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# Forecasting port-level demand for LNG as a ship fuel: the case of the port of Antwerp

Raimonds Aronietis[1*], Christa Sys[2], Edwin van Hassel[2] and Thierry Vanelslander[2]

* Correspondence:
raimonds.aronietis@itf-oecd.org
[1]International Transport Forum at the OECD, 2 rue André Pascal, F-75775 Paris, France
Full list of author information is available at the end of the article

## Abstract

From a European, regional and local perspective, as well as from the point of view of port authorities, it is important that waterborne transport should be sustainable. In this context, liquefied natural gas (LNG) is often put forward as a viable alternative fuel for deep-sea, shortsea and inland navigation.

The present paper develops a forecasting method for determining potential LNG bunker volumes at port level. The proposed method is based on a review of the literature, historical data on technological innovation in shipping (i.e. the transitions from sail to steam and marine diesel engines), expert opinions and present-day bunker volumes. The forecast obtained was subsequently validated by shipping companies, bunker companies and fuel suppliers operating in the port of Antwerp. In addition, a sensitivity analysis was conducted to assess the impact of a number of relevant independent variables on the forecast.

Overall, it is found that switching to LNG as a ship fuel, like any innovation, exhibits a slow adoption pattern, with sluggish growth initially but picking up some speed with time. At the same time, there is evidence of a chicken-and-egg dilemma, with shipping companies unwilling to invest in LNG-powered ships as long as supply is insufficient or uncertain, and fuel suppliers not willing to provide storage and bunker facilities as long as demand is low. Our analysis points at many uncertainties, which are used as discriminating factors between the different scenarios tested. However, whichever scenario is played out, the indications are that LNG bunkering volumes in Antwerp will not increase sharply between now and 2050. The volume growth under the strong development scenario is about four times greater than that under the weak development scenario, but remains modest.

**Keywords:** Sustainable shipping, LNG fuel, Forecasting, Port of Antwerp

## Introduction

From a European, regional and local perspective, as well as from the point of view of port authorities, it is important that waterborne transport should remain sustainable. In this context, liquefied natural gas (LNG) has been put forward as a viable alternative fuel in deep-sea, shortsea and inland navigation. A number of port authorities have already expressed their intention to facilitate the introduction of LNG as a ship fuel, not least because of the prospect of stricter sulphur emissions standards in so-called Sulphur Emission Control Areas (SECAs) from 2015 onwards (Sys et al., 2015). Furthermore, global regulations aimed at further reducing shipping-related sulphur emissions are expected to come into force from 2020 onwards.

However, if ship owners are to switch to LNG, ports must provide the necessary LNG bunker infrastructure. Port authorities, for their part, can only invest meaningfully in such facilities if they have a rough idea of potential demand for LNG bunker from deep-sea, shortsea and inland navigation, as LNG is increasingly substituted for Heavy Fuel Oil (HFO) and/or Marine Gas Oil (MGO). This paper proposes a generic forecasting method for LNG demand at port level, and applies it to the case of Antwerp. Potential demand for LNG bunker may provide a basis for strategic longer-term planning and project development aimed at the promotion of LNG as a ship fuel.

Our assessment of potential demand for LNG as a bunker fuel is based on current bunkering volumes, the composition of the fleet calling at a given port, and a review of the literature on potential future demand for LNG. Additionally, our findings were assessed by various stakeholders, including leading shipping companies, naval architects, port authorities and bunkering companies.

The remainder of this paper is structured as follows. First, section 2 presents a review of the literature on LNG as a ship fuel and on forecasting methods for estimating potential demand for LNG bunker. Section 3 explains the model structure applied. Section 4 presents the data used in our study with a specific application to the port of Antwerp. The research results are presented in section 5. Section 6 consists in a validation and sensitivity analysis of the results obtained. Finally, conclusions are drawn in section 7.

## Literature review

A literature review was conducted with the aim of gaining a historical perspective on ship propulsion, the drivers of innovation in this sector, forecasting of shipping fleet development and fuel demand, and trends in alternative fuel use.

### Historical perspective on ship propulsion

The literature reviewed describes two major technological evolutions in shipping. The first advance was the transition from sail to steam power, the second that from steam propulsion to internal combustion engines. Grübler (1990) describes these major technological advances (Fig. 1) and the evolution of the respective market shares held by sailing ships, steamers and combustion-powered vessels. While no global historical data is available, the UK (together with the USA) was the market leader when it came to the introduction of steam-powered shipping.

The first technological leap (from sail to steam) in maritime shipping was inspired by the huge success of steam as a propulsion method in rail transport. In practice, the transition proved a relatively lengthy process that coincided with improvements to sailing ship technology that even briefly heralded a new clipper age.[1] As it turned out, sailing ships continued to operate in the shipping market for about a century after the introduction of steamships.

The transition from steam to internal combustion diesel engines was made around 1925, at the peak of steamer shipping. The change was prompted by the operational simplicity, robustness and fuel economy of the diesel engines. By the early 1950s, diesel ships held over 50 % market share. Any switch to LNG-powered vessels is unlikely to induce a similarly dramatic decline in steamer shipping as the introduction of steam caused in sail shipping, across all market segments, since LNG-powered carriers continue also to be fitted with steam turbines, allowing boil-off gas to be used for steam production.

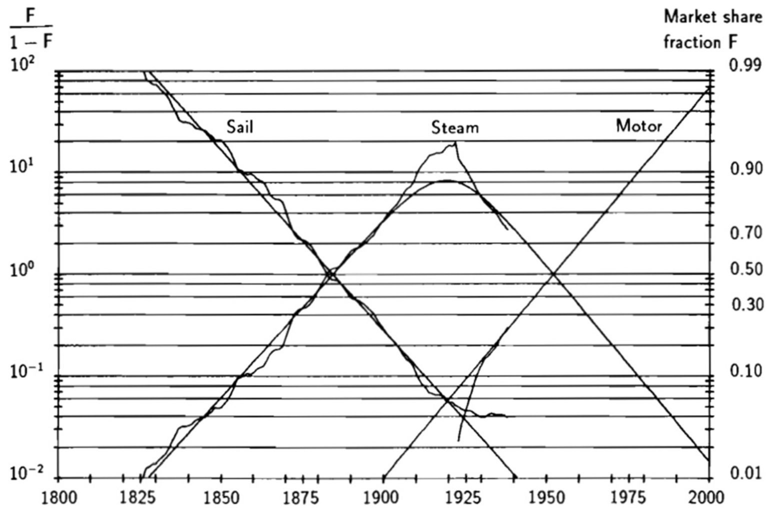


**Fig. 1** Share of sail-, steam-, and motorships in gross tonnage registered in the commercial ship fleet of the United Kingdom. Source: Grübler (1990)

Each of the two aforementioned technological revolutions in shipping unfolded over a period of approximately a hundred years. The rate of the technological change is similar in both cases. As argued by Rosenberg (1976), expectations regarding the future course of technological progress is a significant determinant in the adoption of innovations: a rapid rate of technological change leads to a slower rate of adoption and diffusion. This counter-intuitive[2] observation is taken into account in growth forecasting in the present research.

Technological changes in ship propulsion also result in changes in bunkering requirements at ports of call. Steamships were initially fuelled with wood, subsequently with coal or fuel oil. Moreover, at the time of the transition from coal to marine diesel fuels, there was no fully fledged bunkering network. A similar situation presents itself today in respect of LNG as a bunker fuel, hence this aspect too is taken into consideration in our analyses.

## Drivers of innovation

As an innovation, LNG conversion of existing ships and LNG-fuelled newbuilding provides external environmental benefits. In the scientific literature (see for example Horbach (2008) and Erzurumlu and Erzurumlu (2013)), three types of drivers are identified for environmentally-friendly innovative practices. Table 1 provides an overview of the drivers that typically lead to such eco-innovation.

Insofar as the introduction of LNG as a fuel in shipping is concerned, just two types of drivers (shaded in Table 1) would appear to be at play: (1) operational drivers, with the availability of technology and the urge to save costs, and (2) regulatory drivers, in the shape of policy steps by governments and other organizations at national and international level.

Examples of operational drivers are described in, for example, Mattila (2013), who asserts that the LNG supply chain is more expensive than that for oil, especially in the start-up phase when volumes are inevitably small. Stipa (2013) also dwells on the better availability of alternative fuels other than LNG. In relation to cost drivers, Maloni et al. (2013) identify extra-slow steaming as the most beneficial vessel speed, yielding a 20 % reduction in total costs and a 43 % reduction in carbon dioxide emissions. Sources investigating regulatory drivers include Greenship (2013), who deals with emission

**Table 1** Drivers of eco-innovation activities

| | | |
|---|---|---|
| Operational drivers or supply side factors | Technology push | • Technological and management capabilities<br>• Collaboration with research institutes, agencies and universities<br>• Access to external information and knowledge<br>• Size |
| | Cost-saving | • Material prices<br>• Energy prices |
| Market drivers or demand side factors | Market pull | • Market share<br>• Market demand for green products |
| Regulatory drivers or environmental policy influences | Regulatory pull/push | • Existing regulation<br>• Expected future regulation<br>• Access to existing subsidies and fiscal incentives |

Source: Based on Erzurumlu and Erzurumlu (2013), Triguero et al. (2013) and Horbach (2008)

abatement options given pending regulation; Johnsen (2013), who details the Norwegian NOx fund; Zheng et al. (2013), who conclude that EEDI has profound impacts not only China as a shipbuilding nation, but on shipbuilding countries around the world; and Hoffmann et al. (2012), who observe that a measure-by-measure approach yields a 5 % decrease in $CO_2$ emission per 1 % increase in capital expenditure, while the set-of-measures approach yields a 2 % emissions decrease per 1 % cost increase.

There would appear to be no obvious market demand for greener shipping, although marketing communications by shipping lines often stress the environmental friendliness of shipping. As appears from interviews of ship owners in Aronietis et al. (2010), shipping demand is influenced mostly by cost considerations. No shipper of goods will opt for a "greener" solution if associated with higher expenses per unit of goods shipped: environmentally friendly solutions are considered appealing only if there is an economic benefit to be had.

The policy actions (regulatory drivers) already implemented in a regulatory push by the European Commission and the ensuing steps towards achieving the EU framework for LNG as an alternative ship fuel are summarized in a communication entitled "Actions towards a comprehensive EU framework on LNG for shipping" (European Commission (2013)).

Hence, our LNG growth forecast must take into account regulatory drivers as well as operational drivers of eco-innovation.

## Available forecasts

There are examples in the literature of general predictions of the development of an LNG-fuelled shipping fleet as well as the associated fuel demands. What follows is a selection of sources cited, which will allow matching these existing forecasts to the situation in Antwerp.

### *Shipping fleet forecasts*

Ocean Shipping Consultants (2013) forecasts that the LNG-fuelled fleet will grow from 40 vessels at present, which is less than 0.1 % of the existing fleet, to approximately 1250 vessels or 1.7 % of the fleet by 2025.

Det Norske Veritas (2012) anticipates a more rapid growth of the LNG-fuelled fleet. It distinguishes between a base line scenario, resulting in 1068 LNG-fuelled vessels by 2020, and a strong growth scenario, yielding 2043 LNG-powered ships by 2020.

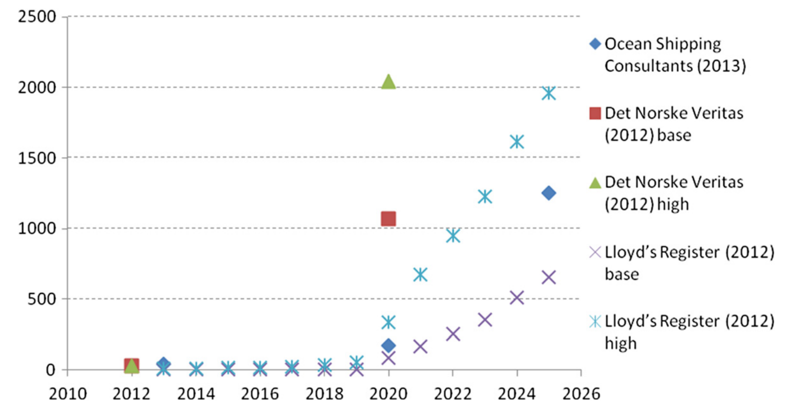


**Fig. 2** Summary of forecasts on LNG-fuelled shipping fleet in the reviewed literature, number of ships. Source: own composition

Lloyd's Register (2012), for its part, forecasts lower growth, but this is due to the fact that its outlook pertains only to deep-sea trade lanes, where ships spend limited time sailing in ECA zones.

The aforementioned forecasts are summarized in Fig. 2, where the horizontal axis represents time and the vertical axis represents LNG-fuelled fleet size. None of the forecasts considered go beyond 2025.

### *Conventional bunker fuel demand forecasts*

Lloyd's Register (2012) forecasts an increase in global HFO bunker consumption volumes from 166.3 million tonnes in 2012 to 241.4 million tonnes in 2025. However, this forecast, too, relates to the deep-sea trade only.

The overall size of the bunkering market is currently approximately 230 million tonnes per year. Ocean Shipping Consultants (2013) forecasts the conventional bunker market segment to grow to 251 million tonnes by 2015, to 278 million tonnes by 2020 and to 306 million tonnes by 2025.

### *LNG fuel demand forecasts*

Different sources provide forecasts for global LNG fuel consumption over the next years. Semolinos et al. (2013) use Total's in-house calculation model based on total consumption per region and type of vessel, whereby the probability for each ship segment of using LNG over time is applied. They forecast LNG bunker fuel consumption in shipping to increase from 10 million tonnes in 2020 to a range of 30-35 million tonnes in 2030.

Det Norske Veritas (2012) provides forecasts from 2012 to 2020, based on a set of four scenarios. Each of these scenarios represents a level of economic growth, and a degree of regulatory and stakeholder pressure. LNG fuel consumption in 2020 varies between 7 million tonnes for the low-growth scenario and 33 million tonnes under the high-growth scenario.

According to the demand projection by Adamchak and Adede (2013), global consumption of LNG as a marine fuel will reach 1 million tonnes in 2020, after which it will increase rapidly to 8.5 million tonnes by 2025.

Additionally, we note that Adamchak and Adede (2013) report on the basis of a literature review, in which no sources are named, that projected LNG bunkering demand ranges widely depending on the scenario considered: from 0.7 to 66 million tonnes for 2025; from 8 to 33 million tonnes for 2020; and up to 65 million tonnes by 2030. European growth is

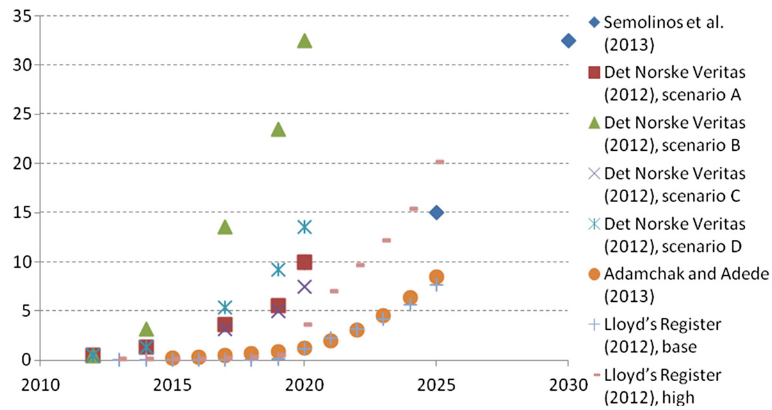


**Fig. 3** Summary of forecasts on LNG marine fuel demand in the reviewed literature, million tons. Source: own composition

forecast to develop in line with growth in other continents, where the sharpest increase is expected to occur in the years leading up to 2025. Total volume for Europe is however, expected to remain below volumes for North America and the Far East, the world's two other major LNG bunkering regions.

Lloyd's Register (2012) considers two scenarios for global LNG bunker demand between 2012 and 2025 for all deep-sea vessel types. The base scenario indicates a growth in demand from 0.1 million tonnes in 2019 to 7.7 million in 2025. Under the high consumption scenario, a demand level of 0.1 million tonnes will already be reached in 2013, followed by a further increase to 20.2 million tonnes by 2025.

The various LNG bunker fuel demand forecasts are summarized in Fig. 3, where the horizontal axis represents the horizontal axis, while the vertical axis represents demand for LNG.

Boardley (2014) considers three scenarios (Global Commons, Status Quo and Competing Nations) for marine fuel consumption. The most optimistic scenario insofar as LNG is concerned is the 'Global Commons' scenario, which anticipates a share for LNG of up to 11 %. The LNG share is much lower under the 'Competing Nations' scenario.

Forecast shares of shipping in global LNG demand are relatively small. It is thought that, by 2025, shipping could account for an LNG consumption of between 7.5 and 20 million tonnes, representing between 1.7 and 4.4 % of a global demand of 450 million tonnes.

Hence shipping clearly does not follow other transport modes or sectors, where LNG is expected to cover 15 % of all fuel needs, even though shipping, after road freight, is the fastest growing transport modes in terms of overall energy shares. The biggest LNG exporters are Russia, Africa and North-America (Exxon Mobil, 2014).

## Latest LNG-related trends in shipping

Today, it is observed that ship owners, when facing investment decisions, tend to hedge their bets between available technologies. While this strategy minimizes the risk of choosing the "wrong" technology, it tends also to come at a higher investment cost.

In relation to LNG, one available technological option is to build LNG-ready ships (Porter, 2013). Such vessels are not intended to be fuelled with LNG immediately, but can be retrofitted for LNG in a matter of weeks. Moreover, with dual-fuel engines, retrofitting would not be irreversible. Alternatively, ship owners may prefer to bear the

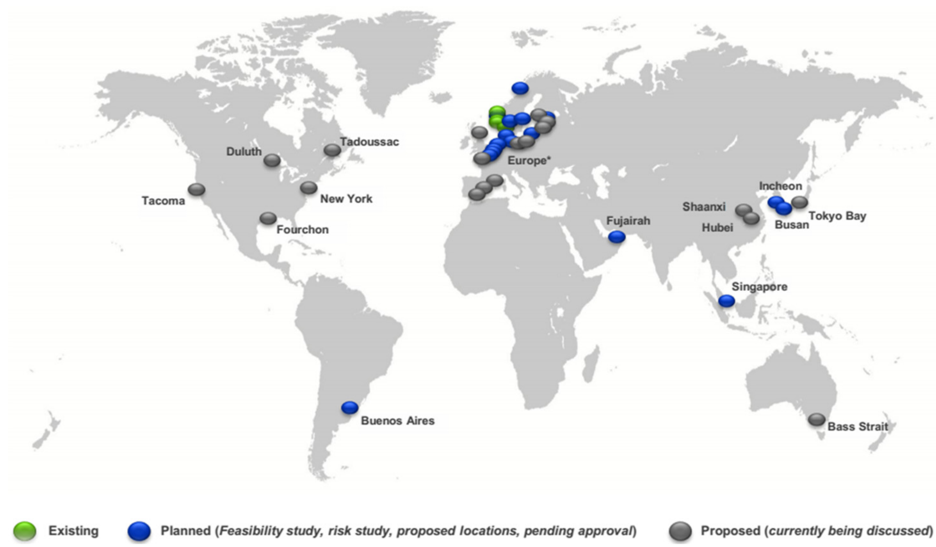


**Fig. 4** Current and forecast global LNG infrastructure by 2020. Source: Rotty (2012) based on DNV LNG bunkering 2020 study

full investment cost at once and order dual-fuel ships from the outset (LNG Global, 2013). The least popular technological option would appear to be the building of LNG-only ships (MarineLog, 2012). If this option is chosen, then usually in a niche-oriented context. Finally, it is noted that some ship owners, such as Maersk Line, are seeking co-operation agreements with LNG producers. (Shipping Watch, 2013).

At the same time, ports are taking action to ensure the supply of LNG fuel will meet demand. Some aim to provide LNG bunkering facilities in the near future (Fig. 4).

While governments are seen to be investing in LNG infrastructure through port authorities, many ship owners continue to prepare for different contingencies and hence decide against investing in LNG-only ships.

Wang and Notteboom (2015) consider current port practices in the development of LNG bunkering facilities in eight ports in Northern Europe. They identify the important role of the evolving port function beyond the traditional model in promoting innovation. In this paper, the port authority is seen as the actor who facilitates the installation of LNG bunker facilities. In order for such an authority to be able to determine the required capacity of LNG bunkering installations, it would need an LNG bunker forecast at port level.

The purpose of the present research is to arrive at an LNG forecast at port level. However, the existing literature on LNG forecasting provides only aggregated forecasts, not port-level forecasts. Therefore, a more specific forecasting method needs to be developed that takes account of historical transitions in shipping fuels, aggregated LNG bunker development forecasts, and current port-specific bunker volumes per ship type. The next section explains in further detail the proposed methodology for port level forecasting.

## Methodology

In order to determine LNG demand at port level, insight is required first and foremost into LNG bunker demand for the different shipping segments served by that port. To this end, current daily bunker volume is used as a basis for calculating potential future LNG bunker volume.

However, for the sake of comparability, the respective units of measurement for LNG bunkers and fuel oils need to be “standardized”. To this end, we propose a common unit of measurement for the different fuel types considered. The various fuels are usually measured in mass units or volume units. However, comparing volumes can be misleading in the sense that the energy content of the fuels differs. A comparison of energy content of three types of marine fuel is shown in Table 2.

For the purpose of our LNG bunker market growth forecast, the respective energy contents are assumed to be 40 MJ/kg for HFO, 43 MJ/kg for MGO, and 45 MJ/kg for LNG (Table 2).

On the basis of the historical evidence described in the literature review and considering current technological evolutions, combined with the argumentation of Rosenberg (1976) on innovation, assumptions can be made on the future characteristics of the demand function for LNG bunker fuel at port level. The aforementioned historical evidence suggests this function may be assumed to be sigmoid in nature (see Fig. 5), with a lower adoption rate of LNG in the bunker market in the initial years, and a saturation period in the final years of adoption.

In the very long run, as other competing technologies emerge, the function will reach its maximum, possibly not reaching 100 % saturation, and subsequently be phased out (not shown in Fig. 5). Again, going by the historical evidence on the introduction of the steam engine and the marine diesel engine (see Fig. 1), the first half of the lifecycle of a marine fuel technology, i.e. up to where decline sets in, is assumed to last approximately 100 years.

A variety of ship types, each operating in a different shipping niche, call at the port of Antwerp. The transition to LNG propulsion is not likely to happen equally quickly for each of these vessel types. Hence, for the purpose of forecast, we apply varying adoption rates depending on ship type and ranging from “Very low adoption rate” to “Very high adoption rate”.

The adoption rates reported in Table 3 are assumed to apply for the different ship types calling at the port of Antwerp, based on the traditional routes and operational profiles of the ships concerned. This assumption is based on actual fuel consumption and disregards the possibility of future fuel-savings due to technological improvements to vessels.

When estimating the values in Table 3, for smaller ships (container, general cargo, tankers, bulk carriers) the assumption is that they sail mostly in SECA zones and that, in order to comply with regulations, they are LNG-powered. For larger ships, the assumption is that LNG is as a supportive fuel and that, upon exiting a SECA, these vessels are able to switch to HFO.

**Table 2** Energy content of HFO, MGO and LNG

| Source | Unit | HFO | MGO | LNG |
|---|---|---|---|---|
| Kumar et al (2011) | [Mj/l] | 38.3 | 34.5 | 25 |
| Bengston et al. (2011) | [Mj/kg] | 40.4 | 43 | 48 |
| Verbeek et al. (2011) | [Mj/kg] | | 42.7 | 49 |
| Astbury (2008) | [Mj/kg] | | 47.97 | 19.98 |
| Engine producer: ABC | [Mj/m^3] | | | 38 |
| Man B&W | [Mj/x] | | 42.7 (x = kg) | 28 (x = Nm^3) |

Source: De Petter (2013)

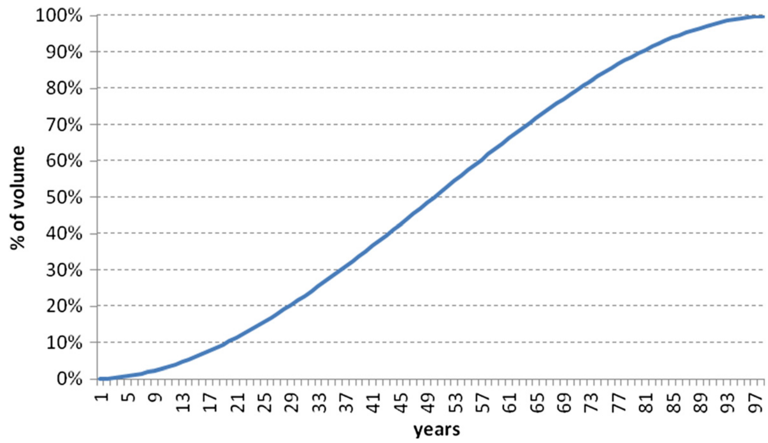


**Fig. 5** Example of a sigmoid function. A sigmoid formula is a mathematical function having an "S" shape. Source: own composition

The assumed 100-year timespan for the full adoption of LNG as a ship fuel (see Table 3) is beyond the forecasting horizon. If one changes the assumptions within a reasonable range for a function as shown in Fig. 5, the impact on the forecast in the first 11 years (the scope of this research) remains minimal. The possible adoption rate of LNG-propulsion by the various ship types, as listed in Table 3, was determined on the basis of estimations by twenty independent international experts (engine producers; academics; policymakers; consultants). In order to assess the implications of these estimations on the total forecast, a sensitivity analysis is conducted in section 6 of this paper.

For forecasting purposes, taking into account the varying energy content of fuels (see Table 3), the future level of energy bunkered in a port is assumed to be constant. This assumption is based on historical bunkering data at port level (see section 4).

**Table 3** Adoption of LNG as a fuel in different ship types calling at Antwerp

| Ship type | Size | Adoption rate | Possible adoption in 100 years |
|---|---|---|---|
| Small RORO | <180 m | Very high | 100 % |
| Large RORO | >180 m | Medium | 70 % |
| Small container | <2,000TEU | High | 90 % |
| Large container | 2,000-8,000TEU | Low | 20 % |
| Very large container | >8,000TEU | Low | 20 % |
| Small general cargo | <5,000DWT | High | 90 % |
| Large general cargo | >5,000DWT | Medium | 70 % |
| Small tankers | <25,000DWT | High | 90 % |
| Large tankers | 25,000-200,000DWT | Very low | 20 % |
| Small bulk carriers | <35,000DWT | High | 90 % |
| Large bulk carries | >35,000DWT | Low | 20 % |
| VLCC/ULCC | >200,000DWT | Very low | 5 % |
| Inland shipping | All sizes | Very low | 5 % |
| Other | All sizes | Medium | 50 % |

Source: own composition

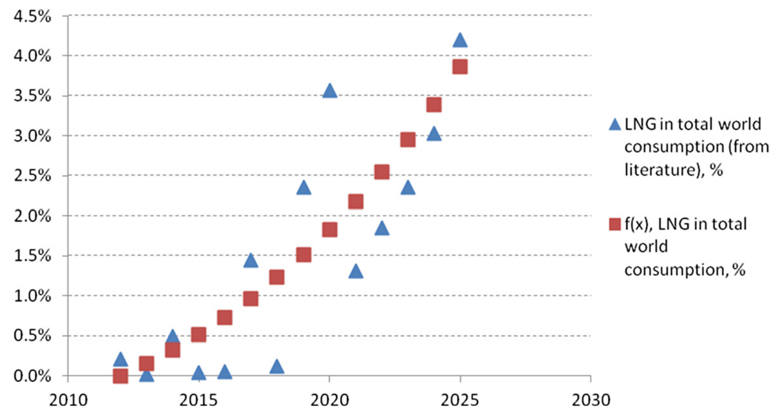


**Fig. 6** LNG as % of total world bunker market. Source: own calculation based on forecasts in the literature review

Based on the average forecasts presented in the literature review, the share of LNG relative to total world consumption (in %) can be calculated in an aggregate way. This data can be approximated with a sigmoid function:

$$f(x) = \frac{x}{\sqrt[a]{b + x^2}}, \quad (1)$$

where f(x) is the share of LNG and x is a year in the forecasts used, and a and b determine the shape of the curve. To determine the values of *a* and *b*, the $R^2$ between the sigmoid function and the average values of all LNG demand forecasts from the literature review is minimized by making a and b vary. The values of a = 1.1623 and b = 0.9994 are obtained. The coefficient of determination $R^2$ is 0.71. The result is shown in Fig. 6 with square markers.

Since the adoption of LNG as a ship fuel is unlikely to happen at the same rate for different vessel types, for forecasting purposes, the sigmoid function obtained allows one to assign growth factor values to the adoption rates. The specific values to be used in the forecast function are shown in Table 4 and are based on the calculated value of *a* in Eq. 1. The value of *a* is determined for each adoption rate (i.e. very low, low, etc.) in such a way that the corresponding maximum adoption rate in 100 years is equal to the percentages given in Table 4.

The sigmoid function and the estimated values in Table 3 allow one to forecast the potential LNG bunkering market in Antwerp. The very long-term forecasts per ship type are presented in Fig. 7, where the proportion of LNG relative to conventional bunker fuel is shown. It should be noted that Fig. 7 is merely intended to demonstrate the

**Table 4** Growth factor relation to adoption rates

| Adoption rate | Growth factor value (*a*) |
|---|---|
| Very low | 0.9298 |
| Low | 1.0461 |
| Medium | 1.1623 |
| High | 1.2785 |
| Very high | 1.3948 |

Source: own composition

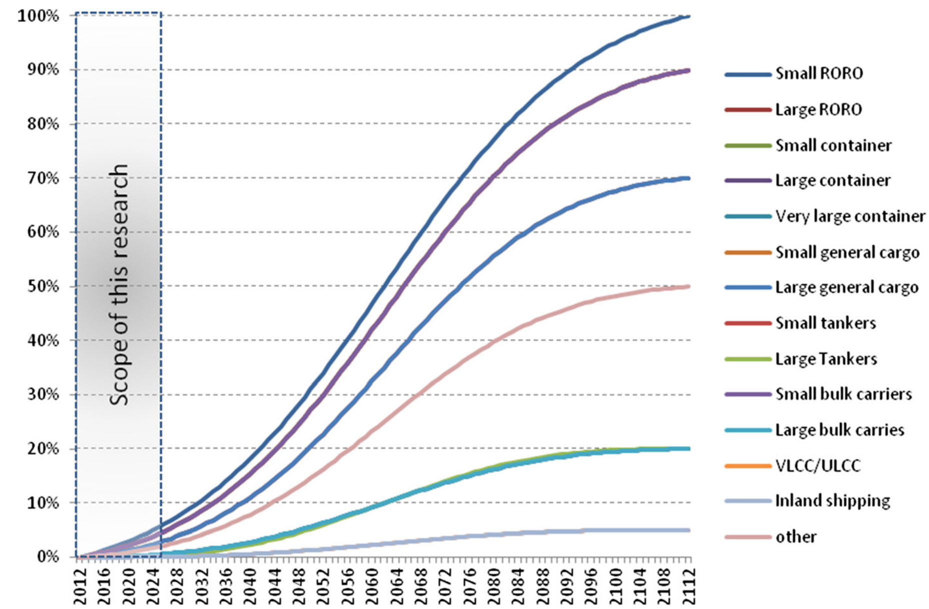

**Fig. 7** LNG as % of total world bunker market. Source: own composition

application of the sigmoid functions in the forecast as well as the scope of this research, which is limited to the first 11 years of the lifecycle of this marine technology.

With the proposed methodology, LNG bunkering forecasts can be made for the different shipping segments up to 2025. In the next section, the data needed for the calculations is presented, with an application to the port of Antwerp.

## Data

For forecasting purposes, insight is required into current bunkering requirements per ship at a given port, i.c. the port of Antwerp. However, collecting this data was not a straightforward proposition. The port of Antwerp provided us with three sets of data which needed to be combined in order to arrive at a complete set of bunker data per ship type.

The three different data sets are: bunkering data, ship calls data and customs data.

– Bunkering data
  This dataset contains records of bunkerings reported to the Harbour Master of the Port of Antwerp (PoA) (data since recording started in November 2011, up to 6 September 2013). It includes bunkering information such as date, bunkering company, location, bunker ship, ship bunkered, previous port of call, next port of call, type of fuel bunkered, volume bunkered, etc. It is noted by the PoA that this data is most likely incomplete, as reporting bunkerings is not mandatory.
– Ship calls data
  This dataset contains the records of ships having called at the port of Antwerp (between 1 January 2008 and 30 June 2013) and includes the vessel's name, its IMO number, its dimensions, tonnage, type, and the times of port entry and exit.
– Customs data
  This dataset contains a summary of fuel bunkered (as reported to Customs) per company, split by fuel type (HFO/MGO/lubrication oil) for the years 2006 to 2012,

in volume (tonnes) and value (€). The source of this dataset is the Administration of Customs and Excise duties. While this data is more complete, it is also more aggregated, hence no details are available on ship types, individual bunkering volumes, etc.

The approach used for estimating the bunkering volumes in the port of Antwerp comprises four steps. It is assumed that the Customs data is complete and includes all fuel bunkered in the port. The bunkering data, however, is more detailed, but includes only a part of the volume that is covered in the Customs dataset. Both datasets include the volumes bunkered per company. Therefore, as a first step in the estimation approach, the factors that show under or overreporting are calculated by balancing PoA data and Belgian Customs Office data.

Data for a certain company may be unavailable. For example, a company may, for some reason or other, choose not to report its bunkering activity to the port authorities. Therefore, as a second step in the approach, we estimate the bunkering volumes for companies where factor calculation is impossible. One of the data sources may lack data on a specific company, e.g. customs data may have been accidentally omitted by the administration. To estimate the bunkering volume for such a company, it is assumed that the volume reported in the customs data is accurate. If no volume is reported in the customs data, we rely on the bunkering volume reported in the bunkering data of the PoA.

In the third step, combining the volumes obtained per company on the basis of the calculation of factors (first step) and estimated volumes (second step) are combined in order to obtain an overall estimate of bunkerings at the port of Antwerp, through aggregation of individual company and ship data. The estimations relate to the year 2012, as this was the only available full year of bunkerings data at the moment of the analysis.

In practice, the PoA database of bunkering data, which provides the greatest detail, is increased with additional bunkerings to fit the estimated value in the first and second steps. For each company, the assumed distribution of bunkerings is based on Customs data. For the estimated missing data, since the company-specific bunkerings are not

**Table 5** Detailed estimations of bunkering in the Port of Antwerp in 2012, t

| Shipping segment | MGO, t | HFO, t |
|---|---|---|
| Small ro/ro <180 m | 22,238 | 229,310 |
| Large ro/ro >180 m | 119,503 | 1 890,873 |
| Small container <2 000 TEU | 9,720 | 187,593 |
| Large container 2 000-8 000 TEU | 59,079 | 2 355,537 |
| Very large container >8 000 TEU | 5,670 | 155,328 |
| Small general cargo <5 000 DWT | 28,087 | 45,544 |
| Large general cargo >5 000 DWT | 113,488 | 1 546,950 |
| Small tankers <25 000 DWT | 109,006 | 436,724 |
| Large tankers 25 000-200 000 DWT | 61,341 | 494,974 |
| Small bulk carriers <35 000 DWT | 21,004 | 100,821 |
| Large bulk carries >35 000 DWT | 28,434 | 248,743 |
| Other all sizes | 61,982 | 129,619 |

Source: Aronietis et al (2015) based on Port of Antwerp data

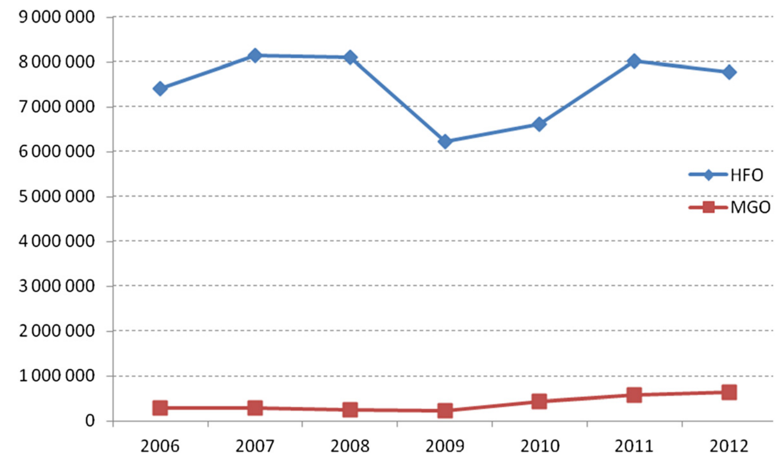


**Fig. 8** Historic bunkering data in the port of Antwerp, tonnes. Source: Aronietis et al. (2015) based on Port of Antwerp data

available, a general distribution for the whole bunkering market in the port of Antwerp is assumed. This allows a double alignment, both with Customs data division over companies and with the PoA data division.

The bunkering estimations should be expressed in a manner that allows a split between the required shipping segments, as shown in Table 3. Therefore, in the fourth step, the ship calls data that contains ship characteristics, including vessel type, is linked to the estimated bunkering data. Sometimes ship type may change, as a hull is retrofitted or adapted to a different purpose. In such cases, the hull IMO number remains the same, but the ship type changes. For the purpose of defining shipping segments for the bunkering data, the last reported ship type is used for such vessels.

Table 5 provides bunkering data for both HFO and MGO, in the port of Antwerp. A detailed overview of the data collection and calculation process, as well as the data validation process through several bunkering companies, is provided in Aronietis et al. (2015).

Figure 8 represents a historical overview of the bunker volumes in the Port of Antwerp for 2006 to 2012.

From Fig. 8, it can be concluded that bunker volumes declined substantially in 2009 – 2010, which coincided with the financial crisis and a sharp decrease in cargo throughput in the port. In 2011 and 2012, throughput figures and bunker volumes recovered to pre-crisis levels. Also noticeable in Fig. 8 is the increase in MGO bunkerings.

In the next section, the forecasting methodology is applied to the data from section 4, and the results are validated through sector interviews.

## Forecasting LNG demand in the port of Antwerp: validation and sensitivity analysis

The forecasting results are presented in section 5.1, followed by validation in the subsequent sections.

### Forecasting results

For the purpose of calculating our forecasts of LNG bunkering per shipping segment, tonnages are converted into TJ (terajoule), an energy unit that allows comparison between different fuel types. However, for conceptual reasons, our results are reported in tonnes.

**Table 6** Forecast LNG demand per shipping segment in the port of Antwerp, tonnes

| | 2012 | 2013 | 2014 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|
| Small ro/ro | - | 658 | 1,358 | 2,104 | 6,571 | 12,446 |
| Large ro/ro | - | 1,877 | 4,013 | 6,421 | 23,016 | 48,541 |
| Small container | - | 360 | 752 | 1,177 | 3,847 | 7,573 |
| Large container | - | 232 | 555 | 974 | 4,699 | 11,689 |
| Very large container | - | 15 | 37 | 65 | 314 | 780 |
| Small general cargo | - | 138 | 288 | 450 | 1,471 | 2,896 |
| Large general cargo | - | 1,552 | 3,317 | 5,307 | 19,022 | 40,118 |
| Small tankers | - | 1,007 | 2,103 | 3,291 | 10,759 | 21,180 |
| Large tankers | - | - | - | - | 153 | 1,243 |
| Small bulk carriers | - | 224 | 469 | 733 | 2,397 | 4,719 |
| Large bulk carries | - | 27 | 64 | 112 | 543 | 1,350 |
| Inland shipping | - | - | - | - | 1 | 12 |
| Other | - | 130 | 279 | 446 | 1,598 | 3,370 |

Table 6 shows forecast LNG demand in the port of Antwerp (in tonnes) by shipping segment. The VLCC and ULCC categories are excluded from these tables, because no such ships call at the port of Antwerp. As can be observed in Table 6, the RoRo sector and general cargo vessels are the shipping segments with the highest forecast bunker volumes.

Table 7 summarizes the figures on aggregated demand for LNG as a bunker fuel and actual bunkered LNG in the port of Antwerp. Total LNG bunker demand in the port of Antwerp is forecast to amount to 21,081 tonnes in 2015 and to grow to 74,391 tonnes by 2020 and to 155,914 tonnes by 2025.

The results obtained are validated mainly through interviews with ship owners, bunkering companies and fuel providers. To this end, the interviewees were approached with a questionnaire on the state of the bunkering market.

**Table 7** Forecast LNG demand per shipping segment in the port of Antwerp, tonnes

| | Forecasted LNG demand, t | Actual bunkered LNG*, t |
|---|---|---|
| 2012 | 0 | 16 |
| 2013 | 6,221 | 94 |
| 2014 | 13,235 | - |
| 2015 | 21,081 | - |
| 2016 | 29,799 | - |
| 2017 | 39,430 | - |
| 2018 | 50,018 | - |
| 2019 | 61,644 | - |
| 2020 | 74,391 | - |
| 2021 | 88,259 | - |
| 2022 | 103,297 | - |
| 2023 | 11,9553 | - |
| 2024 | 137,076 | - |
| 2025 | 155,914 | - |

*Source: port of Antwerp

**Table 8** List of interviews with shipping and bunker companies and fuel providers

| | Shipping company | Fuel providers | Bunkering companies |
|---|---|---|---|
| 1. | Clipper | Total | Belgian Trading and Bunkering |
| 2. | Exmar | Exxon | General Bunkering Services |
| 3. | Fednav | | O.W. Bunker (Belgium) |
| 4. | Grimaldi | | Transcor Energy |
| 5. | Hambug Süd | | Victrol |
| 6. | MSC | | |
| 7. | TransAtlantic | | |
| 8. | Wallenius Wilhelmsen | | |
| 9 | Maersk Line | | |

Source: own composition

The questionnaire begins with a number of questions designed to validate the bunkering volumes at the port of Antwerp, as the forecasts of the market shares of bunker fuels were produced based on the basis of a set of assumptions about the future adoption of LNG as a bunker fuel by various vessel types. In order to validate these assumptions, the respondents were asked to evaluate the potential transition to LNG per ship type based on two parameters: the adoption rate and the likely adoption saturation.

Shipping companies calling at Antwerp and occupying offices there were selected as prime target respondents for the survey. Within these companies, individual were contacted who are directly involved in making bunkering decisions. It immediately became clear that such decisions tend to be taken at the head offices of the companies concerned. In other words, the local offices in Antwerp were used as entry points to gain access to the relevant decision-makers, irrespective of where they were posted. Additionally, bunkering companies and fuel providers were questioned. Table 8 provides an overview of the shipping companies interviewed. The interviews took place between June and November 2014.

### Validation by shipping companies

In relation to the bunker market forecast, the shipping companies commented that the forecast for LNG seems reasonable, but that they have different expectations regarding evolutions of MGO use from 2015 onwards, following the introduction of an ECA in the North Sea. It was generally agreed by the interviewees that the global sulphur cap might impact on the bunker fuel market from 2025, the final year covered by the forecast. The general expectation was that a global sulphur cap is very unlikely to come into force from 2020.

The perceptions of the shipping companies in relation to the adoption of LNG were tested by presenting respondents with Table 3 and asking them to comment. The responses confirmed the assumption made by the researchers for the purpose of forecasting, namely that smaller ships involved in coastal trades within ECAs are more likely to adopt LNG. However, almost all respondents felt that the adoption of LNG depends not so much on ship type as on the specific trade on which the vessel is deployed. For example, ro/ro ships typically have a higher LNG adoption rate and saturation point, simply because they tend to be deployed in ECAs.

It was pointed out that significant drops in oil prices have obviously impacted positively the potential for LNG adoption, while geo-political factors, including wars, are seen as a possible cause of market disruption. Furthermore, land markets are considered to be crucial to fuel market developments, not ship bunkering.

### Validation by fuel providers

The fuel providers interviewed generally expect a high MGO share, considering that HFO would be banned in ECAs. LNG was seen as a potentially viable option on structured and regular lanes, unlike in tramping. In the short run, fuel providers expect a shift from HFO to MGO rather than to LNG. They also point out that low-sulphur fuel can cause ship engines to break down due to insufficient lubrication.

Alternatives to classical fuel are generally regarded with some scepticism. Use of scrubbers is expensive (up to USD 2-3 mn for typical scrubbers; see also Nixon, 2014) and, while the option of LNG is being developed (e.g. Interstream barging in Europe), availability and infrastructure remain a problem. Port authorities were seen to bear responsibility in relation to the latter.

### Validation by bunkering companies

The interviews with bunkering companies suggest that, on the whole, they do not see LNG becoming a major source of propulsion in shipping in the near future, though it might gain in importance in the longer run. They expect a slow adoption process, mainly because of the considerable investment associated with the retrofitting of ships. By contrast, marine gasoil requires no investment, while it is also compliant with imminent legislation. According to bunkering companies, only a small proportion of their clients consider LNG to be a realistic option for meeting environmental standards. Demand for LNG will only pick up if the market price of LNG justifies investing in LNG retrofitting or newbuilding.

A more realistic option for the near future is the use of low-sulphur fuels. While low-sulphur fuel as such is more expensive, it does offer the advantage of requiring no additional investment. Low-sulphur fuels also cut out the risks associated with LNG as a bunkering fuel. In view of the low margins generated in shipping in recent years, shipping companies have become more risk averse and hence may be prepared to pay a premium for such lower-risk low-sulphur fuels.

In the next section, the results obtained are subjected to a sensitivity analysis under various scenarios in order to ascertain the impact of the expert-based future projections of the adaption rate of LNG as a bunker fuel for the various ship types considered.

## Sensitivity scenario analysis

A scenario analysis is carried out with a view to linking aggregate demand for LNG bunkering in the port of Antwerp to other relevant independent variables. In this manner, a longer-term view is obtained on expected aggregate demand under a number of policy and market development scenarios (uncertainties). The newly developed growth model uses the following scenarios:

– Weak development,

– Status quo,
– Strong development.

In developing the future scenarios, we base ourselves on LNG-related uncertainties that are obvious today from the review of the current legislative framework, but also from the developments in the global fuel supply. These uncertainties, as enumerated by Adamchak and Adede (2013), are fivefold:

– Timing of global sulphur cap
  There is currently uncertainty in relation to the application of the MARPOL Annex VI provisions. The IMO is required to complete a review of the availability of 0.50 % sulphur content of fuel by 2018. Based on the results of such a review, the parties to MARPOL Annex VI will decide whether the global cap of 0.50 % can be enforced from 1 January 2020. If not, the 0.50 % global sulphur cap will be enforced on 1 January 2025 without any additional review.
– Expansion of ECAs
  Another uncertainty is the possible expansion of ECAs, imposing a broader requirement to use lower-sulphur fuel. The existing, planned and discussed ECAs are uncertain about their implementation in the next years. It should be noted that the installation of new ECAs depends on parties submitting a proposal to the IMO regarding the designation of such areas; as such it is not an IMO-led initiative. (Adamchak and Adede, 2013)
– Next regulatory developments
  There is also a need for regulations regarding the deployment of LNG-fuelled vessels in international trade. Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships were adopted in 2009. Recently, the draft International Code of Safety for Ships using Gases or other Low Flashpoint Fuels (IGF Code), along with proposed amendments to make the Code mandatory under SOLAS, were agreed by the inaugural session of the Sub-Committee on Carriage of Cargoes and Containers (CCC 1). The earliest possible entry-into-force date for the IGF Code is July 2017. This means that there is a degree of uncertainty in relation to the requirements of the IGF Code and the timing of its entry into force. Other future regulatory developments are uncertain. (IMO, 2014)
– Supply and demand developments
  Certain types of infrastructure and equipment are required to produce, store and transport bunkers, and to bunker LNG-fuelled ships. Interviews with bunkering companies and with shipping companies in previous stages of this research indicate that a chicken-and-egg dilemma constitutes a barrier to the development of supply and demand in the LNG bunkering market. On the one hand, shipping companies will postpone investing in LNG-powered vessels as long as there is uncertainty regarding the availability of LNG at the vessels' ports of call, and the market price of LNG must moreover justify any additional investment required for LNG conversion or newbuilding. On the other, bunkering companies will remain reticent to invest in new (or retrofitted) bunkering vessels as long as there are no guarantees that future demand for LNG justifies such financial commitment. The same logic applies to investments in LNG bunkering infrastructure.

– Fuel supply and pricing

  Within the shipping sector, there is uncertainty about whether LNG supply will be sufficient to ensure the economic viability of investments in LNG newbuilds and retrofits. This is due to the fact that the size of the global bunker fuel market amounts to about 70 % of the global LNG market, and a significant shift from marine bunker fuel to LNG would require a similar increase in LNG supply. With the forecast increase in global LNG demand, this is an important caveat. (Adamchak and Adede, 2013)

Another element to take into account is that LNG could have other than fuel applications. In one important development, LNG could become a raw material for the chemical industry. Today, Europe's chemical industry relies primarily on oil. A shift to LNG could impact on the availability of LNG as a shipping fuel.

The three scenarios considered were elaborated on the basis of the uncertainties identified, as presented in Table 9. The status-quo scenario is used for developing the forecasts at the beginning of this section. In addition, a weak and a strong scenario are developed to take into account the aforementioned uncertainties. Under the weak development scenario, the most negative contingencies are assumed to materialize, while under the strong development scenario, the assumptions are as positive as they can be. The three scenarios are summarized in Table 9. They turn out to be in line with the 2014 Global Commons, Status Quo and Competing Nations scenarios proposed by Lloyd's Register, Boardley (2014).

At the time of forecasting, an adoption rate of LNG technology was set for each ship type. These adoption rates were based on the literature and on expert opinions. For the two additional scenarios considered, new adoption rates per shipping segment were determined. These alternative adoption rates will impact the parameter $a$ in formula 1 (see also Table 4). On the basis of the new adoption rates (and thus scenarios), a new forecast can be made. Table 10 gives the adoption rates under the weak and

**Table 9** LNG market development scenarios

| | Weak development scenario | Status quo scenario | Strong development scenario |
|---|---|---|---|
| Global sulphur cap | Global sulphur cap is introduced in 2025 | Global sulphur cap is introduced in 2025 | Global sulphur cap is introduced in 2020 |
| Expansion of ECA's | No additional ECA's | No additional ECA's | Planned and discussed ECA's are introduced |
| Regulatory developments | Currently announced regulation prevails, no additional regulation is announced or comes into force | Currently announced regulation prevails, no additional regulation is announced or comes into force | Active development of new environmental legislation |
| Supply and demand developments | Fuel suppliers are waiting for demand before investing, shipping companies are waiting for supply before invest in LNG ships | Fuel suppliers are waiting for demand before investing, shipping companies are waiting for supply before invest in LNG ships | Investments in LNG demand and supply by respectively the ship-owners and fuel suppliers |
| Fuel supply and pricing | The demand for LNG worldwide is not sufficiently met, prices for LNG are high | The demand for LNG worldwide is partially met, prices for LNG are at the level of alternatives | The demand for LNG worldwide is fully met, prices for LNG ensure quick payback of investments in LNG |

Source: Own compilation

**Table 10** Impact of scenario on adoption rate

| Shipping segment | Weak development scenario | Status quo scenario | Strong development scenario |
|---|---|---|---|
| | Adoption rate | Adoption rate | Adoption rate |
| Small ro/ro | *Med* | Very high | Very high |
| Large ro/ro | *Low* | Medium | *High* |
| Small container | *Med* | High | *Very high* |
| Large container | Low | Low | *Med* |
| Very large container | Low | Low | Low |
| Small general cargo | *Med* | High | *Very high* |
| Large general cargo | *Low* | Medium | *High* |
| Small tankers | *Med* | High | *Very high* |
| Large tankers | Very low | Very low | Very low |
| Small bulk carriers | *Med* | High | *Very high* |
| Large bulk carries | *Very low* | Low | Low |
| VLCC/ULCC | Very low | Very low | Very low |
| Inland shipping | Very low | Very low | *Low* |
| Other | *Low* | Medium | *Med* |

the strong scenarios, with the changes in adoption rate as compared to the status quo highlighted in italics. Table 11 shows the new forecast volumes under the three different scenarios.

In absolute terms, the LNG bunker volume forecast for 2025 varies from 62,000 tonnes under the weak development scenario to 266,500 tonnes under the strong development scenario. The scenario analyses show that varying the adoption rates of the different ship types affects the forecast volume. However, as we consider only the first 12 years of the sigmoid curve, the impact of large changes in adoption rates is minimal.

**Table 11** Overview of the forecast market shares of bunker fuels, t (different scenario's)

| | Weak development scenario | Status quo scenario | Strong development scenario |
|---|---|---|---|
| | Bunkered LNG, t | Bunkered LNG, t | Bunkered LNG, t |
| 2012 | - | - | - |
| 2013 | 1,740 | 6,221 | 12,312 |
| 2014 | 3,877 | 13,235 | 25,769 |
| 2015 | 6,433 | 21,081 | 40,424 |
| 2016 | 9,429 | 29,799 | 56,331 |
| 2017 | 12,889 | 39,430 | 73,545 |
| 2018 | 16,835 | 50,018 | 92,123 |
| 2019 | 21,350 | 61,644 | 112,160 |
| 2020 | 26,516 | 74,391 | 133,754 |
| 2021 | 32,291 | 88,259 | 156,921 |
| 2022 | 38,704 | 103,297 | 181,722 |
| 2023 | 45,784 | 119,553 | 208,221 |
| 2024 | 53,559 | 137,076 | 236,481 |
| 2025 | 62,061 | 155,914 | 266,565 |

## Conclusions

For the purpose of this research, a port-level LNG demand forecast method was developed and subsequently applied to the port of Antwerp. The first section of our paper reports on the literature study that formed the basis for defining the parameters of the LNG demand forecast. After developing a workable methodology and collecting the necessary data, efforts were focused on making a specific LNG bunker market growth forecast for the port of Antwerp. It is predicted that the market share of LNG is likely to stay relatively small in the coming years. The growth rate is expected to be particularly slow in the first years and to accelerate somewhat subsequently. Our calculations show that LNG bunkering in Antwerp will grow from almost 0 % at present to 2 %, or 156,000 tonnes, by 2025.

The sensitivity analysis conducted in the last section of the paper links aggregate demand for LNG bunkering in the port of Antwerp to other, relevant independent variables. This provides a longer-term view on expected aggregate demand under a number of policy and market development scenarios. We find that the share of LNG (in terms of energy content) is small under all three scenarios. Under the weak development scenario, LNG volume is limited to 62,061 tonnes, while under the strong development scenario, it reaches 266,565 tonnes by 2025.

The analysis provides interesting insights into the likely evolution in terms of the adoption of LNG as a ship fuel in the specific context of the port of Antwerp, as well as into the factors that are likely to stimulate or impede this process.

In the current research, we forecast LNG bunker demand at port level starting from current bunker volumes per shipping segment. Our approach does not take into account fuel consumption of future vessels calling at the port under consideration; should ships become more fuel-efficient, they will obviously require less bunker fuel. Secondly, we assume the number of ships calling at a given port to remain constant. Obviously, any significant increase or, as the case may be, decrease in port calls will also affect demand for bunker in general and for LNG specifically. Another limitation of our approach is that obtaining the port bunkering data required for forecasting can be time-consuming.

One of our future research goals is to apply the proposed methodology to other ports, particularly in Northern Europe and the Baltic. The aggregated results for all these major ports should provide a good indication of LNG demand across the European SECA. Secondly, it would be interesting to further study the variables that impact most strongly on bunkering choices and how these attributes are likely to affect LNG bunkering demand. Thirdly, an additional variable representing the future number of ships calling at a port could be incorporated into our forecasting model for port-level LNG-demand in shipping.

## Endnotes

[1]See Ward (1967) and Rosenberg (1976) for details.

[2]The adoption of a rapidly improving technology holds the danger of it soon becoming obsolete, hence the potential buyer might decide to postpone. Rosenberg (1976) suggests that the rate of technological adoption might be quicker when the rate of technological change slows down, because potential buyers may feel more confident that their technologies will not be superseded in the near future.

**Competing interests**
The authors declare that they have no competing interests.

### Authors' contributions
RA participated in development of the methodology, completed the literature study and performed the forecasting calculations. EvH participated in the development of the methodology of the study, joined the interviews and consulted on ship engineering aspects. CS performed the sensitivity analysis, consulted on the shipping economics aspects and compiled the final manuscript. TV conceived the study and participated in the development of the methodology, supervised the data collection, added to the literature review and joined the interviews with shipping companies and bunker fuel providers. All authors read and approved the final manuscript.

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### Author details
[1]International Transport Forum at the OECD, 2 rue André Pascal, F-75775 Paris, France. [2]Department of Transport and Regional Economics, University of Antwerp, Prinsstraat 13, B-2000 Antwerp, Belgium.

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