,053. Net tonnage: 13,712. LNG: Cheikh el Mokrani. Gross tonnage: 52,855. Net tonnage: 15,856. Cruise: Costa Favolosa. Gross tonnage: 113,216. Net tonnage: 86,831.
Expected developments until 2025	Growth rate: 10% until 2025 (about 1% annually) Main trends in the market: ▪ Improve container activities in both areas: Marseille and Fos ▪ Marseille (Eastern basin: passenger and cargo trade): □ Develop cruise operations, cruise ship repair, and RoRo services ▪ Fos (Western basin: deepsea, worldwide activity): □ Develop trade in LNG and dry bulk
Large operators (vessel owners):	▪ CMA- CGM ▪ Maersk ▪ MSC ▪ China Shipping ▪ Costa
Port infrastructure and facilities	
Quay usage	Approx. 100 berths
Current bunkering infrastructure	In the oil terminals, bunkering is done via the loading/unloading arms and hoses. For the other ships, bunkering is done with the help of 5 bunkering barges, with a capacity of 2,000 m^3 each. Total bunker quantity : 500,000 tons (HFO and MGO) – port estimate.
Current LNG bunkering infrastructure	No ships are being bunkered with LNG at the moment. On the other hand, there are already 2 LNG terminals in the port supplied by large LNG carriers sailing to Marseille: ▪ Fos Cavaou: □ can welcome tankers from 15,000 to 270,000 m^3 □ regasification capacity: 8.25 billion m^3 □ storage capacity: 330,000 m^3, 3 identical tanks

Topic	Value
	▪ Fosmax LNG - capacity: ▫ can welcome tankers carrying less than 75,000 m^3 ▫ storage capacity: 150,000 m^3 The terminals can load trucks (10 at a time) and barges. Currently, there is no demand in place.
Planned LNG infrastructure	No concrete plans.
Policy issues	
Port in SECA (2015)	No
Other relevant issues	The current constraints are: ▪ In France, LNG as a commodity belongs to the hazardous goods category. The same strict restrictions and permits issuance procedure is also applied to LNG as bunker fuel. The implication for Marseille Fos is that LNG could not be bunkered by either barge or truck in the Eastern basin, which is situated too close to the city center. ▪ Currently, the port estimates the demand for LNG bunkering to be 0. ▪ It is considered that a demand threshold volume of 300,000 m^3 and firm contracts should be in place before any operator will consider beginning the process of obtaining the permits and securing the necessary supply infrastructure (barge and/or trucks) to perform LNG bunkering.

Figure 40 Port of Marseille Fos – Basins



Source: Michel-Bonvalet, Spataru (2013) – 'Welcome to Marseille Fos!'

B.6 Port of Constantza

Topic	Value
Port activity	
Throughput 2014	**Maritime cargo**: 43 million tons tons (+0.9% vs. 2013) ▪ Cereals: 11.5 million tons (27%) ▪ Crude oil: 6.7 million tons (16%) ▪ Oil products: 4.2 million tons (10%) ▪ Iron ore: 3 million tons (7%) ▪ Coal: 1.4 million tons (3%) Containers: ▪ 6.8 million tons (+3.6% vs. 2013) ▪ 665,237 TEU, evenly divided between Loaded (335,566 TEU) and Unloaded (329,671 TEU) **River cargo** (via the Danube): 12.5 million tons **Cruise passengers:** 64,861 (+20% vs. 2013) – the most visited port in the Black Sea Largest Black Sea port and 10th largest in Europe
Ships 2014 (number)	Total maritime ship calls: 4,772 (1.3% drop vs. 2013) ▪ Container ships: 578 (-1,2% vs. 2013) ▪ Solid Bulk: 559 (+4% vs. 2013) ▪ Liquid bulk: 719 (+13% vs. 2013) ▪ General cargo: 2,145 (-15% vs. 2013) ▪ Cruise ships: 95 (+39% vs. 2013) Total river ship calls: 9,972 (7.5% increase vs. 2013)
Origin/ Destinations	Worldwide network: ▪ Deep Sea Intercontinental shipping: • Containers: Far East, Middle East, Northern Europe • Mineral ores: Brazil, India, South Africa, Australia • Coal: US • Cereal/wood: South America, Africa, Asia, Middle East • Passengers: Mediterranean, Russia ▪ Short sea shipping to other Black Sea countries: □ Feeder vessels □ Ferry lines ▪ River traffic (via the Danube)

Topic	Value
Typical ship types used	**Containers** ▪ Ex: ▫ California Jupiter. Length: 248 m. Dwt: 34,438. Gross tonnage: 41,668 t. Net tonnage: 13,913. ▫ APL Oman . Length: 275 m. Dwt: 63,271. Gross tonnage: 50,963 t. Net tonnage: 30,224. **Solid Bulk** ▪ General: 150–200,000 tons dwt, length: 200-300 m ▪ Ex: ▫ KWK Legacy. Length: 271 m. Dwt: 149,518. Gross tonnage: 77,273 t. Net tonnage: 47,299. ▫ Ghent Max. Length : 225 m. Dwt: 73,220. Gross tonnage: 38,489. Net tonnage: 24,721. **Liquid bulk:** ▪ Allegra. Length: 180 m. Dwt: 40,400. Gross tonnage: 25,864 t. Net tonnage: 11,369. ▪ Breezy Victoria. Length : 228 m. Dwt: 74,998. Gross tonnage: 40,964. Net tonnage: 22,285. **Cruise:** ▪ MSC Opera. Passenger capacity: 1,712. Length: 251 m. Dwt: 6,561. Gross tonnage: 59,058 t. Net tonnage: 33,747. ▪ Costa Deliziosa. Length : 294 m. Dwt: 9,909. Gross tonnage: 92,720. Net tonnage: 59,465.
Expected developments until 2025	Growth rate: No specific growth rate is available by the port. Assumed was that growth was the same as the assumed main growth of maritime trade in Europe (annual growth of 1.55%). Main trends in the market: ▪ Growing freight traffic with Central Europe via the Danube: Austria, Serbia, Hungary ▪ Sources of traffic growth: cereals, mineral ores, Ro-Ro, containers, passengers ▪ Investment directions included in the 2020– 2040 Masterplan: ▫ A new artificial island hosting new terminals for cereals and containers ▫ A new passenger terminal ▫ A new car terminal ▫ A new LNG terminal
Large operators (vessel owners):	Line services: ▪ Containers: MSC, CMA-GMC, China Shipping Agency ▪ Ferry/RoRo: Ukrferry LLC Ukraine, Neptune Shipping Lines ▪ Cruise: Viking River Cruises, Costa, Princess, MSC

Topic	Value
Port infrastructure and facilities	
Quays	▪ 156 berths (out of which 140 operational) ▪ Total surface: 3,926 ha ▪ Quay length - almost 30 km ▪ Length of breakwaters (north + south) – 14 km ▪ Natural water depths between 8 and 19 m ▪ Total handling capacity – over 120 million tons/year Terminals: ▪ Passengers: 1 terminal – annual operating capacity: 100,000 passengers ▪ Containers: 5 terminals. The most recent one has an annual operating capacity of 1.5 million TEU ▪ Liquid bulk: 1 oil products terminal, 1 crude oil terminal ▪ Solid bulk: □ Ore, coal, coke : 2 terminals – 13 piers □ Chemical products and fertilizers: 1 terminal – 10 piers □ Cereals: 14 piers □ Bulk cement and construction materials: 2 terminal ▪ RoRo: 2 terminals
Current bunkering infrastructure	Bunkering is done via: ▪ 5 bunker barges (diesel, HFO), with a capacity of 5,000 tons/ship ▪ Trucks – small quantities for interior waterways ships Total diesel quantity : 120,000 tons/month (port representative estimate). Shore-to-ship electricity infrastructure is available for almost all the operational piers (over 130 out of the total 140 operational ones).
Current LNG bunkering infrastructure	No LNG infrastructure. Currently, the neighboring Port of Midia hosts Romania's largest liquefied petroleum gas (LPG) terminal, with a capacity of 4,000 m^3 (10 storage tanks of 400 m^3 each).
Planned LNG infrastructure	1 small bunkering station ▪ Capacity: 5,000 m^3 ▪ Completion horizon: 2020 ▪ Meant for: inland waterways vessels and trucks ▪ Location: at the entrance on the Danube – Black Sea Channel ▪ At this point, LNG would be supplied by truck or ship from Revithoussa (Greece) or Ereğli (Turkey) Large LNG terminal ▪ Capacity: 100,000 m^3 ▪ Completion horizon: 2025 ▪ Considered options: tank on shore or LNG ship (plant) ▪ Location: at the entrance to the port –until 2025
Policy issues	
Port in SECA (2015)	No
Other relevant issues	Favourable factors: ▪ Space is available to build the terminal. ▪ Ensuring safe operations is important. There is no concern that the safety regulations cannot be implemented. The large LNG terminal is to be built in a more isolated area of the port. Barriers: ▪ Demand: at the moment, the interest in LNG is limited

Topic	Value
	▪ Costs are an important barrier. Possible funding sources: EU funds and private parties : partners who would act as operator of the terminal

B.7 Port of Antwerp

Topic	Value
Port activity flows	

Throughput 2014	Total: 199 million ton
	▪ Dry bulk 13.5 million
	▪ Liquid bulk: 62.9 million
	▪ General cargo: 122.7 million
	  □ Containers: 108.3 million
	  □ RoRo (excl. containers): 4.5 million
	  □ Conventional general cargo: 9.9 million
	▪ Containers 108 million ton/9.0 million TEU
	▪ Other general cargo: 13 million ton
	
	Containers
	▪ Total throughput: 9.0 million TEU
	▪ Short sea share: 25% (2.25 million TEU)
	
	Cars: 1.2 million units

Ships 2014 (number)	Total: 14,009 seagoing vessels, of which ▪ Tanker: 3,887 (28%) ▪ Container: 3,874 (27%) ▪ General cargo: 2,906 (21%) ▪ Ro-Ro: 1,368 (10%) ▪ Gas carrier: 896 (6%) ▪ Dry bulk carriers: 421 (3%) ▪ Fruit carriers: 378 (3%) ▪ Other: 279 (2%)
Origin/Destinations	Worldwide network: ▪ Deep Sea Intercontinental shipping: the Port of Antwerp has direct connections to more than 500 ports around the world, with at least 300 of these connections being called at weekly ▪ Short sea European shipping: 200 destinations for short-sea container and feeder traffic Container traffic: Antwerp market share as % of total direct calls  Source: Port of Antwerp (Antwerp Port Authority, 2013), Antwerp – your port of choice. Containers.
Typical ship types used	Great variety in terms of ship size: ▪ Typical deep sea container vessel: MSC Abidjan

Topic	Value
	▫ Capacity: 8,827 TEU ▫ Length: 300 m ▫ Deadweight: 110,806 ▫ Gross tonnage: 95,390 ▫ Main engine: MAN-B&W 9S90ME-C8 ▫ Installed power: 47,430 kW ▫ Service speed: 22 knots ▪ Typical short sea vessel: Hanse Courage ▫ Capacity: 830 TEU ▫ Length: 139 m ▫ Deadweight: 11,000 ▫ Gross tonnage: 7,000 ▫ Main engine: B&W 5S50MC-C ▫ Installed power: 7,902 kW ▫ Maximum speed: 18 knots
Expected developments until 2025	Growth rate: No specific growth rate is available by the port. Assumed was that growth was the same as the assumed main growth of maritime trade in Europe (annual growth of 1.55%). Development plans: ▪ Further development of intermodal links and hinterland infrastructure ▪ Further solidify relationships with shipping alliances and major players ▪ Invest in the Saeftinghe Development Area which will bring about an extra 1,000 ha for maritime, industrial and logistics opperations ▪ Build new logistics parks (Schijns and Waasland) and further develop existing ones Main trends in the market: ▪ Growth in the size of (container) ships. However the benefits derived from this growth should be weighted against the risks (e.g. insurance) and effects on port logistics that also accompany it.
Large operators (vessel owners):	Deep sea shipping: Maersk Line, MSC and CMA CGM Short sea shipping: H&S Container Line, Samskip
Port infrastructure and facilities	
Quay usage	Quay length: 151 km Conventional fuel can be bunkered anywhere in the port. Some terminals impose conditions. The 7 container terminals within the Port of Antwerp

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<tr><th>Topic</th><th>Value</th></tr>
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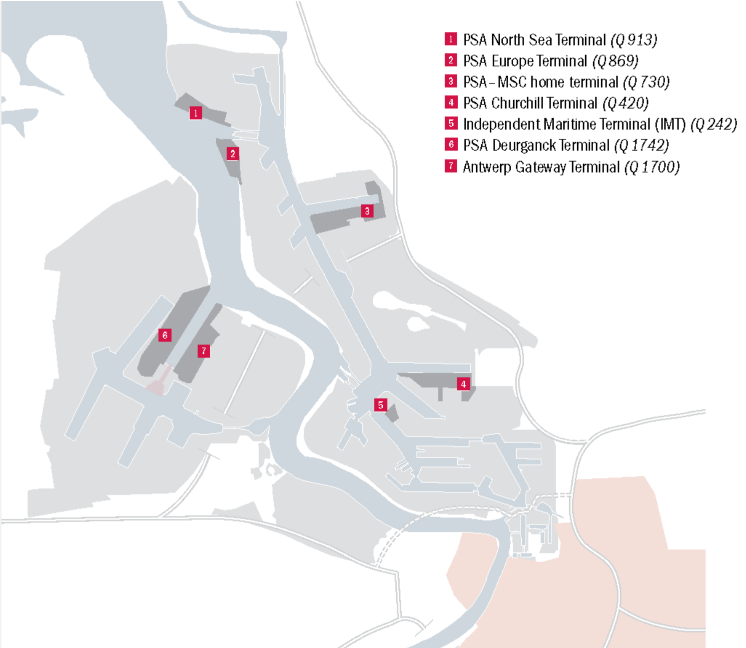


Source: www.portofantwerp.com/en/containers</td></tr>
<tr><td>Current bunkering infrastructure</td><td>Total annual quantity : 8–10 millions tons HFO/year (2nd largest within EU, 5th largest in the world).
10 bunkering agents are active in the port.
All bunkering activity is ship–to–ship. 30 to 40 bunkering barges are used.</td></tr>
<tr><td>Current LNG bunkering infrastructure</td><td>Inland shipping ships - truck-to-ship
▪ Since 2012, 4 inland vessels bunker in Antwerp once or twice per month. The same ships also operate in Rotterdam, so they can opt to bunker LNG in either one of the two ports
▪ An inland vessel requires about 50 m³ of LNG per bunkering operation, which means 1 truckload
▪ The LNG for these operations is supplied from the import terminal in Zeebrugge or Rotterdam
▪ The port authority is not actively involved in the bunkering activities. For the first LNG bunkering operation, the operator is required to submit a risk analysis to the port. Upon the review of the analysis, the port issues the bunkering agent a permit for LNG bunkering operations. The permit needs to be obtained 3 days before the operation takes place
▪ Multiple LNG suppliers: Shell, GDF Suez</td></tr>
<tr><td>Planned LNG infrastructure</td><td>Inland shipping ships - LNG bunker terminal
▪ Capacity: 400 m³
▪ The project is subsidized by the European Union TEN-T body through the LNG Masterplan
▪ The project should be completed by Q3 2016
▪ The Port Authority will own 100% of the terminal, but will not be involved in neither operations nor management
▪ Progress: location is identified, the Port Authority is currently busy with negotiations regarding the building phase of the project and the operational management
▪ With this terminal in place, bunkering operations would become more easy to plan and execute
▪ Truck-to-ship bunkering would not necessarily be prohibited when the terminal is in place

Maritime shipping</td></tr>
</table>

Topic	Value
	▪ Strategic partnership signed in 2013 between the port of Antwerp and Exmar to build an LNG bunkering ship that should have made LNG bunkering for seagoing vessels possible beginning with 2015 ▪ This joint venture was discontinued because: a) the demand was not there to justify the investment; and b) two market driven projects (GDF Suez – 5,100 m^3, Shell - 6,500 m^3) also envisaged building LNG bunkering ships that would operate in Antwerp and satisfy the demand here ▪ The Port Authority currently supports the existing commercial projects in terms of requirements for operations in the port: e.g. safety, pilotage standards ▪ If LNG demand takes up and this demand is not satisfied by the available commercial offering, we would re-consider potential investment projects in necessary infrastructure
Policy issues	
Port in SECA (2015)	Yes

Other relevant issues	Significant progress is observed for sea-going vessels:
	▪ The International Maritime Organization (IMO)
	  □ The IGF code (International Code of Safety For Ships Using Gases. Or other Low-Flashpoint Fuels) to enter into force in 2017
	  □ The IMO is also working on a training model for the crew on LNG-fuelled vessels, with the same time horizon as the IGF code
	▪ Port authorities: A number of ports are moving forward with LNG certifications, as result of the WPCI (World Ports Climate Initiative) working group
	▪ Shipping companies:
	  ▪ Fuel: MGO prices have unexpectedly dropped since June 2014, with a huge impact on LNG business cases. But a lot of questions remain: for how long will this dynamics last? How high will it rise when the current trend is reversed? The LNG price is also currently dropping. But the same questions as those mentioned for MGO are also applicable here.
	  ▪ Retrofit is very difficult due to various reasons: a) low profit margins, b) LNG is not applicable to all vessels, c) the retrofit might only be applicable to relatively young ships, in order to recover the investment during the remaining life time
	  ▪ New-builds: The number is increasing, but it is not an explosive figure, mainly due to three sources of uncertainty:
	    □ Price MGO: will it rise?
	    □ NECA: will it appear or not? If it does, will that be starting with 2020 or later?
	    □ Global Sulphur cap: when does it come into force - 2020/2025?
	▪ Regulatory drivers: discussions are underway about introducing a NECA (concerning NO_x emissions) in the North Sea and Baltic Sea beginning with 2018–2019, but it is uncertain when and how these discussions will be finalized. NECA is an important driver for LNG, as scrubbers and MGO are only helpful when complying with SECA (regarding SO_x emissions).

B.8 Port of Kristiansand

Topic	Value
Port activity flows	

Throughput 2013	**Cargo:**
	▪ Ferry terminal: 492,892 tons. 50% of containerized goods are transported by RoRo
	▪ Container terminal:
	    □ Number of TEU: 48,652
	    □ Goods quantity: 426,289 million ton
	▪ Bulk and general cargo: 185,000 tons
	Passengers:
	▪ Ferry terminal: 1,273,532
	▪ Cruise ships (2014): 160,000

Ships 2013 (number)	▪ Ferries: 952 calls ▪ Containers: 243 calls ▪ Cruise ships: 2013 - 58 calls; 2014 – 78 calls. The number of calls might reduce this year due to the SECA regulation coming in force. The number should pick up again in 2016, when the cruises will have installed scrubbers ▪ Offshore supply vessels: 8 calls. Spot market with growing activity
Origin/Destinations	▪ Ferries: Denmark ▪ Feeder vessels: all main European hubs ▪ Project cargo (oil industry) - Singapore, Korea, Great Lakes area, Canada

Typical ship types used	Skandi Acergy
	▪ Length: 157 m
	▪ Gross Tonnage: 16,500
	▪ Transit Speed: 15 knots
	▪ Maximum speed: 18 knots
	▪ Main engines: 6 x Man: 2 x 8L32/40 - 3840kW/720 rpm, 4 x 6L32/40 - 2880kW/720 rpm
	▪ Total installed power: 19,300 kW
	▪ Storage:
	    □ Fuel Oil: 1,000 m^3
	    □ Fresh Water: 1,740 m^3
	    □ Ballast Water: 150 m^3

Expected developments until 2025	Growth rate: RoRo/container 400% growth by 2065 ▪ Double container activity ▪ Develop offshore supply hub ▪ Port strategy until 2016 has been finalized. The port (except for the ferry traffic and the LNG terminal) is moved to another location further away from the city center. 1/3 of that location is already built ▪ Invest in the development of LNG and railway infrastructure Main trends in the market: ▪ Ferry freight traffic is currently stagnating due to competition from other ports in the area ▪ Platform supply vessels working for state owned companies need to comply with high environmental regulations ▪ More and more newbuilds are LNG
Large operators (vessel owners):	Ferry: Fjord Line, Color Line Bulk: NorLines (LNG), Norcem, Cemex Container: Maersk, MSC, Team Lines
Port infrastructure and facilities	
Quay usage	7 terminals 4 km of piers

Topic	Value
	300 acres of hinterland
Current bunkering infrastructure	▪ Bunkering quantity: □ MGO: 100,000-200,000 tons □ HFO - 50,000 ▪ Bunkering method: □ Mainly by pipe □ For limited quantities, by truck and barge
Current LNG bunkering infrastructure	Occasionally, LNG powered ships are bunkered by truck
Planned LNG infrastructure	1 larger-capacity LNG terminal ▪ Memorandum of Understanding signed with Gassnor: Port of Authority is the owner of the real estate, Gassnor is in charge of obtaining the necessary permits and approvals and constructions ▪ Construction starts in 2016 ▪ Targeted capacity: 4,000 m^3 ▪ This tank will be used to: refill smaller tanks in the nearby region (via barges with a capacity of 1,000 m^3), supply the gas network, supply gas to local buses 1 smaller LNG terminal ▪ Targeted capacity: 750 m^3 ▪ This tank would be used to bunker ship in the port
Policy issues	
Port in SECA (2015)	Yes
Other relevant issues	EU assistance: bureaucracy, financial support. The access to this type of support is more difficult because Norway is not an European Union member state.

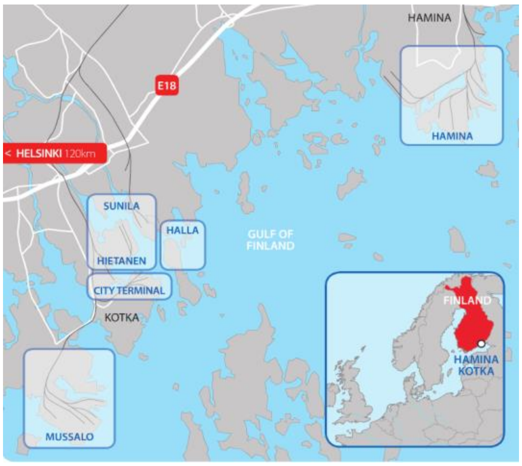
B.9 Port of HaminaKotka

Topic	Value
Port activity flows	
Throughput 2014	Total: 13.4 million tons (-4.2% vs.2013) General cargo: 8.6 million tons (-6.2% vs 2013), including: ▪ Containers: 574,982 TEU (-8.3% vs. 2013) ▪ Ro-Ro: 20,157 units (-10.7% vs. 2013) ▪ Vehicles: 74,238 units (-18.6%) Dry bulk: 1.7 million tons (-2.8% vs 2013) Liquid bulk: 3 million tons (+1.3%)
Ships 2014 (number)	Total: 2,634 ships calls ▪ Container ships: 658 ships of approx. 1,000 TEU (25%) ▪ Ro-Ro carriers (forest product): 605 vessels of approx. 10,000 ton (23%) ▪ General cargo & Liquid bulk: 658 ships of approx. 7,000 ton (25%)
Origin/Destinations	▪ Containers: transshipment to Russia, connections to other Finnish ports, as well as to European destinations such as: Rotterdam, Antwerp, Hamburg ▪ Forest products (either containers or break bulk): □ Sawn products: generally exported to North-East Asia, the UK, Mediterranean and Japan □ Unfinished sawn timber: mainly carried to China and North Africa
Typical ship types used	General cargo: ▪ Diamant ▪ Length: 99.99 m

Topic	Value
	▪ Deadweight: 5,279 ▪ Gross tonnage: 3,739 ▪ Engine: 1x Wärtsilä 9L20 - 4 stroke single acting 9 cylinder 200 x 280 mm diesel engine - 1.800 kW ▪ Generators: 2x Sisu 74-CTA-4V - 6 cylinder 108 x 134 mm diesel engine at 1,500 rpm coupled with Stamford generator 212,5 kVA each ▪ Speed:12 knots ▪ Tank capacities: □ Ballast water: 1,909 m^3 □ Potable Water: 42 m^3 □ Fuel: 366 m^3 □ Lubricating Oil: 8.8 m^3 □ Dirty Oil: 7.7 m^3 □ Sewage: 8 m^3 □ Gas oil: 33 m^3
Expected developments until 2025	Growth rate: 1-2% (annually) Main trends in the market: ▪ Given the sanctions imposed by EU states on Russia, the evolution of volumes heading in and out of this country are uncertain ▪ Maersk plans to use bigger vessels and lower speed
Large operators (vessel owners):	▪ Containers: MSC, MAERSK, Unifeeder, Green Alliance, Team Lines, OOCL, Hapag-Lloyd, CMA CGM ▪ RoRo & ferries: Transfennica, Finnlines, KESS, UECC ▪ Liquid bulk: Chrystal Pool ▪ Currently no passenger traffic
Port infrastructure and facilities	
Quay usage	General information: ▪ 1,100 ha of land areas ▪ 1,400 ha of sea areas ▪ max. draught 15.3 m ▪ 9 km of quays □ containers □ dry bulk □ liquid bulk □ forest products □ ro-ro traffic, trade cars □ ferries and leisure vessels ▪ 76 berths ▪ tank capacity 1.1 million m^3 ▪ 80 km of railways *3 terminals:* Hamina: 3.2 km quay Products: Containers (capacity: 500,000 TEU), forest products, liquid bulks (storage - 830,000 m^3) including terminal for LPG (liquefied petroleum gas) Hietanen: Products: forest products, general cargo, vehicles Mussalo Products: Container terminal (capacity: 1 million TEU), bulk terminal, liquid bulk terminal
Current	Total bunker quantity: NA

Topic	Value
bunkering infrastructure	Bunkering is done by truck: 25 bunkering trucks. 10 companies deliver bunkering fuel to ships. Some of them get the fuel from the refinery that lies 100 km away from the port, other companies source fuel from the terminals located inside the port. It is cheaper to buy bunkering fuel from Russia: e.g. St. Petersburg.
Current LNG bunkering infrastructure	There is currently no LNG bunkering infrastructure in place. One time operation: the coast guard vessel was bunkered with 50 tons LNG from a truck. It is uncertain what the state of the LNG infrastructure in Russia is. LNG pipes are coming from Russia to Finland, with one pipe coming all the way to the port. Other applications: LNG is already used for houses.
Planned LNG infrastructure	General plan or ambition : LNG terminal operational by 2018 ▪ Storage capacity: 1 storage tank, with a capacity of 30,000 m^3 ▪ Estimated annual throughput volume: 90,000-118,000 tons ▪ The terminal will include infrastructure to load LNG into trucks ▪ The LNG terminal will also include a CHP (combined heat & power) plant of 50 MW ▪ The environmental permit was obtained to build the LNG pier ▪ Hamina Energy received a 27.6 million EUR subsidy from the Finnish government to build the terminal ▪ The Port Authority applied for TEN-T funds to investigate the bunkering option
Policy issues	
Port in SECA (2015)	Yes
Other relevant issues	Drivers: ▪ LNG pipeline available in port ▪ All the necessary safety and environmental permits were obtained ▪ The Coast Guard is using an LNG powered vessel Barriers: ▪ LNG bunkering is a new market: no infrastructure is installed. LNG use is currently limited to houses and factory buildings. LNG facilities and the rules for operating these facilities need to be put in place ▪ In Finland, pilotage is required for ships carrying LNG. Pilotage fees are an additional cost that deter shipping lines from using LNG powered ships in this area

Figure 41 Ports within the HaminaKotka Group



Source: HaminaKotka Port Authority.

B.10 Port of Cartagena

Topic	Value
Port activity flows	

Throughput 2014	4th largest port in Spain
	
	Total: 32.3 million goods (+10% vs. 2013)
	▪ Liquid bulk: 25.8 million tons (+8.8% vs. 2013)
	  ▫ 1st largest port in Spain
	  ▫ Cargo type: crude oil, refined oil, chemical products, LNG
	▪ Solid bulk: 5.3 million tons (+17.7% vs. 2013)
	▪ General cargo: 1.2 million tons (+7.8% vs. 2013)
	▪ Containers: 88,563 TEU
	
	Passengers: 137,985

Ships 2014 (number)	Total: 1,854 calls a year, out of which: ▪ 10% cruise lines: 150–180 ▪ 25% General cargo and container lines ▪ 15% - solid bulk ▪ 50%: liquid bulk (very large vessels)
Origin/Destinations	▪ Liquid bulk (crude oil): Middle East, Caribbean, west coast of Africa ▪ Solid bulk (coke): from Spain to Morocco ▪ Sulphur: Spain to Morroco ▪ Container (feeder) lines: going to North Europe (England, Netherlands, France, Germany), Baltic Sea, Algeria ▪ Cruise: mainly Mediterranean traffic, only a few (approx. 10) have transatlantic routes

Typical ship types used	▪ Oil tankers: 100,000 gross tonnage
	▪ LNG: over 100,000 gross tonnage
	▪ Chemical tankers: 10,000 gross tonnage
	▪ Container lines: 500 TEU–700 TEU
	Ex. RBD Dalmatia
	  ▫ Max TEU capacity: 698
	  ▫ Length: 129.2 m
	  ▫ Deadweight: 8,400 ton
	  ▫ Gross tonnage: 7,430 ton
	  ▫ Engine: MAK 7M43
	  ▫ Power output: 7,200 kW
	  ▫ Speed:17.5 knots
	  ▫ Consumption: 30 million tons IFO 380
	  ▫ Cruise: average 200 m length, gross tonnage 40,000

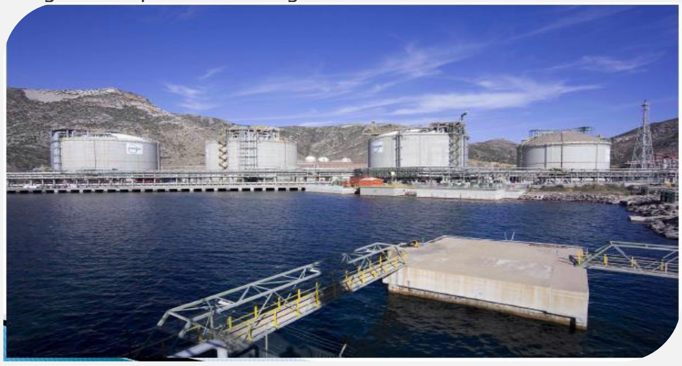
Expected developments until 2025	Growth rate: ▪ Solid and liquid bulk: growth should continue at a pace of 2-4% on a yearly basis. The existing capacity can accommodate an annual capacity of 40–45 million tons. ▪ General cargo & containers: a master plan is in place for a new container terminal in a new basin. This terminal would increase the annual container handling capacity from 100,000 to 2.5 million TEU. There is a big opportunity to tap into the growing traffic around the Straight of Gibraltar. The terminal should be operational in 2023-24. Main trends in the market: ▪ Stable outlook ▪ Main risk for the new container terminal is not have a private partner investing in the port
Large operators	Liquid bulk tankers: vessels contracted by Repsol, Sarez, BP

Topic	Value
(vessel owners):	LNG: Enegas – national logistic operator Cruises: P&O Containers: WEC HOLLAND MAAS, MSC, HAPAG LLOYD, MAERSK LINE, OPDR
Port infrastructure and facilities	

Quay usage	2 different basins: Cartagena and Escombreras
	11 km of piers: 22 piers
	
	Cartagena basin:
	▪ Touristic boats: 1 pier
	▪ Leisure time boats:1 pier
	▪ Passenger terminal: 1 pier
	▪ Containers and general cargo: 4 piers
	▪ General cargo: 2 piers
	Escombreras basin:
	▪ Commercial area
	  □ Liquid bulks: 1 pier
	  □ Solid and liquid bulks and LNG: 1 pier
	  □ Solid bulks: 5 piers
	▪ Oil products area
	  □ Liquid bulks, chemicals and vegetal oil: 1 pier
	  □ Liquid bulks, refined, bioethanol and chemicals: 1 pier
	  □ Liquid bulks, refined, chemicals, vegetal oil and GPL: 1 pier
	  □ Liquid bulks, refined and chemicals: 2 piers
	  □ Refined products: 2 piers
	  □ Crude oil: 2 piers
	▪ Crude oil terminal
	  □ Solid bulks: 4 piers

Current bunkering infrastructure	Total quantity (2014): 5,000 MTOE bunkering total port Infrastructure: ▪ Pipeline: MGO, HFO pipelines are available on all the main quays. The fuel is sourced from the refinery located in the port ▪ Trucks: approx. 200 trucks. Trucks are used to bunker smaller ships

Current LNG bunkering infrastructure	Existing LNG infrastructure:
	▪ LNG regasification plant: Enagas - 5 storage tanks, totalling a capacity of 587,000 m^3. The plant can load 50 trucks/day
	▪ Truck fleet: aprox. 150-200 trucks
	
	LNG utilization:
	▪ Transshipment point: LNG hub between source points (Middle East, the Caribbean area) and consumption areas (Japan)
	▪ National consumption following a national focus on shifting to green energy
	  □ Serve Spanish national gas grid. In total, Spain has 7 re-gasification plants in 7 different ports.
	  □ 3 electrical plants powered by LNG (working at 20% of their capacity) are located in the port of Cartagena
	Truck-to-ship bunkering operations:
	▪ 2014: 3 such operations took place for ships built in Turkey or the Middle East travelling to their use locations in the Baltic Sea
	▪ 2015: 4 operations planned
	
	Bunkering volumes
	For a ferry with an LNG storage tank of 400 m^3, 8 truckloads were used for the bunkering operation. This capacity can be sourced today without difficulties. But the

Topic	Value
	unloading rate per truck is too slow. If more ships request this bunkering service, other options will be considered: ship-to-ship and/or shore-to-ship. Enagas LNG plant in Cartagena  Source: Enagas (2013), LNG Trucking: A First Step to the Development of LNG for Fuel for Transportation.
Planned LNG infrastructure	Infrastructure: The port currently has 2 LNG quays. The port authority together with Enagas plan to refurbish the smaller LNG quay to make it suitable for ship bunkering. An application for European funds has been submitted to support these plans. The two considered options are: a) shore-to-supply and b) supply LNG to barges which would then bunker ships in small ports in the region. Capacity would increase from 40 m^3/hour (truck unloading rate) to 600–800 m^3. Aside from bunkering, the port of Cartagena is also assessing the potential LNG demand generated by small electricity plants located on the islands in the region switching to this type of fuel. Provided that such a demand is substantial enough, the port would consider building a barge to supply LNG from Cartagena to these plants.
Policy issues	
Port in SECA (2015)	No
Other relevant issues	LNG is mainly an interesting fuel option for new vessels meant to sail in controlled emission level areas. There are already discussions to also impose emission restrictions in the Mediterranean Sea. When these discussions materialize into agreements on accepted emission levels and the corresponding implementation horizons, more operators will look into LNG powered ships. Another important driver is a more pervasive LNG bunkering infrastructure. Other small-scale LNG applications are the first step in building this infrastructure: small ships that transport LNG from large re-gasification plants (such as the one in Cartagena) to smaller LNG powered electricity plants in the region could also be used for bunkering services. Available funding is also an important driver, as it is necessary to first establish that there is a market for LNG in the port/region.

Annex C Factsheets on LNG infrastructure development in the selected ship types

C.1 Ferry: Viking Grace

Source: SAACKE Marine Systems GmbH (2013), Application report – Marine boilers & systems: New passenger ship.

Subject	Value
Technical characteristics	
Ship size	▪ Length: 218 m ▪ Width: 31,8 m ▪ Dead weight tonnage: 5,030 ▪ Gross tonnage: 57,565 ▪ Route: Turku–Mariehamn/Långnäs–Stockholm ▪ Number of passengers: 2,800 ▪ Number of cabins: 880 ▪ Lane meters: cargo 1,275 m, passenger cars 500 m on deck 4 and 500 m on deck 5
Engine size	4 electric engines (Wartsila 8L50DF). Total installed power 30,400 KW
Tank size	84 metric tons = 187 m^3 LNG
Max sailing speed	23 knots
Operational characteristics	
Operational hours per year	6,450 h (21.5 h/day x 300 days)
Operational average sailing speed	22 knots

Subject	Value			
Fixed bunker locations	Stockholm **LNG bunkering operation: the Seagas barge supplies Viking Grace with LNG**  Source: (Cars, 2013), LNG in the Ports of Stockholm.			
Average time between bunkering	The ship bunkers every day due to limited LNG supply in Stockholm. Fuel consumption: 56 t/day = 126 m^3/day			
Total bunkering volume per year	19,600 ton MGO/HFO, or 17,000 tons = 38,200 m^3 LNG + 340 ton MGO			
Effect on costs for ECA compliancy options (compared to HFO): scenario A (2015 or 2020). Requirements: 0.1% sulphur				
	LNG	Low sulphur diesel	Scrubber	
Investment costs new build	15 million EUR			
Investment costs Retrofit	For the ferry business, LNG is only an option for new builds.			
Effect on costs for ECA compliancy options (compared to HFO): scenario B (2025 or 2030). Requirements: 0.1% sulphur and Tier III NO_x.				
	LNG	Low sulphur diesel	Scrubber	Catalyst
Investment costs new build				
Operational costs	The clean combustion of gaseous fuel reduces emissions and maintenance expenses for the boiler as well as the exhaust gas boiler. Savings: ▪ lubricating oil: much reduced consumption, cheaper variant ▪ cleaning agents: much reduced consumption (from 10,000 l/years to 2,000 l/year) ▪ the need to provide passengers compensation for clothes damaged by smoke residues is removed ▪ lower maintenance costs			
Safety effects LNG				
Safety on board				
Safety during bunkering	Bunkering is done at the same time as loading/unloading passengers and goods. The bunkering happens on the sea side, far away from other activities.			
Other	…			
Operational effects LNG				
Loss of storage space (cargo capacity)	No storage space was lost: the deadweight tonnage is sufficient to support the higher length required to accommodate the LNG bunkers.			
Effect on bunkering time	All bunkering activities take about 45 mins. The time available at pier is 1 hour. Therefore bunkering time has no consequence on the ship's schedule.			

Subject	Value
Other	…
Other effects LNG	
Environmental effect	▪ Significantly reduced emissions: □ Nitrogen oxides: 80% lower than IMO Tier III limits □ Particulate matter emissions: 90% lower than that of a diesel engine □ No sulfur oxides ▪ No visible exhaust ▪ Better air quality: no exhaust odors or soot ▪ Low waves from the bow and stern ▪ The ship is very quiet: below 50 dB(A) at 100 meters distance from the ship ▪ More environmentally friendly cleaning agents can be used
Other relevant issues	▪ Fuel price: LNG vs. other fuels ▪ EU/National government financial support is an effective incentive: for the development of Viking Grace the innovation aid received from the Finish government amounted to 28 million EUR
Qualitative assessment stakeholder	▪ Viking Line: □ 2 new LNG vessels for Viking Line by 2025 ▪ Other: □ Competitor ordered an LNG ferry for the route Helsinki – Tallinn (bunkering in Tallinn) □ Other ferry companies in Stockholm are looking at the feasibility of building small LNG powered ferries

C.2 Platform supply vessel: Viking Princess

Source: Kleven–Viking Princess. (Kleven, 2011).

Subject	Value
Technical characteristics	
Ship size	Length: 90 m Width: 24 m Dead weight tonnage: 4,800 Gross tonnage: 5,381 gt Storage capacity: 7,6=864 m^3 cargo space Fuel Oil 823 m^3 Potable water 1,036 m^3 Drill Water/Ballast 1,781 m^3 *Liquid mud 1,392 m^3 Methanol 210 m^3 Dry bulk 300 m^3 Brine max3 1,667 m^3 Base Oil max3 243 m^3 Special products LFL* 412 m^3
Engine size	2nd generation LNG technology Total: 7,332 KW Wärtsila 6L34DF 2 x 2,610 kW Wärtsila 6L20DF 2 x 1,056 kW Second generation LNG technology: ▪ improvements on emissions and consumption ▪ approx. 25% reduced fuel consumption versus earlier solutions Power Requirement Reducing Measures: ▪ New engine configuration, 2 large + 2 small ▪ New hull shape for best fuel economy at operational speed 12-13 knots ▪ Power Consumption Tuning, «Econometer» ▪ LLC (Low Loss Concept) – switchboard system ▪ Heat recovery on AC/vent. systems

Subject	Value
Tank size	233 m^3 LNG
Max sailing speed	Unknown
Operational characteristics	
Operational hours per year	7,920 (330 days)
Operational average sailing speed	12–13 knots
Fixed bunker locations	No
Average time between bunkering	Average: 6 days
Total bunkering volume per year	4,907 ton MGO, or 9,569 m^3 LNG

C.3 Cruise ship: Costa Favolosa

Source: www.shipspotting.com

Subject	Value
Technical characteristics	
Ship size	Cargo load: 3,800 passengers Berths : 4,196 Cabins : 1,508 Ship category: Deadweight: 10,000 Gross tonnage: 114,500 Length: 289.65 m
Engine size	Total installed capacity: 75,600 kW (main engine) + 42,000 kW Engines: 6 x 12,600 kW Wärtsilä 12V46 C at 514 rpm medium-speed diesel electric Generators: 6 x 14,000 kVA Ansaldo 3 phase AC 60Hz generators
Tank size	HFO: 3,069 m^3 MDO: 425 m^3 If Costa Crociere were to build an LNG powered ship, they would be looking at a tank capacity of 3,500+ m^3 LNG, which should allow for 10-14 days of operations. The company is currently having exploratory discussions with various ports across Europe regarding planned LNG infrastructure.
Max sailing speed	23.2 knots
Operational characteristics	
Average cargo load	Most cruise vessels are operating full.
Operational hours per year	365 days/year: 50% sea/50% port
Operational hours/year inside ECA	Northern Europe – seasonal: 30% Southern Europe – all year
Operational average sailing speed	Service speed: 19.6 knots Average speed: 16–18 knots

Subject	Value			
Fixed bunker locations	Barcelona, Marseille, Civitavecchia, Southampton, Rotterdam.			
Average time between bunkering	14 days			
Time in port	Bunkering (every 14 days): 4-5 hours			
Total bunkering volume per year	46,574 ton MGO/HFO, or 90,824 m^3 LNG,			
Effect on costs for ECA compliancy options (compared to HFO): scenario A (2015 or 2020). Requirements: 0.1% sulphur				
	LNG	Low sulphur diesel	Scrubber	
Investment costs new build				
Investment costs Retrofit	Higher costs for LNG retrofit than for scrubbers.			
Effect on costs for ECA compliancy options (compared to HFO)): scenario B (2025 or 2030). Requirements: 0.1% sulphur and Tier III NO_x.				
	LNG	Low sulphur diesel	Scrubber	Catalyst (if Tier III)
Investment costs new build				
Investment costs Retrofit				
Operational costs*				
Safety effects LNG:				
Safety on board	Codes are in place. Safety issues can be overcome.			
Safety during bunkering				
Other	…			
Operational effects LNG				
Loss of storage space (cargo capacity)				
Effect on bunkering time				
Other	…			
Other effects LNG				
Environmental effect	LNG is a very "green" fuel and a good way to be compliant.			
Other relevant issues	Price: Some discount on LNG prices can also be observed, but the difference is not so high anymore. Infrastructure: the infrastructure is not yet in place. The ferry industry is currently considering all solutions that would make ships compliant with the emission limits.			
Qualitative assessment stakeholder	Expected number of LNG vessels 2020, 2025, 2030: There should be LNG powered ships sailing by 2020, but it is difficult to estimate how many.			

C.4 Container ship: New LNG powered vessel

Source: Nordic Hamburg.

Subject	Value
Technical characteristics	
Ship size	Cargo load 1,004 TEU Ship category 16,900 metric tons dwt
Engine size	Main engine Wartsila 7RT-flex50DF 2-stroke, low pressure, dual fuel, installed power 10,080 kW 3 Auxiliary engines: 1x 1,014 kW, 2x 550 kW
Tank size	700 m^3 t HFO 700 m^3 LNG, 130 m^3 MGO The primary fuel is LNG. The other fuels are meant to ensure flexibility if the ship is used in areas with insufficient LNG supply infrastructure.
Max sailing speed	19 knots
Operational characteristics	
Operational hours per year	200 sea days
Operational average sailing speed	15 knots
Fixed bunker locations	Finland (location is not yet known), St. Petersburg, Rotterdam
Average time between bunkering	Average: 14 days round voyages. Starting point - Rotterdam
Total bunkering volume per year	MGO consumption: MGO – 0.5 tons/day, HFO consumption - 0 LNG consumption at max speed: 35 m^3/day LNG consumption at average speed: 20-22 m^3/day Range when full (700 m^3): 3,500 nautical miles ▪ Days at sea: Total volume per year: 200 sea days/14 days (average trip duration) x 700 m^3 (full tank) = 10,000 m^3 ▪ Days in port: 1 auxiliary engine can use the boil-off gas ▪ Port call: LNG 160 days x 2.5 metric tons (=6.175 m^3)/day = 988 m^3 Annual bunkering volume:

<table>
<tr><th>Subject</th><th colspan="4">Value</th></tr>
<tr><td></td><td colspan="4">5,600 ton MGO/HFO, or 10,988 m^3 LNG +180 ton MGO</td></tr>
<tr><td colspan="5">Effect on costs for ECA compliancy options (compared to HFO): scenario A (2015 or 2020). Requirements: 0.1% sulphur</td></tr>
<tr><td></td><td>LNG</td><td colspan="2">Low sulphur diesel</td><td>Scrubber</td></tr>
<tr><td>Investment costs new build</td><td>125% of a regular new built.

New fleet: 4 identical sister vessels. 2 of them will be delivered in 2016, while the last 2 will follow in 2017.

This fleet is used in the Baltic Sea.</td><td colspan="2"></td><td>The charterer (Containerships, Finland) preferred the new build plan, because of the possibility to adjust the decks of the new ship to other containers than the ISO standards.

LNG powered vessels with flexible decks are an interesting niche market.</td></tr>
<tr><td>Investment costs Retrofit</td><td>Decision factors:
▪ Age of the ship
▪ Financial situation of the vessel
▪ Who do the ships belong to
▪ Return on investment – assessed to be equal to the current value of the vessel</td><td colspan="2"></td><td>Main alternative.

The investment required to install scrubbers is equivalent to only 1/3 of that associated with retrofitting a ship with LNG (3-4 million EUR).

The size of this investment still requires resorting to a bank for credit. In order to grant the credit line, banks request a long term contract and the rates associated to the vessel service. No chaterer wanted to conclude such a contract for a retrofit.</td></tr>
<tr><td colspan="5">Effect on costs for ECA compliancy options (compared to HFO)): scenario B (2025 or 2030). Requirements: 0.1% sulphur and Tier III NO$_x$</td></tr>
<tr><td></td><td>LNG</td><td>Low sulphur diesel</td><td>Scrubber</td><td>Catalyst
(if Tier III)</td></tr>
<tr><td>Investment costs new build</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Operational costs</td><td colspan="4">Operational costs are higher than with normal fuels, due to LNG specific maintenance operations.
Positive effects: cleaner engine room, no maintenance on purifiers.</td></tr>
<tr><td colspan="5">Safety effects LNG:</td></tr>
<tr><td>Safety on board</td><td colspan="4">The first vessels will be delivered within the next 1.5 years. The crew in general needs to have basic training. Engine room and master deck staff require more elaborate certificates for sailing on these vessels.

We are following the standards imposed by the IGF code issued by IMO (International Code of Safety For Ships Using Gases or Other Low-Flashpoint Fuels).</td></tr>
<tr><td>Safety during</td><td colspan="4">This topic appeared to be an issue in the initial phase of introducing LNG as a bunkering</td></tr>
</table>

Subject	Value
bunkering	fuel (the 'initial resistance' period). Currently, safety during bunkering is no longer considered problematic. Nordic Hamburg expects that the manufacturers, the port authorities and IMO will provide them with clear instructions on how to operate this type of vessels (LNG powered). There are already 80–100 vessels sailing with a 4-stroke dual engine, which means that the expertise on how to safely operate such vessels is available.
Other	…
Operational effects LNG	
Loss of storage space (cargo capacity)	Tank size is the downsize when using LNG to power the vessel. Considered issues when designing the vessels: ▪ What type of tanks? ▪ How many tanks should be used? ▪ What is the operational range a given capacity can cover? In order to accommodate the LNG tanks, the ship length had to be increased by approx. 5%. But the minimum of storage capacity was lost because the ship design makes is possible to stow container units close to the LNG tanks.
Effect on bunkering time	Technically, bunkering can be performed at the same time with loading/unloading operations. But Nordic Hamburg expects that port authorities will impose limitations on the number of areas in the port where LNG bunkering can be performed. If that is the case, the duration of the ship's port call will increase. Charters will opt for ports that do not impose this restriction, in order to prevent delays and additional costs.
Other	…
Other effects LNG	
Environmental effect	The ship produces only a minimal amount of sludge (oil) that needs to be given a shore. No black gasses are coming out of the funnel.
Other relevant issues	▪ Competitive advantage to be gained by positioning the company in a niche market ▪ Container fleet: Shipping companies need to secure financial and contractual support from charters before they can apply for the credits they need from banks ▪ Triangle: □ **LNG suppliers** would like to have a commitment from vessel owners that more LNG powered vessels will be built □ **Shipping companies** would like to have a commitment from LNG suppliers regarding the price level □ **Shipping companies** would like to have a commitment from charterers that future contracts for LNG powered ships will include premium rates □ **Charterers (line services)** are looking for certainty in the location of the stock points and price levels □ Progress is observed: LNG infrastructure has significantly improve in comparison to 2 years ago. EU played a role in this improvement.
Qualitative assessment stakeholder	Expected number of LNG vessels 2020+: 50 ▪ Optimistic forecast ▪ Mainly container vessels and small bulk carriers, sailing in the Baltic Sea The arguments supporting this forecast are: ▪ The current order book is small ▪ It takes about 1.5 years to go through the feasibility & financial planning phase which precedes the construction of a vessel ▪ Conventional bunker fuel prices registered for the past half year do not support investment in LNG Further evolutions for container and bulk vessels:

Subject	Value
	▪ Current phase: Vessels are sailing only within one area (US - ECA. Europe - SECA). ▪ Next phase: Bigger vessels will sail between emission control area (ex. Both in ECA and SECA). Once companies see the impact of paying higher prices for 0.5% fuel, LNG will become more attractive. LNG domino: 1. Government authorities and industry bodies (IMO) they activate the first domino piece 2. Industry (charterers/liner services) have to comply, otherwise they cannot access those areas with their vessels 3. Shipping companies have to build a vessel that complies with the regulations 4. Main engine OEMs are asked by shipping companies to provide an adequate engine model Newbuilds are more interesting for main engine OEMs than retrofits because retrofitting requires a considerable additional investment with testing and adjusting the existing engine. The industry is also not pushing for retrofits.

C.5 General cargo ships: standard size

Subject	Value
Technical characteristics	
Ship size	Cargo load 11,000 tons Ship category: 12,000 dwt
Engine size	Total: 5,860 KW Main engine 4,860 kW Auxiliary engine 1,000 kW
Tank size	400 m^3 diesel oil 780 m^3 gas oil
Max sailing speed	15-16 knots
Operational characteristics	
Operational hours per year	6,000 hours
Operational average sailing speed	10.5 knots
Fixed bunker locations	No, ship functions on the spot market.
Average time between bunkering	Average: every 30 days
Total bunkering volume per year	5,300 ton MGO, or 10,000 m^3 LNG

C.6 General cargo ship – LNG: Eidsvaag Pioner

Source: Rolls Royce.

Subject	Value			
Technical characteristics				
Ship size	Cargo load (total loading capacity): 1,450 tons of fish feed Payload: 1,300 tons of fish feed Ship category: 1,450 dwt Tank capacity: ▪ 30 m^3 of water ▪ 938 m^3 of water ballast			
Engine size	Main engine: Bergen C26:33L9PG gas engine, installed power 2,430 kW Auxiliary engines: 2 x Scania DI 1655 M engines, of 469 kW each Shaft generator: Marelli B5J450LC4 of 1,100 kW			
Tank size	35 m^3 diesel oil 27 m^3 gas oil 110 m^3 LNG (95%) – range: around 1,750 nautical miles			
Max sailing speed	15.5 knots			
Operational characteristics				
Operational hours per year	6,000 hours			
Operational average sailing speed	14.5 knots			
Fixed bunker locations	By trucks. 3 ports within the Kristiansund area.			
Average time between bunkering	2 times a week			
Total bunkering volume per year	560 ton MGO/HFO, or 1,200 tons LNG + 0.5 ton MGO (used in port or for operations where extra power is needed)			
Effect on costs for ECA compliancy options (compared to HFO): scenario A (2015 or 2020). Requirements: 0.1% sulphur				
	LNG	Low sulphur diesel	Scrubber	
Investment costs new build	NOK 200 million (2011) This investment is assessed to be			

Subject	Value			
	20% higher than that required for a diesel powered vessel.			
Investment costs Retrofit				
Effect on costs for ECA compliancy options (compared to HFO)): scenario B (2025 or 2030). Requirements: 0.1% sulphur and Tier III NO_x.				
	LNG	Low sulphur diesel	Scrubber	Catalyst (if Tier III)
Investment costs new build				
Investment costs Retrofit				
Operational costs*	More or less the same operational costs. Lower maintenance costs – it is not possible to calculate at this point how much lower these costs are in comparison to a diesel fuelled engine since the ship has only been in operation for 2 years. However, the reduction sources seem to be: spare parts, and fewer maintenance operations for the engine.			
Safety effects LNG:				
Safety on board	The crew had a 1 day LNG operations training. Since it was related to a new-build, the training course was provided by the supplier of the LNG tank and equipment. Engine suppliers also organize this type of course. We do not see any challenge with a ship operated on LNG. LNG is safer than the MGO.			
Safety during bunkering	No special procedures. In Norway you can bunker on any pier. For a new pier, a risk analysis is performed together with the LNG supplier.			
Other	…			
Operational effects LNG				
Loss of storage space (cargo capacity)	The size of the LNG tanks not optimal, but a larger LNG tank would have meant diminished capacity for storage tanks.			
Effect on bunkering time	Bunkering is done from trucks. 1-2 truckloads is bunkered at a time. Loading 1 truckload (50 tons) takes 1 hour. Because the LNG bunkering operation happens at a different location than the pier where we perform cargo loading/unloading, we cannot perform both operations at the same time. But this limitation is only a logistical one. Technically, it is possible to simultaneously bunker and handle cargo.			
Other	…			
Other effects LNG				
Environmental effect	▪ The Rolls-Royce Bergen B-Series lean burn gas engines, as used in the Environship, emit around 17 percent less CO_2 (per unit of power) than a diesel engine ▪ The use of gas fuelled engines means that Nitrogen Oxide (NO_x) emissions are reduced by about 90 percent while Sulphur Oxide (SO_x) emissions are negligible ▪ 100% less fine particles emission ▪ No noise impact			
Other relevant issues	Eidsvaag is satisfied with the performance of this LNG ship. They are now planning a new-built, that will also be LNG-fuelled. The new ship should use the same type of engine, but harbor a larger LNG tank, as well as larger cargo tanks. The main challenge is where to position to LNG tank. Lately, it is becoming			

Subject	Value
	possible to position the tank on the foredeck, which reduces the need to cut on storage tank capacity elsewhere.
Qualitative assessment stakeholder	Expected number of LNG vessels by 2025: the current number of LNG powered vessels in Norway (50) should double. Drivers ▪ Government subsidy. The Norwegian government imposes taxes on CO_2 and NO_x emissions. These taxes are collected into the NO_x fund, which is then used to finance environmentally friendly projects: 80% of the additional costs associated with the investment in the LNG ship (in comparison to an investment in a vessel running on conventional fuel) is compensated by the Fund. Given this context, Eidsvaag only had to invest 2% more (out of a total of 20% extra costs) for the LNG ship. ▪ Price: □ LNG own price index. At the moment the price for LNG is negotiated by LNG suppliers individually with every customer, on the basis of different other fuel type indexes. □ The market for LNG is more stable than that for MGO. ▪ The price of LNG equipment should go down: LNG powered ships now require 20% more investment. In the future, this figure should go down to 5-10%.

Annex D Cost-benefit analyses: results per case study

D.1 Stockholm ferry case

Currently, in the Port of Stockholm there is one vessel that is bunkering LNG which is the Ro-Pax ferry Viking Grace, equipped with 4-stroke dual-fuel engines. The LNG is provided by means of an LNG bunkering vessel (Seagas). The LNG comes from the import terminal in Nynäshamn and is transported by truck from the import terminal to the storage facility at the Loudden energy port of the Port of Stockholm. At the storage facility the LNG bunkering vessel is loaded. Road distance between the import terminal and the storage facility is about 60 km.

In the cost-benefit analysis three bunkering infrastructure options that differ with respect to the bunkering capacity and the LNG transport between the import terminal and the ferry were analyzed (Table 57). In all three options it was assumed that the LNG-fuelled ferry has the same characteristics as the Viking Grace.

In the first option, the current LNG transport chain (truck+bunker vessel) is considered, but the LNG bunkering capacity is assumed to be higher due to more and larger tank trucks and due to an increased activity of the trucks and of the bunker vessel. In the second and third option, the LNG is no longer assumed to be transported by truck but by a bunker vessel. A larger bunker vessel is assumed to transport the LNG directly from the import terminal to the ferry. To this end, a jetty has to be built at the LNG import terminal. Option 2 and 3 differ with respect to the capacity of the bunker vessel that would replace the current bunker vessel. The distance between the Port of Stockholm and the import terminal at Nynäshamn is around 200 km over sea.

Table 57 Alternative LNG scenarios Stockholm ferry case

	Option 1	Option 2	Option 3
Bunker platform	5 tank trucks with capacity of 80 m^3, 1 bunker vessel with capacity of 175 m^3	1 bunker vessel with capacity of 1,000 m^3	1 bunker vessel with capacity of 2,000 m^3
Capacity per year	340,000 m^3	432,000 m^3	624,000 m^3

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 58 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price[43].

[43] The results for the financial and social CBA provided in the following tables do not add up due to rounding.

Table 58 Estimated LNG bunkering prices for Stockholm ferry case

LNG bunkering price	Option 1		Option 2		Option 3	
	2020	2030	2020	2030	2020	2030
Compared to LNG import price	+46%	+45%	+13%	+13%	+13%	+13%
Compared to HFO bunkering price	+29%	-12%	0%	-31%	0%	-31%
Compared to MGO bunkering price	-11%	-46%	-31%	-58%	-31%	-58%

The LNG bunkering price is expected to be the highest for Option 1 (45% mark-up in 2030 on top of LNG import price) and comparable for options 2 and 3 (about 13% mark-up).For Option 2 and 3 it holds that the LNG bunkering price is lower than the MGO bunkering price and comparable to the HFO-price. Option 1 is associated with relatively high LNG infrastructure costs which is why the LNG bunkering price is higher than the HFO bunkering price; it is still lower than the MGO bunkering price though.

Table 59 Results Financial CBA for the Stockholm ferry case (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	Option 2	Option 3	Option 1	Option 2	Option 3
Fuel cost saving	-4	9	9	27	40	40
LNG ship costs (additional CAPEX and non-fuel OPEX)	7	7	7	15	15	15
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0	0	0
Net present value	-12	+2	+1	+11	+25	+24
Pay-back period	23 yrs	9 yrs	10 yrs	8 yrs	6 yrs	6 yrs

Using an LNG-fuelled ferry instead of an MGO-fuelled ferry is a positive business case for all three infrastructure options considered, with pay-back times of around 6-8 years.

Using an LNG-fuelled ferry instead of a HFO-fuelled ferry equipped with a scrubber is a positive business case only for infrastructure options 2 and 3, with a pay-back time of around 9-10 years. For Option 1, fuel expenditures of an LNG-fuelled ferry would be higher than for the HFO-fuelled ferry, turning it into a negative business case.

The additional costs for purchasing an LNG-fuelled ferry differs between the two baseline scenarios and are higher if an MGO-fuelled ferry is taken as a reference point. However, since MGO is significantly more expensive than HFO, the overall business case is always more positive for the MGO baseline.

Social CBA

Table 60 Results Social CBA for the Stockholm ferry case (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	Option 2	Option 3	Option 1	Option 2	Option 3
Fuel cost saving	-3	14	14	40	58	57
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	189	189	189	190	190	190
LNG ship costs (additional CAPEX and non-fuel OPEX)	7	7	7	14	14	14
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Innovation/ competitiveness	Qualitative	Qualitative	Qualitative	Qualitative	Qualitative	Qualitative
Net present value	+180	+197	+197	+216	+233	+233

The net environmental benefits from using an LNG-fuelled ferry are positive for both baselines, increasing the present value of the net benefits for all options. As a consequence also Option 1 features a positive net benefit if a HFO/scrubber baseline applies. Net environmental benefits from using LNG are slightly higher if MGO is used in the baseline.

D.2 Dover/Calais ferry case

Currently, the port of Dover has no LNG infrastructure in place. In the alternative LNG scenarios it is assumed that a ferry which is used for the Dover-Calais route, will bunker LNG in the port of Calais by means of ship-to-ship bunkering. The LNG is assumed to stem from the import terminal in Dunkirk which is located nearby Calais, at around 40 km distance over sea. At the import terminal in Dunkirk, facilities for bunker ship loading are planned but have actually not been built yet.

Several bunkering infrastructure options are analyzed for the LNG scenario in Dover (Table 61). These options differ with respect to the bunkering capacity.

Table 61 Alternative LNG scenarios of Dover/Calais ferry case

Possible options	Option 1	Option 2	Option 3
Bunker platform	1 bunker vessel with capacity of 175 m^3	1 bunker vessel with capacity of 500 m^3	1 bunker vessel with capacity of 1,000 m^3
Capacity per year	144,000 m^3	384,000 m^3	528,000 m^3

In the LNG scenarios, the LNG-fuelled ferry is assumed to have the same characteristics as the Viking Grace, whereas in the reference scenario a ferry with the same engine power and energy consumption as the Viking Grace is considered.

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 62 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 62 Estimated LNG bunkering prices for Dover/Calais ferry case

LNG bunkering price	Option 1		Option 2		Option 3	
	2020	2030	2020	2030	2020	2030
Compared to LNG import price	+23%	+23%	+13%	+13%	+11%	+11%
Compared to HFO bunkering price	+9%	-25%	0%	-32%	-2%	-32%
Compared to MGO bunkering price	-25%	-54%	-31%	-58%	-32%	-58%

The expected LNG bunkering price is the highest for Option 1 and the lowest for Option 3, whereas the difference between Option 2 and Option 3 is not significant. For all options it holds that the expected LNG bunkering price is lower than the MGO bunkering price and also lower than the 2030 HFO bunkering price. For the 2020 LNG bunkering price however the options differ inasmuch as for Option 1 it is expected to be higher than, for Option 2 comparable to, and for Option 3 lower than the HFO bunkering price.

Table 63 Results Financial CBA for Dover/Calais ferry case (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	Option 2	Option 3	Option 1	Option 2	Option 3
Fuel cost saving	5	9	10	36	40	41
LNG ship costs (additional CAPEX and non-fuel OPEX)	7	7	7	15	15	15
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0	0	0
Net present value	-3	+1	+2	+20	+25	+25
Pay-back period	11 yrs	10 yrs	9 yrs	6 yrs	6 yrs	6 yrs

Using an LNG-fuelled ferry instead of an MGO-fuelled ferry is a positive business case for all three infrastructure options considered, with pay-back times of around 6 years.

Using an LNG-fuelled ferry instead of a HFO-fuelled ferry equipped with a scrubber is also a positive business case for infrastructure Options 2 and 3, with a pay-back time of around 9-10 years, however not a positive business case for Option 1.

The additional costs for purchasing an LNG-fuelled ferry differs between the two baseline scenarios and are higher if an MGO-fuelled ferry is taken as a reference point. However, since MGO is significantly more expensive than HFO, the overall business case is always more positive for the MGO baseline.

Social CBA

Table 64 Results Social CBA for Dover/Calais ferry case (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	Option 2	Option 3	Option 1	Option 2	Option 3
Fuel cost saving	10	14	15	54	58	58
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	189	189	189	190	190	190
LNG ship costs (additional CAPEX and non-fuel OPEX)	7	7	7	14	14	14
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Innovation/competitiveness	qualitative	qualitative	qualitative	qualitative	qualitative	qualitative
Net present value	+192	+197	+197	+229	+233	+234

Net environmental benefits from using an LNG-fuelled ferry are positive for both baselines, increasing the present value of the net benefits for all options. As a consequence, also Option 1 features a positive net benefit if a HFO/scrubber baseline applies. Net environmental benefits from using LNG are slightly higher if MGO is used in the baseline.

D.3 Civitavecchia ferry and cruise vessel case

Currently, there is no LNG supply infrastructure in place in the Port of Civitavecchia, but an LNG-fuelled ship, a tug boat, has been fuelled with LNG once, making use of tank-to-truck bunkering. The LNG used had been delivered by truck from Zeebrugge.

Two LNG scenarios are differentiated in the cost-benefit analysis (Table 65). In both options ship-to-ship bunkering is applied, but the size of the bunkering vessel differs. In the first option, which is the option with the small bunkering vessel, only ferries are assumed to bunker LNG, since the capacity is not sufficient for cruise ships. In the second option, with the larger bunkering vessel, either ferries or cruise ships are assumed to bunker LNG in the Port of Civitavecchia.

For both options it is assumed that storage tanks, including a pipeline and a jetty to enable loading a bunkering ship, are built in the port and that a short sea vessel supplies these tanks with LNG which stems from the LNG import terminal Panigaglia nearby La Spezia. To this end facilities for the loading of the short sea ships would need to be built at the import terminal first. Sea distance between La Spezia and the Port of Civitavecchia is around 290 km.

Table 65 Alternative LNG scenarios Civitavecchia ferries and cruise vessels

Possible options	Option 1	Option 2
Bunker platform	1 bunker vessel with capacity of 1,000 m^3	1 bunker vessel with capacity of 3,000 m^3
Capacity per year	768,000 m^3 for ferries	912,000 m^3 for ferries or 3,800,000 m^3 for cruise vessels

The LNG bunkering price for both is estimated to constitute a 9% increase of the LNG import price if only ferries are taken into account and a 4% increase of the LNG import price if, for the second option, only cruise vessels are considered.

In the alternative LNG scenario, the Viking Grace is taken as the reference LNG-fuelled ferry and regarding the cruise ship, a cruise vessel with the same engine power and energy consumption as the Costa Favolosa, a (not LNG-fuelled) cruise ship that is calling at Civitavecchia on a regular basis, is considered.

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 66 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 66 Estimated LNG bunkering prices in the Civitavecchia ferry case

LNG bunkering price	Option 1		Option 2	
	2020	2030	2020	2030
Compared to LNG import price	+16%	+16%	+16%	+16%
Compared to HFO bunkering price	+3%	-29%	+2%	-30%
Compared to MGO bunkering price	-29%	-56%	-29%	-57%

The LNG bunkering prices are expected to be similar for both options (16% mark-up on LNG import price), leading to a 2020 LNG bunkering price that is slightly higher than the HFO-price and about 30% lower than the MGO price and to a 2030 LNG bunkering price that is approximately 30% lower than the HFO-price and approximately 60% lower than the MGO price.

Table 67 Results Financial CBA for the Civitavecchia ferry case (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	**Option 2**	**Option 1**	**Option 2**
Fuel cost saving	8	8	39	39
LNG ship costs (additional CAPEX and non-fuel OPEX)	7	7	15	15
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0
Net present value	0.0	0.0	+24	+24
Pay-back period	10 yrs	10 yrs	6 yrs	6 yrs

Using an LNG-fuelled ferry instead of an MGO-fuelled ferry is a positive business case for both infrastructure options considered, with pay-back times of 6 years.

Using an LNG-fuelled ferry instead of a HFO-fuelled ferry equipped with a scrubber is also a (slightly) positive business case for both options with net benefits however being relatively low pay-back times of around 10 years.

The additional costs for purchasing an LNG-fuelled ferry differs between the two baseline scenarios and are higher if an MGO-fuelled ferry is taken as a reference point. However, since MGO is significantly more expensive than HFO, the overall business case is always more positive for the MGO baseline.

Table 68 Estimated LNG bunkering prices for the Civitavecchia cruise vessel case

LNG bunkering price	Option 2	
	2020	**2030**
Compared to LNG import price	+11%	+11%
Compared to HFO bunkering price	-2%	-33%
Compared to MGO bunkering price	-32%	-59%

Since the annual LNG bunkering capacity turns out to be higher if cruise vessels and not ferries are bunkered in the Port of Civitavecchia, the LNG bunkering price for Option 2 turns out to be lower than for the ferry case (see Option 2 in Table 66). As a consequence, the price difference between LNG and HFO and between LNG and MGO is lower in the cruise vessel case too (see for an explanation Section 4.3).

Table 69 Results Financial CBA for the Civitavecchia cruise vessel case (in million euro PV at 10% discount rate)

	Compared to HFO +scrubber	Compared to MGO
	Option 2	**Option 2**
Fuel cost saving	25	98
LNG ship costs (additional CAPEX and non-fuel OPEX)	16	35
Difference wage cost technical personnel	PM	PM
Difference safety measures	PM	PM
Evaporation of LNG	PM	PM
Financial policies/discounts	0	0
Net present value	+9	+63
Pay-back period	8 yrs	5 yrs

Using an LNG-fuelled cruise vessel instead of a HFO-fuelled cruise vessel equipped with a scrubber or instead of an MGO-fuelled cruise vessel is a positive business case for the LNG bunkering infrastructure option (Option 2) considered here, with a pay-back time of 8 and 5 years respectively.

The additional investment costs are higher when comparing LNG to MGO than to HFO combined with a scrubber. However, since MGO is significantly more expensive than HFO, the overall business case is always more positive for the MGO baseline.

Social CBA

Table 70 Results Social CBA for the Civitavecchia ferry case (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	Option 2	Option 1	Option 2
Fuel cost saving	14	14	58	58
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	190	190	192	192
LNG ship costs (additional CAPEX and non-fuel OPEX)	7	7	14	14
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Innovation/competitiveness	qualitative	qualitative	qualitative	qualitative
Net present value	+198	+198	+235	+235

Table 71 Results Social CBA for the Civitavecchia cruise vessel case (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber	Compared to MGO
	Option 2	Option 2
Fuel cost saving	40	142
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	454	455
LNG ship costs (additional CAPEX and non-fuel OPEX)	15	33
Stranded assets MGO bunkering	PM	PM
Difference wage cost technical personnel	PM	PM
Difference safety measures	PM	PM
Evaporation of LNG	PM	PM
Innovation/competitiveness	qualitative	qualitative
Net present value	+478	+564

Net environmental benefits from using an LNG-fuelled cruise vessel are positive for both baselines, increasing the present value of the net benefits for all options. Net environmental benefits from using LNG are slightly higher if MGO is used in the baseline.

D.4 Southampton cruise vessel case

Currently, there is no LNG infrastructure in place in the Port of Southampton and the port has no plans for investing into LNG infrastructure.

In the two LNG scenarios (Table 72) it is assumed that LNG bunkering via ship-to-ship bunkering is offered in the port since this is the only workable LNG bunkering method for cruise ships. LNG is assumed to stem from Grain LNG import terminal situated on the Isle of Grain (UK) which lies at a sea distance of around 325 km from the Port of Southampton. The LNG is assumed to be transported with a short sea LNG supply vessel from the import terminal to the Port of Southampton where it is stored in storage tanks.

Table 72 Alternative LNG scenarios

Possible options	Option 1	Option 2
Bunker platform	1 bunker vessel with capacity of 3,000 m^3	1 bunker vessel with capacity of 10,000 m^3
Capacity per year	3,800,000 m^3	5,550,000 m^3

In the two LNG scenarios and in the reference scenario a cruise ship with the same characteristic in terms of engine power and energy consumption as the Costa Favolosa is assumed (see Annex C).

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 73 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 73 Estimated LNG bunkering prices for Southampton cruise vessel case

LNG bunkering price	Option 1		Option 2	
	2020	2030	2020	2030
Compared to LNG import price	+10%	+10%	+10%	+10%
Compared to HFO bunkering price	-3%	-33%	-3%	-33%
Compared to MGO bunkering price	-33%	-59%	-33%	-59%

The LNG bunkering price is expected to be about 10% higher than the LNG import price for both infrastructure options, leading to an expected 2020 LNG bunkering price that is around 3% lower than the HFO-price and about 33% lower than the MGO price and to an expected 2030 LNG bunkering price that is about 33% lower than the HFO-price and about 60% lower than the MGO price.

Table 74 Results Financial CBA for Southampton cruise vessel case (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	Option 2	Option 1	Option 2
Fuel cost saving	25	25	99	99
LNG ship costs (additional CAPEX and non-fuel OPEX)	16	16	35	35
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0
Net present value	+9	+9	+63	+63
Pay-back period	8 yrs	8 yrs	5 yrs	5 yrs

For both LNG infrastructure options and for both baselines it holds that using an LNG-fuelled cruise vessel is a positive business case.

If the reference point is a HFO-fuelled cruise vessel equipped with a scrubber, the pay-back time is around 8 years, whereas if the reference point is an MGO-fuelled cruise vessel, the pay-back time is lower, around 5 years.

The additional costs for purchasing an LNG-fuelled cruise vessel differs between the two baseline scenarios and are higher if an MGO-fuelled cruise vessel is taken as a reference point. However, since MGO is significantly more expensive than HFO, the overall business case is always more positive for the MGO baseline.

Social CBA

Table 75 Results Social CBA for Southampton cruise vessel case (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	**Option 2**	**Option 1**	**Option 2**
Fuel cost saving	40	41	143	143
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	454	454	455	455
LNG ship costs (additional CAPEX and non-fuel OPEX)	15	15	33	33
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Innovation/competitiveness	qualitative	qualitative	qualitative	qualitative
Net present value	+480	+480	+565	+565

Net environmental benefits from using an LNG-fuelled cruise vessel are positive for both baselines, increasing the present value of the net benefits for all options. Net environmental benefits from using LNG are slightly higher if MGO is used in the baseline.

D.5 Kristiansand Platform Supply Vessel case

Currently, LNG is incidentally bunkered in the Port of Kristiansand via truck-to-ship bunkering. The port has planned to invest in an LNG storage tank and a bunkering vessel in the future.

Three alternative LNG scenarios are differentiated in the cost-benefit analysis (Table 76). In the first scenario, the short run scenario, an LNG-fuelled PSV is assumed to bunker LNG via truck-to-ship bunkering and the LNG is assumed to stem from the import terminal in Øra (Fredriksstad, Norway) that is located at a road distance of around 230 km from the Port of Kristiansand.

In Scenarios 2 and 3, ship-to-ship bunkering is considered and it is assumed that an LNG storage tank is built in the Port of Kristiansand. The LNG is assumed to stem from the import terminals in Øra (Fredrikstad, Norway) which is located at a sea distance of around 220 km from the Port of Kristiansand where facilities for LNG ship loading are already in place. The LNG is in both options assumed to be transported by short sea vessel from the import terminal to the storage tank.

Table 76 Alternative LNG scenarios Kristiansand PSVs

Possible options	Option 1	Option 2	Option 3
Bunker platform	3 tank trucks with capacity of 80 m^3	1 bunker vessel with capacity of 500 m^3	1 bunker vessel with capacity of 1,000 m^3
Capacity per year	130,000 m^3	560,000 m^3	710,000 m^3

In the three LNG scenarios as well as in the baseline scenario, an LNG-fuelled PSV vessel is assumed to be used that has the same characteristics as the Viking Princess in terms of engine power and fuel consumption.

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 77 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 77 Estimated LNG bunkering prices for Kristiansand PSV case

LNG bunkering price	Option 1		Option 2		Option 3	
	2020	2030	2020	2030	2020	2030
Compared to LNG import price	+42%	+40%	+16%	+16%	+15%	+15%
Compared to HFO bunkering price	+25%	-15%	+2%	-30%	+2%	-30%
Compared to MGO bunkering price	-13%	-47%	-29%	-57%	-30%	-57%

The estimated LNG bunkering price is relatively high for LNG infrastructure Option 1 compared to Option 2 and Option 3 with the latter two options resulting in similar LNG bunkering prices (about 15% higher than LNG import price). The expected 2020 LNG bunkering price is nevertheless higher than the HFO-price for all of the three infrastructure options. This is not the case for 2030 where the LNG bunkering price is expected to be lower than the HFO-price for all three options.

For all three options it also holds that, for 2020 and for 2030, the expected LNG bunkering price is lower than the MGO price.

Table 78 Results Financial CBA for Kristiansand PSV case (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	-0.5	2	2	7	10	10
LNG ship costs (additional CAPEX and non-fuel OPEX	2	2	2	4	4	4
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM

	Compared to HFO + scrubber			Compared to MGO		
Financial policies/discounts	0	0	0	0	0	0
Net present value	-2	0	0	+4	+6	+6
Pay-back period	18 yrs	9 yrs	9 yrs	7 yrs	5 yrs	5 yrs

If a HFO-fuelled platform supply vessel equipped with scrubber is taken as reference point, using an LNG-fuelled PSV is a positive business case for Option 2 and Option 3 (around 9 years pay-back time and relative low net benefits respectively), whereas it is not a positive business case for Option 1. This can be explained by the relative high LNG bunkering price in Option 1.

If an MGO-fuelled PSV is the reference point, the business case is positive for all three options, i.e. even for Option 1, with pay-back times between 5 and 7 years.

Social CBA

Table 79 Results Social CBA for Kristiansand PSV case (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	-0.2	4	4	11	15	15
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	48	48	48	48	48	48
LNG ship costs (additional CAPEX and non-fuel OPEX)	2	2	2	3	3	3
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Innovation/ competitiveness	qualitative	qualitative	qualitative	qualitative	qualitative	qualitative
Net present value	+46	+50	+50	+55	+59	+59

Net environmental benefits from using an LNG-fuelled PSV are positive for both baselines, increasing the present value of the net benefits for all options. As a consequence also Option 1 features a positive net benefit if a HFO/scrubber baseline applies. Net environmental benefits from using LNG are slightly higher if MGO is used in the baseline.

D.6 Marseille cruise and container vessel case

The port of Marseille is currently not investing in LNG bunkering. In the baseline scenario, cruises use HFO or MGO as bunkering fuel and LNG in the alternative options. Newly built LNG-fuelled cruises are considered to be feasible in 2025. For the alternative LNG options, two STS-bunkering options with different capacities are taken into account (Table 80). In these options, the Costa Favolosa is taken as a reference vessel, consuming 90,824 m3 LNG per year.

Table 80 Alternative LNG options Marseille cruise ships

Possible options	Option 1	Option 2
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3
Capacity per year	3,800,000 m^3	5,550,000 m^3

For container vessels, the options that are taken into account are STS- and PTS bunkering (Table 81). Next to that, the Nordic Hamburg LNG powered container vessel is used as reference vessel, considering an annual consumption of 10,988 m^3 LNG and 180 m^3 MGO.

Table 81 Alternative LNG options Marseille container vessels

Possible options	Option 1	Option 2	Option 3
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3	Shore-to-ship via a jetty and loading arm
Capacity per year	2,500,000 m^3	3,600,000 m^3	2,150,000 m^3

In the LNG options for bunkering cruise ships as well as container vessels, LNG is imported from the import terminal at Fos. For both types of vessels, no additional infrastructure is needed besides the bunkering vessel and pipelines depending on the type of bunkering.

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 82 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 82 LNG bunkering prices in Marseille (container vessels)

LNG bunkering price	Option 1		Option 2		Option 3	
	2020	2030	2020	2030	2020	2030
Compared to LNG import price	+8%	+8%	+8%	+8%	+6%	+6%
Compared to HFO bunkering price	-5%	-34%	-5%	-35%	-6%	-35%
Compared to MGO bunkering price	-34%	-60%	-34%	-60%	-35%	-60%

Both Option 1 and 2 describe the additional bunkering costs due to investments in ship-to-ship bunkering infrastructure, which is 8% of the LNG import price. The mark-up on the import price in case of pipeline-to-ship bunkering (Option 3) is lower (6%) compared to STS-bunkering. Comparison of the 2030 LNG bunkering price with the both HFO and MGO bunkering price shows that for all options the LNG bunkering price is about 35% lower than the HFO-price and about 60% lower than the MGO price.

Table 83 Results Financial CBA container vessels Marseille (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	2	2	3	11	11	12
LNG ship costs (additional CAPEX and non-fuel OPEX)	4	4	4	6	6	6
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0	0	0
Net present value	-2	-2	-1	+5	+5	+5
Pay-back period	12 yrs	12 yrs	12 yrs	7 yrs	7 yrs	7 yrs

The results of the financial CBA shows that LNG bunkering provides benefits due to the price difference between LNG and HFO/MGO. These benefits are larger when compared to MGO bunkering due to higher MGO bunkering price. In addition, the additional investment costs for LNG-fuelled container vessels are lower than the benefits from LNG bunkering compared to a MGO-fuelled vessel, resulting in a positive NPV. The additional cost for an LNG-fuelled container vessel are lower when compared to a vessel using HFO including a scrubber (and not MGO), however, the benefits from LNG bunkering are not high enough to result in a positive NPV.

Table 84 Estimated LNG bunkering prices in Marseille (cruise ships)

LNG bunkering price	Option 1		Option 2	
	2020	**2030**	**2020**	**2030**
Compared to LNG import price	+8%	+8%	+7%	+7%
Compared to HFO bunkering price	-5%	-35%	-5%	-35%
Compared to MGO bunkering price	-34%	-60%	-34%	-60%

Both Option 1 and 2 describe the additional bunkering costs due to investments in ship-to-ship LNG bunkering infrastructure, which is 7-8% of the LNG import price. Comparison of the 2030 LNG bunkering price with both HFO and MGO bunkering price shows that the LNG bunkering price is 35% lower than the HFO-price and 60% lower than the MGO price. The estimated LNG bunkering prices in case of cruise ships are comparable to the case of container vessels.

Table 85 Results Financial CBA cruise ships Marseille (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	**Option 2**	**Option 1**	**Option 2**
Fuel cost saving	23	23	102	102
LNG ship costs (additional CAPEX and non-fuel OPEX)	16	16	36	36
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0
Net present value	+7	+7	+66	+66
Pay-back period	9 yrs	9 yrs	5 yrs	5 yrs

The results of the financial CBA shows that LNG bunkering provides large benefits due to the bunkering price difference between LNG and HFO/MGO. These benefits are larger when compared to MGO bunkering due to a higher MGO price. In addition, the additional investment costs for LNG-fuelled cruise ships are lower than the benefits from LNG bunkering resulting in a positive NPV.

Social CBA

Table 86 Results Social CBA container vessels Marseille (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	3	4	4	16	16	17
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	50	50	50	-52	-52	-52
LNG ship costs (additional CAPEX and non-fuel OPEX)	4	4	4	6	6	6
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Innovation/ competitiveness	qualitative	qualitative	qualitativ e	qualitative	qualitative	qualitative
Net present value	+49	+50	+50	+63	+63	+63

The results of the social CBA show more or less the same results for LNG ship costs and fuel cost difference, with an addition of the emission reduction value, resulting in positive NPVs for all options and compared to both baseline marine fuels. From a social perspective, it is beneficial to invest in LNG as a bunkering fuel for container vessels in Marseille.

**Table 87	Results Social CBA cruise ships Marseille (in million euro PV at 3% discount rate)**

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	**Option 2**	**Option 1**	**Option 2**
Fuel cost saving	35	35	145	145
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	430	430	455	455
LNG ship costs (additional CAPEX and non-fuel OPEX)	15	15	33	33
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Innovation/competitiveness	qualitative	qualitative	qualitative	qualitative
Net present value	+451	+451	+566	+566

The results of the social CBA show more or less the same results for LNG ship costs and fuel cost difference, with an addition of the emission reduction value, resulting in a large positive NPV for all options for both baseline marine fuels. From a social perspective, it is beneficial to invest in LNG as a bunkering fuel for cruise vessels in Marseille.

D.7 Antwerp container vessel case

Currently, LNG bunkering is possible for inland shipping ships, with LNG supplied from Zeebrugge, while other types of ships, such as the Hanse Courage as reference vessel, bunker MGO. In the alternative options (Table 88), LNG is used as bunker fuel, assuming the Nordic Hamburg LNG powered container vessel as reference vessel, with an annual consumption of 90,824 m^3 LNG.

**Table 88	Alternative LNG options Antwerp container vessels**

Possible options	Option 1	Option 2
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3
Capacity per year	1,900,000 m^3	3,250,000 m^3

In the LNG options, (short-sea) container vessels will be bunkered by ship-to-ship bunkering, and LNG will be supplied from Zeebrugge by bunker vessels. The investments required are the bunkering vessels needed to transport LNG from Zeebrugge to Antwerp where the container vessels are bunkered.

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 89 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 89 Estimated LNG bunkering prices in Antwerp

LNG bunkering price	Option 1		Option 2	
	2020	2030	2020	2030
Compared to LNG import price	+8%	+8%	+6%	+6%
Compared to HFO bunkering price	-4%	-34%	-6%	-36%
Compared to MGO bunkering price	-34%	-60%	-35%	-60%

The additional costs on top of the LNG import price due to the investments in LNG infrastructure are higher in the case of STS-bunkering with a small bunkering vessel (Option 1) compared to a larger bunkering vessel (Option 2). On the other hand, the capacity of LNG bunkering plays an important role in determining the LNG bunkering price which explains the difference between the two options of STS-bunkering.
The 2030 LNG bunkering price is 35% lower than the HFO bunkering price and 60% lower than the MGO bunkering price.

Table 90 Results Financial CBA container vessels Antwerp (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	Option 2	Option 1	Option 2
Fuel cost saving	2	2	11	11
LNG ship costs (additional CAPEX and non-fuel OPEX)	3	3	6	6
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0
Net present value	-1	-1	+5	+5
Pay-back period	12 yrs	11 yrs	7 yrs	7 yrs

The results of the financial CBA for container vessels in Antwerp show that the fuel cost difference is larger than the additional ship investment costs, resulting in a positive NPV in case of the MGO baseline. For the HFO baseline, however, the fuel cost difference is not sufficient to overcompensate the additional investment costs, resulting in a negative NPV. Although the additional investment costs are larger when compared to MGO-fuelled ships, the benefits from the difference in bunkering prices are much larger compared to HFO bunkering, resulting in a higher NPV.

Social CBA

Table 91 Results Social CBA container vessels Antwerp (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber		Compared to MGO	
	Option 1	**Option 2**	**Option 1**	**Option 2**
Fuel cost saving	3	3	16	16
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	50	50	55	55
LNG ship costs (additional CAPEX and non-fuel OPEX)	3	3	6	6
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM
Innovation/competitiveness	qualitative	qualitative	qualitative	qualitative
Net present value	+50	+50	+65	+65

The results of the social CBA for container vessels in Antwerp show large benefits from emission reduction resulting in a positive NPV for both bunkering options. From a social perspective, it is beneficial to invest in LNG as a bunkering fuel for container vessels in the port of Antwerp.

D.8 Constanta container vessel case

Currently there is no LNG bunkering or LNG infrastructure at this port. It is assumed that typical container vessels use MGO as fuel in the current situation. The port of Constanta is gaining expertise in LNG and planning to invest in an LNG import terminal in the coming decade. The use of LNG is expected to be feasible for newly built container vessels. Again, the Nordic Hamburg LNG powered container vessel is used as a reference vessel, considering an annual consumption of 10,988 m^3 LNG and 180 m^3 MGO.

Table 92 Alternative LNG options Constanta container vessels

Possible options	Option 1	Option 2	Option 3
Bunker platform	1 Bunker vessel with capacity of 3,000 m^3	1 Bunker vessel with capacity of 10,000 m^3	Shore-to-ship via a jetty and loading arm
Capacity per year	2,500,000 m^3	3,600,000 m^3	2,150,000 m^3

In the case of LNG bunkering, LNG can be currently supplied from the import terminal in Ereglisi (Turkey) via short sea supply vessels and bunkering can happen ship-to-ship or shore-to-ship. In the future an import terminal will be built in Constanta, allowing for STS and PTS bunkering. This will be taken into account in the three options (Table 92).

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 93 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 93 Estimated LNG bunkering prices in Constanta

LNG bunkering price	Option 1		Option 2		Option 3	
	2020	2030	2020	2030	2020	2030
Compared to LNG import price	+8%	+8%	+8%	+8%	+195%	+195%
Compared to HFO bunkering price	-4%	-34%	-4%	-34%	+161%	+79%
Compared to MGO bunkering price	-34%	-59%	-34%	-60%	+80%	+10%

The estimated LNG bunkering price is comparable for the STS-bunkering Options 1 and 2 (about 8% mark-up on top of the LNG import price). These results are also in the same range as LNG bunkering of container vessels with the STS-method in previously studied case ports. Investing in PTS-infrastructure however shows a significantly large increase of the LNG bunkering price compared to the import price. The bunkering price of LNG in Option 3 is higher than the HFO and the MGO bunkering price due to large investments in PTS bunkering and the lower capacity used.

Table 94 Results Financial CBA container vessels Constanta (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	2	2	-20	10	10	-11
LNG ship costs (additional CAPEX and non-fuel OPEX)	3	3	3	6	6	6
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0	0	0
Net present value	-1	-1	-22	+4	+4	-17
Pay-back period	12 yrs	12 yrs	-	8 yrs	8 yrs	-

The results of the financial CBA for LNG-fuelled container vessels in the Port of Constanta show positive results for STS-bunkering options in case of the MGO baseline and negative NPVs for the STS-bunkering options in case of the HFO baseline as well as for the PTS bunkering options, independent of the baseline. The relatively high LNG bunkering price in case of the PTS bunkering makes investing into an LNG-fuelled container vessel a negative business case. Only if STS-bunkering infrastructure is in place could an investment in an LNG-fuelled container vessels be a positive business case in the port of Antwerp. However, only if a container vessel was MGO-fuelled in the baseline.

Social CBA

Table 95 Results Social CBA container vessels Constanta (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	4	3	-21	15	15	-9
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	50	50	50	52	52	52
LNG ship costs (additional CAPEX and non-fuel OPEX)	3	3	3	6	6	6
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Innovation/ competitiveness	qualitative	qualitative	qualitative	qualitative	qualitative	qualitative
Net present value	+51	+50	+27	+61	+61	+37

The results of the social CBA for LNG-fuelled container vessels show, in contrast to the financial CBA, positive results for all options and both baseline fuels due to the benefits from emission reduction. From a social perspective, it is thus beneficial to invest in LNG as bunkering fuel for container vessels in the Port of Constanta.

D.9 HaminaKotka general cargo vessel case

Currently there is no LNG infrastructure in place in the port, but a LNG import terminal will be in operation in the future. In the baseline scenario, a typical cargo vessel (such as the Diamant) uses HFO as fuel. In the alternative options, the cargo vessels use LNG as bunkering fuel, assuming annual LNG consumption of 10,000 m^3 LNG (standard size cargo vessel).

Table 96 Alternative LNG options HaminaKotka cargo vessels

Possible options	Option 1	Option 2	Option 3
Bunker platform	1 Bunker vessel with capacity of 1,000 m^3	1 Bunker vessel with capacity of 3,000 m^3	Shore-to-ship via a jetty and loading arm
Capacity per year	970,000 m^3	1,710,000 m^3	2,090,000 m^3

In the LNG options, LNG can be supplied from an import terminal in Nynsham (Sweden) or from the planned terminals in Finland and Estonia via a bunkering vessel. In 2018 the port is expected to have an import terminal with a capacity of 30,000 m^3. This is taken into account in the options for LNG-fuelled cargo vessels, bunkered using ship-to-ship bunkering or shore-to-ship bunkering (Table 96).

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 97 a comparison is presented between the estimated LNG bunkering price, the LNG import price and the HFO/MGO bunkering price.

Table 97 Estimated LNG bunkering prices in HaminaKotka

LNG bunkering price	Option 1		Option 2		Option 3	
	2020	2030	2020	2030	2020	2030
Compared to LNG import price	+15%	+15%	+12%	+12%	+383%	+383%
Compared to HFO bunkering price	+2%	-31%	-1%	-32%	+327%	+193%
Compared to MGO bunkering price	-30%	-57%	-32%	-58%	+195%	+81%

For STS-bunkering (Option 1 and 2), the mark-up on top of the LNG import price lies in the range of +12-15% and the estimated 2030 LNG bunkering price is about 30% lower than the HFO bunkering price and about 60% lower than the MGO bunkering price.

For PTS bunkering (Option 3) the estimated LNG bunkering price is much higher, almost 400% above the LNG import price and thus also higher than the HFO and the MGO bunkering price.

Table 98 Results Financial CBA general cargo vessels HaminaKotka (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	Option 2	Option 3	Option 1	Option 2	Option 3
Fuel cost saving	2	3	-36	10	11	-28
LNG ship costs (additional CAPEX and non-fuel OPEX)	1	1	1	3	3	3
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Financial policies/discounts	0	0	0	0	0	0
Net present value	+1	+1	-37	+7	+8	-31
Pay-back period	8 yrs	7 yrs	-	5 yrs	5 yrs	-

The results show that in case of STS-bunkering (Option 1 and 2), investing in an LNG-fuelled cargo vessel is a positive business case, independent of the baseline. The PTS bunkering option results in a negative NPV due to the additional costs of fuel bunkering caused by the significant increase of LNG bunkering price compared to the bunkering prices of HFO and MGO.

Social CBA

Table 99 Results Social CBA general cargo vessels HaminaKotka (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber			Compared to MGO		
	Option 1	**Option 2**	**Option 3**	**Option 1**	**Option 2**	**Option 3**
Fuel cost saving	4	4	-17	15	15	-6
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	50	50	50	50	50	50
LNG ship costs (additional CAPEX and non-fuel OPEX)	1	1	1	3	3	3
Stranded assets HFO/MGO bunkering	PM	PM	PM	PM	PM	PM
Difference wage cost technical personnel	PM	PM	PM	PM	PM	PM
Difference safety measures	PM	PM	PM	PM	PM	PM
Evaporation of LNG	PM	PM	PM	PM	PM	PM
Innovation/competitiveness	qualitative	qualitative	qualitative	qualitative	qualitative	qualitative
Net present value	+52	+52	+31	+62	+62	+40

The results of the social CBA for LNG-fuelled general cargo vessels in the HaminaKotka show, in contrast to the financial CBA, positive results for both baseline fuels and all options, thus even for the PTS bunkering option.

D.10 Cartagena cargo vessel case

The port of Cartagena already has an LNG import terminal where vessels are bunkered via truck-to-ship bunkering. In the future, shore-to-ship bunkering is planned to be used. It is expected to be feasible for newly built ships. In the baseline scenario, the container vessels, such as the RBD Dalmatia, use HFO as fuel. In the LNG option, shore-to-ship bunkering is analyzed (Table 100), for cargo vessels fuelled by LNG and assuming annual LNG consumption of 10,000 m^3 LNG (standard size cargo vessel).

Table 100 Alternative LNG options Cartagena cargo vessels

Possible options	Option 1
Bunker platform	Shore-to-ship via a jetty and loading arm
Capacity per year	2,090,000 m^3

Financial CBA

Calculating the LNG bunkering price by adding the LNG infrastructure costs to the import price, gives different estimations of LNG bunkering prices for the different infrastructure options. In Table 102 an overview is given on how the estimated LNG bunkering price compares to the LNG import price and the HFO/MGO bunkering price.

Table 101 Estimated LNG bunkering prices in Cartagena

LNG bunkering price	Option 1	
	2020	**2030**
Compared to LNG import price	+7%	+7%
Compared to HFO bunkering price	-6%	-35%
Compared to MGO bunkering price	-35%	-60%

Investing in PTS bunkering for cargo vessels in Cartagena does lead to an increase in LNG price compared to the import price of about 7%, however, the LNG bunkering price is still lower than the HFO or MGO bunkering price (in 2030 35 and 60% respectively). This means that this bunkering option does have benefits in fuel cost difference as is shown in the results of the financial and social CBA.

Table 102 Results Financial CBA cargo vessels Cartagena (in million euro PV at 10% discount rate)

	Compared to HFO + scrubber	Compared to MGO
	Option 1	Option 1
Fuel cost saving	3	12
LNG ship costs (additional CAPEX and non-fuel OPEX)	1	3
Difference wage cost technical personnel	PM	PM
Difference safety measures	PM	PM
Evaporation of LNG	PM	PM
Financial policies/discounts	0	0
Net present value	+2	+9
Pay-back period	6 yr	4 yrs

The financial CBA shows a positive NPV for LNG bunkering infrastructure with the PTS-method, independent of whether MGO or HFO is used in the baseline.

Social CBA

Table 103 Results Social CBA cargo vessels Cartagena (in million euro PV at 3% discount rate)

	Compared to HFO + scrubber	Compared to MGO
	Option 1	**Option 1**
Fuel cost saving	5	17
Net environmental benefit (CO_2, CH_4, SO_x, NO_x, PM)	50	52
LNG ship costs (additional CAPEX and non-fuel OPEX)	1	3
Stranded assets HFO/MGO bunkering	PM	PM
Difference wage cost technical personnel	PM	PM
Difference safety measures	PM	PM
Evaporation of LNG	PM	PM
Innovation/competitiveness	qualitative	qualitative
Net present value	+53	+66

The social CBA shows a positive NPV for LNG bunkering infrastructure with the PTS-method, independent of whether MGO or HFO is used in the baseline.

D.11 Results sensitivity analysis

NPV results baseline scenario

Baseline	**Stockholm - ferry**		**Dover - ferry**		**Civittavecchi - ferry**		**Civittavecchi - cruise**		**South-ampton - cruise**		**Kristiansand - supply vessel**		**Marseille - container**		**Marseille - cruise**		**Constanta - container**		**Antwerp - container**		**Cartagena - cargo**		**HaminaKotka - cargo**	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	11	-12	20	-3	24	0			63	9	4	-2	5	-2	66	7	4	-1	5	-1	9	2	7	1
FNPV (Option 2)	25	2	25	1	24	0	63	9	63	9	6	0	5	-2	67	7	4	-1	5	-1			8	1
FNPV (Option 3)	24	1	25	2							6	0	5	-1			-17	-22					-31	-37
ENPC (Option 1)	216	180	229	192	235	198			565	479	55	46	63	49	566	451	61	51	65	50	67	53	62	52
ENPC (Option 2)	233	197	233	197	235	198	564	479	565	479	59	50	63	50	566	451	61	50	65	50			62	52
ENPC (Option 3)	233	197	234	197							59	50	63	50			37	27					41	31

NPV results sensitivity Scenario 1

Lower LNG price	**Stockholm - ferry**		**Dover - ferry**		**Civittavecchi - ferry**		**Civittavecchi - cruise**		**South-ampton - cruise**		**Kristiansand - supply vessel**		**Marseille - container**		**Marseille - cruise**		**Constanta - container**		**Antwerp - container**		**Cartagena - cargo**		**HaminaKotka - cargo**	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	21	-2	30	7	34	10			87	33	6	0	8	1	90	31	7	2	8	2	12	4	10	4
FNPV (Option 2)	34	11	34	11	34	10	87	32	87	33	9	3	8	1	90	31	7	2	8	2			10	4
FNPV (Option 3)	34	11	35	12							9	3	8	2			-14	-19					-28	-35
ENPC (Option 1)	229	193	242	206	249	212			597	511	59	49	67	53	598	483	65	55	69	54	70	57	66	56
ENPC (Option 2)	246	210	247	210	249	212	596	510	597	511	62	53	67	54	598	483	65	54	69	54			66	56
ENPC (Option 3)	246	210	247	210							63	53	67	54			41	30					44	34

Higher LNG price	**Stockholm - ferry**		**Dover - ferry**		**Civittavecchi - ferry**		**Civittavecchi - cruise**		**South-ampton - cruise**		**Kristiansand - supply vessel**		**Marseille - container**		**Marseille - cruise**		**Constanta - container**		**Antwerp - container**		**Cartagena - cargo**		**HaminaKotka - cargo**	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	2	-21	11	-13	14	-10			40	-15	1	-5	2	-5	43	-17	1	-4	2	-4	7	-1	5	-2
FNPV (Option 2)	15	-8	15	-9	14	-10	39	-15	40	-14	4	-2	2	-5	43	-17	1	-4	2	-3			5	-1
FNPV (Option 3)	14	-9	15	-89							4	-2	3	-4			-20	-25					-34	-40
ENPC (Option 1)	203	167	216	179	222	185			533	448	52	43	59	45	535	420	57	47	61	46	63	50	59	49
ENPC (Option 2)	220	184	220	184	222	185	533	447	534	448	56	47	59	46	535	420	57	46	61	47			59	49
ENPC (Option 3)	220	183	221	184							56	47	59	47			34	23					37	27

NPV results sensitivity Scenario 2

Lower scrubber costs	Stockholm - ferry		Dover - ferry		Civittavecchi - ferry		Civittavecchi - cruise		South-ampton - cruise		Kristiansand - supply vessel		Marseille - container		Marseille - cruise		Constanta - container		Antwerp - container		Cartagena - cargo		HaminaKotka - cargo	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	11	-16	20	-7	24	-4			63	-1	4	-3	5	-4	66	-3	4	-3	5	-3	9	1	7	0
FNPV (Option 2)	25	-3	25	-3	24	-4	63	-1	63	0	6	-1	5	-4	66	-3	4	-3	5	-2			8	0
FNPV (Option 3)	24	-3	25	-2							6	0	5	-3			-17	-24					-31	-38
ENPC (Option 1)	216	176	229	189	235	195			565	470	55	45	63	47	566	442	61	49	65	48	67	52	62	51
ENPC (Option 2)	233	193	233	193	235	195	564	469	565	470	59	49	63	48	566	442	61	48	65	49			62	52
ENPC (Option 3)	233	193	234	194							59	49	63	49			37	25					41	30

NPV results sensitivity Scenario 3

Lower financial discount rate	**Stockholm - ferry**		**Dover - ferry**		**Civittavecchi - ferry**		**Civittavecchi - cruise**		**South-ampton - cruise**		**Kristiansand - supply vessel**		**Marseille - container**		**Marseille - cruise**		**Constanta - container**		**Antwerp - container**		**Cartagena - cargo**		**HaminaKotka - cargo**	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	21	-10	33	1	37	5			94	20	6	-2	9	-1	96	16	7	0	9	0	13	3	11	2
FNPV (Option 2)	37	6	37	6	37	5	94	19	94	20	10	2	9	-1	96	16	7	0	9	0			11	2
FNPV (Option 3)	37	6	38	6							10	2	9	0			-15	-23					-16	-24
ENPC (Option 1)	216	180	229	192	236	198			565	479	55	46	63	49	566	451	61	51	65	50	67	53	62	52
ENPC (Option 2)	233	197	233	197	236	198	565	479	565	480	59	50	63	50	566	451	61	50	65	50			62	52
ENPC (Option 3)	233	197	234	197							59	50	63	50			37	27					41	31

NPV results sensitivity scenario 4

Lower shadow prices for NOx, PM and SO_2	**Stockholm - ferry**		**Dover - ferry**		**Civittavecchi - ferry**		**Civittavecchi - cruise**		**South-ampton - cruise**		**Kristiansand - supply vessel**		**Marseille - container**		**Marseille - cruise**		**Constanta - container**		**Antwerp - container**		**Cartagena - cargo**		**HaminaKotka - cargo**	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	11	-12	20	-3	24	0			63	9	4	-2	5	-2	66	7	4	-0,9	5	-1	9	2	7	1
FNPV (Option 2)	25	2	25	1	24	0	63	9	63	9	6	0	5	-2	67	7	4	-0,9	5	-1			8	1
FNPV (Option 3)	24	1	25	2							6	0	5	-1			-17	-22					-31	-37
ENPC (Option 1)	122	86	135	99	140	103			339	254	31	22	37	24	339	236	35	26	38	25	41	28	37	27
ENPC (Option 2)	139	103	139	103	140	104	338	253	339	254	35	26	37	25	339	236	35	25	38	26			37	28
ENPC (Option 3)	139	103	140	104							35	26	37	26			11	2					16	6

NPV results sensitivity scenario 5

Lower LNG capacity	**Stockholm - ferry**		**Dover - ferry**		**Civittavecchi - ferry**		**Civittavecchi - cruise**		**South-ampton - cruise**		**Kristiansand - supply vessel**		**Marseille - container**		**Marseille - cruise**		**Constanta - container**		**Antwerp - container**		**Cartagena - cargo**		**HaminaKotka - cargo**	
	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO	MGO	HFO
FNPV (Option 1)	-7	-30	11	-12	17	-6			54	-1	-1	-6	5	-2	65	6	4	-1	5	-1	9	2	7	0
FNPV (Option 2)	19	-4	20	-4	18	-6	49	-6	54	0	5	-1	5	-2	66	6	4	-1	5	-1			7	1
FNPV (Option 3)	19	-4	21	-3							5	-1	5	-1			-10	-15					-31	-37
ENPC (Option 1)	193	156	219	182	229	192			555	469	50	41	63	49	565	450	61	51	65	50	67	53	61	52
ENPC (Option 2)	227	191	228	191	229	192	549	463	555	469	57	48	63	50	566	450	61	50	65	50			62	52
ENPC (Option 3)	226	190	229	192							58	48	63	50			48	37					41	31