ASSISTANCE CORE LNGAS HIVE PROJECT

Top down Analysis

ENAGAS, S.A.

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Customer:	ENAGAS, S.A., P o De Los Olmos 19	Noorderlaan 147
	28005 MADRID Spain	2030 Antwerp
Customer contact:	Enrique Olarte	Belgium
		Tel: +32 (0)3 206 65 40
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Applicable contract(s) governing the provision of this Report:

Objective: The current report comprises the intermediate results of the top down analysis of the CORE LNGas HIVE project activities ET2, ET3 and ET4. This delivery contains the final top down results, as an input to the LNG demand definition.

Prepared by:	Verified by:	Approved by:
Guido Carstensen Principal Consultant	Annelies Van der Maat Principal Consultant	Maarten Bekaert Head of section

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1 INTRODUCTION

More stringent air emission requirements for seagoing vessels are introducing a new challenge for maritime administrations and services. One of the possible solutions for compliance with these requirements for vessels in the sulphur emission control areas (SECAs) is the use of LNG as propulsion fuel for shipping, next to the use of low sulphur fuels and the installation of exhaust gas scrubbers. Except for Norway, the take-up of LNG as ship fuel in Europe is still in an early stage, and key stakeholders typically identify three main barriers: the lack of adequate bunker facilities for LNG, the gaps in the legislative or regulatory framework, and the lack of harmonized standards next to the low fuel price spread (price spread between traditional fuels and LNG).

The recently adopted Directive on the deployment of alternative fuels infrastructure 2014/94/EU aims to solve the first barrier by enforcing the Member States to ensure that an appropriate number of LNG refuelling points for maritime and inland waterway transport are provided in maritime ports of the TEN-T Core Network by 31 December 2025 and in inland ports by 31 December 2030.

The CORE-LNGas hive project has been chosen to be co-financed by the European Commission within the CEF-Transport 2014 call. Enagas is coordinating the project, with as main objective to make a series of studies and pilot tests to advance the development of an integrated, safe and efficient logistics chain for the supply of LNG as a marine fuel in the Iberian Peninsula. DNV GL has been chosen to assist Enagas in the execution of a part of the studies in this project, namely the market studies planned in sub-activities ET2, ET3 and ET4.

This reports details the intermediate results of a part of the overall scope, namely the results of the top down approach. The top down results need to be consolidated in a later stage of the project with the results of the bottom up analysis to lead to the final LNG forecast.

2 METHODOLOGY

The purpose of this project is to estimate the demand for LNG as marine fuel until 2050. The approach used for LNG demand analysis is carried out in four main steps and is reflected in the structure of the following chapters.

(1) Evaluation of current fuel oil demand – baseline, chapter 2.1

(2) Estimation of development of fuel oil consumption, chapter 2.2

(3) Assessment of the relevance of LNG as marine ship fuel, chapter 2.3

(4) Regional share, chapter 2.4

2.1 Evaluation of current fuel oil demand – baseline

Based on an AIS based analysis (Automatic Identification System – an automatic tracking system used on ships that provides position data as well as other information) of more than 12,000 vessels that have called ports in Spain and Portugal in the last two years, the estimated total energy demand from shipping in the area in scope amounts to around 6.1 million metric tons HFO equivalent annually today.

Starting point of the calculation of the relevant current fuel oil demand from shipping was the identification of all vessels that have called ports in Spain and Portugal in the time period 2014-07-01 until 2016-06-30. Based on the chosen time period, two full years of data are included in the analysis. The time period was chosen a) to have most recent data available and b) to compensate for any seasonal differences of traffic or other peak effects.

In the following paragraphs the approach used for analysis of the current fuel oil demand is described.

Area in scope

The area in scope defined by the project includes the Iberian Peninsula and sea areas around it including Mediterranean Sea up to Mallorca and Atlantic Ocean up to the Azores and Canary Islands.

During the project a list of 46 relevant ports was defined, in addition these ports were allocated to three corridors, namely the Atlantic, the Mediterranean and the Gibraltar Strait (GS) and Islands corridor. The following map gives an overview of the area included in scope and the location of the ports. Note that the demand for ports of Gibraltar and Tanger (outside the project area) will be assessed in the consolidation report.

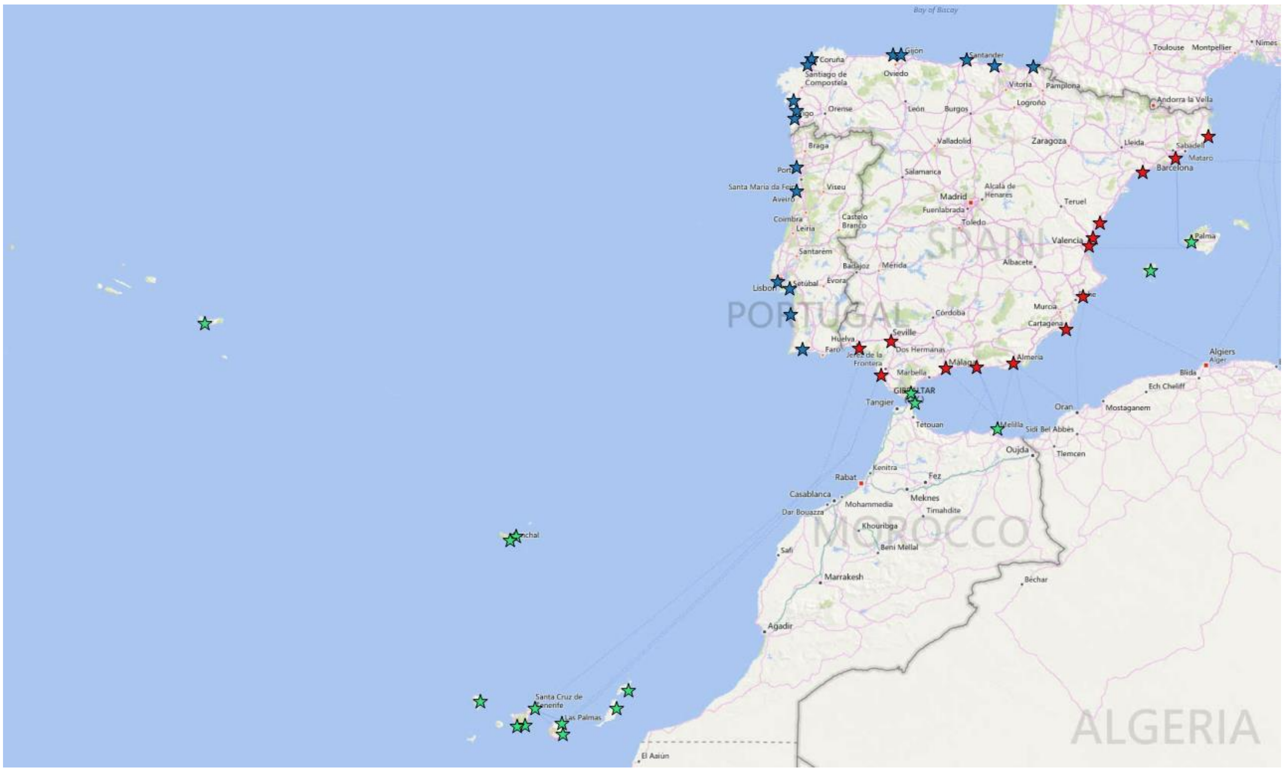


Figure 1: Defined corridors Atlantic, Mediterranean and GS & Islands

The following table gives an overview of the selected 46 Spanish and Portuguese ports in three defined corridors.

Table 1: Corridors and distribution of ports

Atlantic corridor	Mediterranean corridor	GS & Islands corridor
Spain	**Spain**	**Spain**
Aviles	Alicante	Algeciras
Bilbao	Almeria	Arinaga
Ferrol	Barcelona	Arrecife
Gijon	Cadiz	Ceuta
La Coruna	Cartagena	Granadilla
Marin	Castellon de la Plana	Ibiza
Pasaia	Huelva	Las Palmas
Santander	Malaga	Los Christianos
Vigo	Motril	Melilla
Villagarcia de Arousa	Palamos	Palma Mallorca
Portugal	Sagunto	Puerto Rosario
Aveiro	Seville	Santa Cruz de la Palma
Leixoes	Tarragona	Santa Cruz de Tenerife
Lisbon	Valencia	**Portugal**
Portimao		Canical
Setubal		Funchal
Sines		Ponta Delgada

AIS

More than 400,000 ships worldwide are equipped with Automatic Identification System (AIS) transponders as per International Convention for Safety of Life at Sea (SOLAS), issued from the International Maritime Organisation (IMO). The regulation applies for ships above 300 gross tonnage and passenger ships regardless of size involved on international voyages, as well as cargo ships above 500 gross tonnages not involved in international voyages (impact of smaller vessels will be discussed in the consolidation between bottom up and top down). SOLAS regulations require that AIS data provide information about vessel identity (IMO/MMSI number), vessel type, position, course and speed, navigational status and other safety related information. Introduction of the AIS creates a relatively simple way of collecting detailed ship traffic information. DNV GL collects AIS data from vessels around the world on a daily basis and stores it in the DNV GL data warehouse for further processing.

The AIS position signals received of an example vessel (container vessel, 700 TEU) are shown in Figure 2. During the observation period of two years this vessel sailed approximately 160,000 NM (nautical miles) and called ports at the Canary Islands and mainland Spain (Seville).

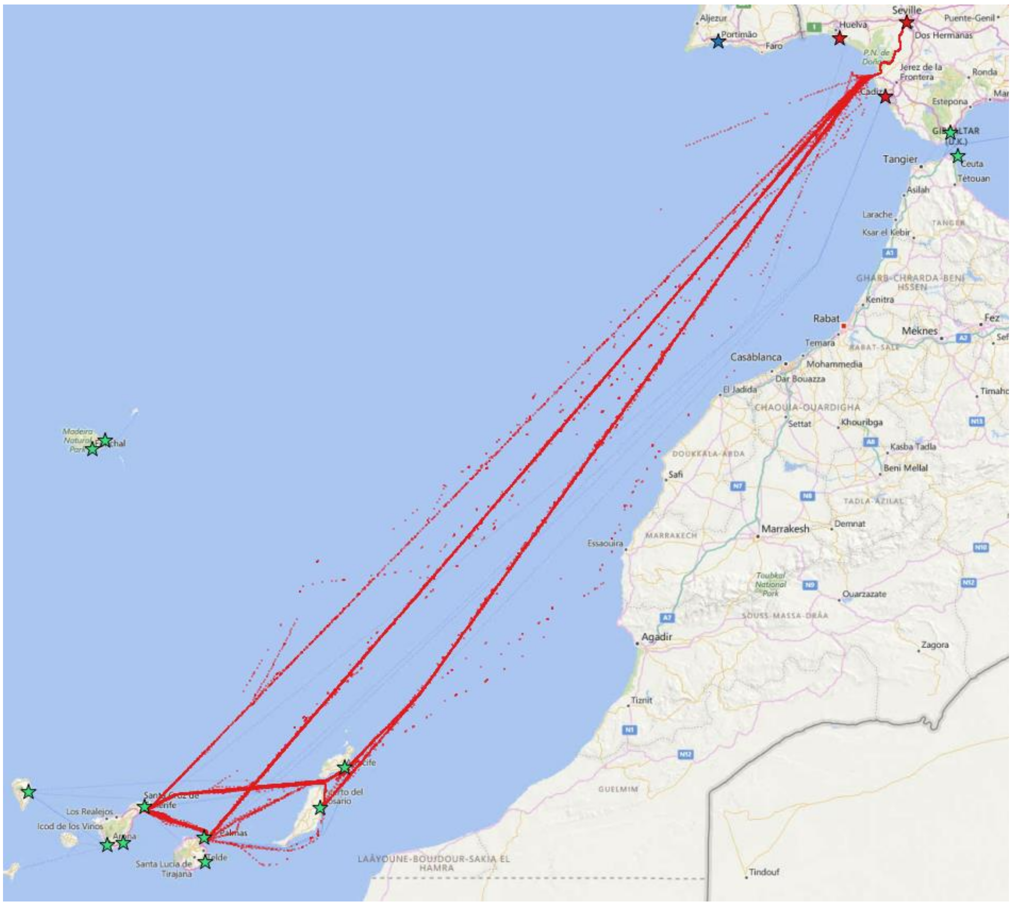


Figure 2: Example of AIS data received for one container vessel

The methodology to calculate sailed distance and identification of port calls is explained in the following chapters.

Calculation of fuel oil consumption

The calculation of fuel oil consumption (FOC) is performed for each vessel (independent of whether regular ports calls take place or whether the vessel is deployed in tramp trade) for a specific time frame. The time frame represents the time between two following vessel's position messages (AIS signal every 10^{th} minute with longitude, latitude and time stamp (UTC)). For the given time frame the appurtenant sailing distance is calculated. In addition, based on the time period and the sailing distance, the speed over ground is calculated and all information being stored in the DNV GL data warehouse together with the information identifying the actual vessel.

The DNV GL data warehouse collects data from several different sources and is used for calculation, grouping and aggregation of data. For instance, the AIS data are linked by the unique IMO number to the ship register of IHS Fairplay, which contains information about engine data, engine type for each vessel, vessel age, etc.

By comparing the ship speed over ground and the ship capabilities (defined as the service speed) for any time period, the engine load factor can be calculated using the speed power curve (this speed power curve is obtained via AIS and is vessel specific). By multiplying, the total engine power, engine load factor (load factor of an engine describes how long an engine can produce its maximum power output, a common way to describe the load factor of an engine is to give its power as an average over a certain period and is expressed as percentage and obtained via following formula, engine load factor = $(speed/service)^3$, where the database assumes 100% engine load for achieving service speed (due to aging of vessel, fouling, etc)) and specific fuel oil consumption (constant at 190g/kWh as per IMO EEDI calculation) for the given time period, the total amount of fuel oil consumed for this period is calculated.

For each vessel, this stepwise approach is performed for the full trajectory of the vessel during the study period (accumulating all AIS signals received from the vessel), to result in the total FOC of the subject vessel. This analysis is repeated for all vessels in the project area.

Port calls

Within the DNV GL data warehouse the vessel specific AIS position data with detailed longitude and latitude information are matched with a comprehensive database of ports as geospatial objects. Please see an example for the port of Valencia in Figure 3. The area framed in green is the geospatial object for the entire port area and the frames in other colours are specific parts of the port such as container terminal, bulker terminals, etc.

Note that the analysis is based on the fair share principle, in essence a theoretical bunker demand based on port calls, and does not account for actual bunkering. Local variations (e.g. due to bunker attractiveness of specific locations and/or bunkering outside the port area) will be accounted for in chapter 4. In addition, the project includes a consolidation step between this report and the bottom-up report (containing results from interviews and an e-survey).

Figure 3: Port of Valencia with geospatial objects

Whenever a vessel has an AIS position signal inside a port frame, the event of a port call is triggered. When the vessel leaves the port frame, the port call is completed and the port call event counter increases by 1. In this way for every vessel and every port the overall port calls are collected. As all these events (port calls) are linked to a time stamp, for any vessel and any time period, the number of port calls can be read out of the DNV GL data warehouse and is available for further processing.

Estimated energy demand from shipping

By using the information of vessel specific FOC and vessel specific port calls the relevant energy demand from shipping ("fair share of bunker volume") is calculated. This is done for every individual vessel and for every port. It is calculated by multiplying the vessel specific FOC with the port calls in that specific port and then divided by the total number of port calls by the subject vessel.

To give an example, a 7,000 TEU container ship has sailed ~180,000 NM in the last two years. Based on speed pattern and technical vessel data the total FOC in that period is estimated to be 40,000 metric tons HFO equivalent (this is a theoretical calculation, independent of fuel used). During the analysed time period this vessel called 204 ports, of which 51 (25%) were in the area in scope. The relevant energy demand in the area in scope is therefore estimated to be 10,000 metric tons HFO equivalent in the analysed two-year period or 5,000 metric tons HFO equivalent annually (40,000 metric tons HFO equivalent x 25% share of port calls = 10,000 metric tons HFO equivalent as estimated energy demand in the area in scope).

All vessels that have only passed by, e.g. on the way from the Suez Canal to North Europe, have been excluded as the likelihood that they will change their trade pattern based on fuel availability or will stop only for bunkering is very small based on shipping expert's experience.

Annual FOC of the individual vessel and the ratio of specific port calls over total port calls of the subject vessel are used to determine the "fair share". Note that this methodology is a theoretical approach (fair share principle) and does not reflect the actual bunkering behaviour, but the energy demand per port related to the individual vessel. In the next phase, these vessel specific data are aggregated by port, by corridor and by vessel segment.

Corridors

During the two-year time period from 2014-07-01 until 2016-06-30 a total of approximately 12,500 vessels have been identified to call one or more of the selected ports in the three corridors. Note that about 21,000 vessels are identified in the area of which circa 12,500 are calling a port in the area. The remaining vessels are on trades not calling the ports in the project area. Table 2 shows the characteristics (shipping segments, vessel size expressed in Gross Tonnage, average age, average speed, min/max BHP, min/max FOC) of the fleet calling the ports in the subject area.

Table 2: Characteristics of the fleet calling ports in the subject area.

Gross tonnage (tons)

Vessel segment	<1000 GT	1000-5000 GT	5000-10000 GT	10000-25000 GT	25000-50000 GT	>50000 GT	Total	% share
1) Container ships		24	193	191	342	607	**1.357**	10,9%
2) Tankers	8	431	356	689	723	691	**2.898**	23,2%
3) Bulk carriers		32	63	784	1.170	254	**2.303**	18,5%
4) General cargo	31	1.426	747	261	18		**2.483**	19,9%
5) Car carriers		1	9	28	98	343	**479**	3,8%
6) Passenger ship	46	21	12	22	43	100	**244**	2,0%
7) Ro-Ro		5	31	40	37	25	**138**	1,1%
8) Ro-Pax	6	25	19	36	31	2	**119**	1,0%
9) Other	1.462	610	236	119	14	20	**2.461**	19,7%
Grand Total	**1.553**	**2.575**	**1.666**	**2.170**	**2.476**	**2.042**	**12.482**	100,0%
% share	12,4%	20,6%	13,3%	17,4%	19,8%	16,4%	100,0%	

Average age (y)

Average Age	<1000 GT	1000-5000 GT	5000-10000 GT	10000-25000 GT	25000-50000 GT	>50000 GT	Grand Total
1) Container ships		20,2	13,1	14,9	12,4	8,7	11,3
2) Tankers	27,4	12,4	10,0	9,3	8,5	9,5	9,7
3) Bulk carriers		26,6	12,9	9,8	8,9	7,1	9,4
4) General cargo	37,8	16,4	11,0	9,7	5,5		14,3
5) Car carriers		44,5	23,4	17,0	13,0	9,2	10,8
6) Passenger ship	22,8	30,8	33,4	27,0	21,4	10,9	19,3
7) Ro-Ro		27,9	21,8	17,3	7,1	7,7	14,2
8) Ro-Pax	25,4	20,1	19,7	17,4	15,2	8,3	18,0
9) Other	18,9	19,1	19,4	19,6	13,8	7,7	18,9
Grand Total	19,4	16,7	12,8	11,2	9,7	8,9	12,9

Average speed (knots)

Average speed	<1000 GT	1000-5000 GT	5000-10000 GT	10000-25000 GT	25000-50000 GT	>50000 GT
1) Container ships		9	10	11	13	15
2) Tankers	2	8	10	10	11	10
3) Bulk carriers		8	8	10	11	11
4) General cargo	4	7	10	12	12	
5) Car carriers		5	11	12	13	14
6) Passenger ship	3	7	8	10	12	13
7) Ro-Ro		6	9	12	15	13
8) Ro-Pax	3	5	6	9	13	20
9) Other	3	6	9	11	4	5

Min/Max Horsepower (horses)

	<1000 GT		1000-5000 GT		5000-10000 GT	
Horsepower	**Min of Total HP**	**Max of Total HP**	**Min of Total HP**	**Max of Total HP**	**Min of Total HP**	**Max of Total HP**
1) Container ships			2712	5812	5982	14358
2) Tankers	405	1400	1001	8158	2402	18082
3) Bulk carriers			1767	4900	2889	8158
4) General cargo					653	12848
5) Car carriers			4599	4599	4759	11258
6) Passenger ship	0	6308	1379	8244	4284	10002
7) Ro-Ro			2780	6118	3001	10062
8) Ro-Pax	799	6092	1250	38484	9246	44596
9) Other					0	37904
	10000-25000 GT		**25000-50000 GT**		**>50000 GT**	
	Min of Total HP	**Max of Total HP**	**Min of Total HP**	**Max of Total HP**	**Min of Total HP**	**Max of Total HP**
1) Container ships	9361	28878	13800	93323	0	109998
2) Tankers			7266	38545	10601	60569
3) Bulk carriers			8226	19415	12782	31159
4) General cargo	3825	23658	9090	17721		
5) Car carriers	8200	22842	7916	22242	12841	28470
6) Passenger ship			13868	43072	0	172478
7) Ro-Ro	6526	32632	14684	58736	16927	31121
8) Ro-Pax	7178	43072	24152	60476	75376	75376
9) Other	0	92278	0	61182	0	65262

Min/Max FOC (ton/y)

	<1000 GT		1000-5000 GT		5000-10000 GT	
FOC	Min of Total HP	Max of Total HP	Min of Total HP	Max of Total HP	Min of Total HP	Max of Total HP
1) Container ships			547	3255	964	7385
2) Tankers	60	2321	210	5211	367	8624
3) Bulk carriers			661	3378	459	4340
4) General cargo	4	530	15	3609	179	8201
5) Car carriers			448	448	2724	3662
6) Passenger ship	0	1038	23	3860	1823	6028
7) Ro-Ro			455	2113	590	4624
8) Ro-Pax	12	1062	122	7369	1981	16215
9) Other	0	1573	0	6316	145	12222
	10000-25000 GT		25000-50000 GT		>50000 GT	
	Min of Total HP	Max of Total HP	Min of Total HP	Max of Total HP	Min of Total HP	Max of Total HP
1) Container ships	1564	13136	1749	24274	1297	64889
2) Tankers	1	12617	905	30450	1111	38005
3) Bulk carriers	583	7269	973	12133	1554	17671
4) General cargo	159	10363	1461	10376		
5) Car carriers	2711	13092	4217	10978	1065	18498
6) Passenger ship	1447	12065	2502	26368	1254	52309
7) Ro-Ro	849	13989	7296	16679	3465	16402
8) Ro-Pax	897	14405	5179	32317	45983	50785
9) Other	103	21258	300	6545	1318	7887

As the LNG forecast model considers solely the vessels calling ports in the subject area, this fleet determines the baseline for energy demand from shipping. Table 3 shows the energy demand by corridor and by country.

Table 3: Estimated share of bunker volume [Mt HFO_{eq}/a]

Corridor/Country	2016
Atlantic	**1,7**
Spain	0,9
Portugal	0,8
Mediterranean	**2,4**
Spain	2,4
GS & Islands	**2,0**
Spain	1,9
Portugal	0,1
Grand Total	**6,1**

Segments

To streamline the analysis, the entire fleet in scope is broken down into eight main vessel segments. These segments are container ships, tankers, bulk carriers, general cargo ships, car carriers, passenger ships, Ro-ro and Ro-Pax. The tanker segment consists mainly of chemical and product tankers, crude oil tankers and LNG tankers. These eight segments account for over 90% of total estimated energy demand from shipping in the subject corridors. All other vessels are summarized in the vessel segment "Others" and are also included in the analysis work. The most important subtypes in the vessel segment "Others" include fishing vessels, refrigerated cargo ships and yachts. The list of subtypes per vessel segment is presented in Table 4.

Table 4: List of subtypes per vessel segment

Container Ship	Container Ship (Fully Cellular), Container Ship (Fully Cellular/Ro-Ro Facility)
General Cargo	Deck Cargo Ship, General Cargo Ship, General Cargo Ship (with Ro-Ro facility), General Cargo Ship, Self-discharging, General Cargo/Passenger Ship, Heavy Load Carrier, Heavy Load Carrier-semi submersible, Refrigerated Cargo Ship, Yacht Carrier-semi submersible
Passenger ship	Air Cushion Vehicle Passenger, Passenger Ship, Passenger/Cruise
Ro-Pax	Passenger/Ro-Ro Ship (Vehicles), Passenger/Ro-Ro Ship (Vehicles/Rail)
Ro-Ro	Palletised Cargo Ship, Ro-Ro Cargo Ship
Tankers	Asphalt/Bitumen Tanker, Bunkering Tanker, Chemical Tanker, Chemical/Products Tanker, Combination Gas Tanker (LNG/LPG), Crude Oil Tanker, Crude/Oil Products Tanker, Edible Oil Tanker, Fruit Juice Carrier, Refrigerated LNG Tanker, LPG Tanker, LPG/Chemical Tanker, Molasses Tanker, Molten Sulphur Tanker, Products Tanker, Replenishment Tanker, Shuttle Tanker, Tanker (unspecified),Vegetable Oil Tanker
Bulk carriers	Aggregates Carrier, Bulk Carrier, Bulk Carrier, Self-discharging, Bulk Cement Storage Ship, Cement Carrier, Limestone Carrier, Open Hatch Cargo Ship, Ore Carrier, Refined Sugar Carrier, Wood Chips Carrier
Car carriers	Vehicles Carrier
Other	Accommodation Platform (semi-submersible), Accommodation Ship, Anchor Handling Tug Supply, Bulk/Oil Carrier (OBO), Buoy Tender, Cable Layer, Crane Vessel, Crew Boat, Crew/Supply Vessel, Cutter Suction Dredger, Diving Support Vessel, Drilling Rig (semi-submersible), Drilling Ship, Factory Stern Trawler, Fish Carrier, Fish Factory Ship, Fish Farm Support Vessel, Fishery Patrol Vessel, Fishery Research Vessel, Fishery Support Vessel, Fishing Vessel, FPSO(Oil), FSO (Oil), Gas Processing Vessel, Grab Hopper Dredger, Hopper (Motor), Hospital Vessel, Icebreaker, Icebreaker/Research, Landing Craft, Landing Ship (Dock Type), Live Fish Carrier (Well Boat), Livestock Carrier, Logistics Vessel (Naval Ro-Ro Cargo), Mooring Buoy, Nuclear Fuel Carrier (with Ro-Ro facility), Offshore Construction Vessel (jack up), Offshore Support Vessel, Offshore Tug/Supply Ship, Patrol Vessel, Pilot Vessel, Pipe Burying Vessel, Pipe Layer, Pipe Layer Crane Vessel, Platform Supply Ship, Pollution Control Vessel, Pusher Tug, Refrigerated Cargo Ship, Research Survey Vessel, Sail Training Ship, Sailing Vessel, Search & Rescue Vessel, Sheerlegs Pontoon, Standby Safety Vessel, Stern Trawler, Stone Carrier, Suction Dredger, Suction Hopper Dredger, Supply Tender, Trailing Suction Hopper Dredger, Training Ship, Trawler, Trenching Support Vessel, Tug, Utility Vessel, Well Stimulation Vessel, Work/Maintenance Pontoon, non-propelled, Work/Repair Vessel, Yacht, Yacht (Sailing)

Within the above mentioned segments, the vessels show similarities in terms of renewal age, efficiency gains, expected LNG penetration, etc.

Table 5 depicts the estimated fuel demand by vessel segment for the Atlantic corridor. Main vessel segments in the Atlantic corridor include tankers (28% of estimated energy demand), container ships (20%), bulk carriers (17%) and general cargo ships (15%).

Table 5: Estimated fuel demand by vessel segment– Atlantic corridor [kt HFO_{eq}/a]

Vessel segment	2016
Container ships	338
Tankers	476
Bulk carriers	294
General cargo	249
Car carriers	80
Passenger ship	87
Ro-Ro	30
Ro-Pax	28
Other	103
Sum	**1.686**

Table 6 depicts the estimated fuel demand by vessel segment for the Mediterranean corridor. Main vessel segments in the Mediterranean corridor include container ships (32% of estimated energy demand), tankers (26%), bulk carriers (9%) and passenger ships (9%).

Table 6: Estimated fuel demand by vessel segment – Mediterranean corridor [kt HFO_{eq}/a]

Vessel segment	2016
Container ships	772
Tankers	620
Bulk carriers	206
General cargo	134
Car carriers	119
Passenger ship	205
Ro-Ro	59
Ro-Pax	171
Other	105
Sum	**2.390**

Table 7 depicts the estimated fuel demand by vessel segment for the GS & Islands corridor. Main vessel segments in the GS & Islands corridor include container ships (30% of estimated energy demand), others (20%), tankers (17%) and Ro-Pax (15%).

Table 7: Estimated fuel demand by vessel segment – GS & Islands corridor [kt HFO_{eq}/a]

Vessel segment	2016
Container ships	599
Tankers	312
Bulk carriers	27
General cargo	129
Car carriers	13
Passenger ship	205
Ro-Ro	36
Ro-Pax	306
Other	378
Sum	**2.005**

Ports

The estimated total fuel demand per corridor can also be split per selected individual port (as the analysis is performed per ship, data can be aggregated per port/corridor or per segment). Table 8 depicts the estimated fuel demand by corridor.

Table 8: Estimated fuel demand by corridor [kt HFO_{eq}/a]

Corridor	2016
Atlantic Corridor	1.686
Mediterranean Corridor	2.390
GS & Islands Corridor	2.005
Total	**6.081**

2.2 Estimation of development of fuel oil consumption

After determining the current energy demand, the second step in determining the potential demand for LNG as a ship fuel is the estimation of the consumption trends for the coming years up to 2050. In estimating the consumption development essentially two opposing effects are taken into account, growth of volumes of transport and development of energy efficiency in the fleet (mainly driven by replacement cycles and energy efficiency of newbuildings replacing older tonnage).

Scenarios

Scenarios describe likely outcomes on technology developments and associated investment levels and strategies in the (maritime) industry resulting from policy options.

A scenario is not a prediction of the future as such but rather a story of what the future might look like. With the scenario approach, we aim at spanning likely developments, at the same time as we want the scenarios to be sufficiently different to explore the effects of the identified trends and main drivers.

In order to reflect the uncertainty of future development, especially for such long time horizons, three scenarios are differentiated and developed in the assessment of consumption trends and LNG demand:

(1) "Basic scenario" – All significant drivers of LNG demand evolve realistically

(2) "Low scenario" – All significant drivers of LNG demand evolve negatively

(3) "High scenario" – All significant drivers of LNG demand evolve positively

The drivers are discussed one by one in the following chapters.

Transport growth

An increase in the demand for transport of important goods for the corridors and the assumption of similar share of modes of transport leads in a good approximation to an increase of consumption of marine fuels. Individual transport growth rates defined per segment are shown in Table 9. The data are extracted from DNV GL Maritime Global Scenario planning 2015 (/1/), which is a DNV GL analysis of IHS Fairplay data.

Table 9: Estimated annual transport growth rate by vessel segment (DNV GL in-house library)

Vessel segment	All scenarios
1) Container ships	1,0%
2) Tankers	1,2%
3) Bulk carriers	1,9%
4) General cargo	0,1%
5) Car carriers	1,3%
6) Passenger ship	1,4%
7) Ro-Ro	0,8%
8) Ro-Pax	0,8%
9) Other	0,9%

Due to the limited influence of the transport growth rate on the overall forecast of LNG demand, the growth rates are – for reasons of simplification – chosen constant for the different scenarios.

Fleet renewal

Since LNG is considered a realistic option for newbuildings, the expected replacement age is a key driver for LNG potential as new tonnage that might be fuelled by LNG is replacing existing tonnage fuelled by HFO over time.

Based on data from Clarksons (/2/), DNV GL assumptions and an analysis of the age structure of the fleet currently deployed in the area in scope, we estimate the average replacement cycles per segment. Replacement in this case includes scrapping as well as re-deployment of tonnage to other areas while deploying new tonnage in the three corridors. The numbers have been varied slightly across the three scenarios and are shown in Table 10.

Clarksons Research data is compiled and updated continuously from all available sources and where appropriate is confirmed by questionnaires and direct contacts with ship owners and shipyards. Regular surveys ensure the quality and completeness of data is continuously improved. Fleet statistics are taken from the Clarksons Research Fleet Database, which contains information of the world fleet along with owners' details plus orderbook, demolition and sales databases. Commercial data (trade, economics, prices, freight rates and earnings, ship prices etc.) are compiled by Clarksons Research from a large variety of in-house, industry, governmental and international sources. They represent an important part of an extensive database of shipping information maintained by Clarksons Research. Information is updated on a weekly or monthly basis.

One key aspect regarding assumed scrapping ages is IMO's Ballast Water Convention entering into force September 2017, where newbuild vessels will be required to have an IMO approved ballast water management system (BWMS) upon delivery while existing vessels must retrofit and install systems onboard. While most vessels on order are 'BWMS ready', the cost of retrofitting vessels is estimated to be anything between $1M and $5M per vessel and greater demolition of older ships is expected in the short to medium-term as vessels approach their compliance dates.

Table 10: Average replacement age by vessel segment

Vessel segment	Basic scenario [a]	Low scenario [a]	High scenario [a]
1) Container ships	24	26	22
2) Tankers	26	28	24
3) Bulk carriers	28	30	26
4) General cargo	24	26	22
5) Car carriers	24	26	22
6) Passenger ship	28	30	26
7) Ro-Ro	25	27	23
8) Ro-Pax	30	32	28
9) Other	25	27	23

Energy efficiency for newbuildings

The increase of fuel consumption caused by growth in transport volumes is partly compensated by an increase in energy efficiency. Progress in energy efficiency is another important factor that determines the LNG potential in the market. The fact that newbuildings replacing older tonnage are usually more efficient is generally obstructing LNG volumes as newbuildings can be up to 30% more efficient compared to current vessels.

The regulatory basis for the energy efficiency increase is the so-called Energy Efficiency Design Index (EEDI) which was made mandatory for new ships at Marine Environment Protection Committee MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)). The EEDI requires a minimum energy efficiency level per capacity mile (e.g. tonne mile) for different ship type and size segments. Since 1 January 2013, following an initial two-year phase zero, new ship design needs to meet the reference level for their ship type. The level is to be tightened incrementally every five years, and so the EEDI is expected to stimulate continued innovation and technical development of all the components influencing the fuel efficiency of a ship from its design phase. MARPOL's EEDI requires up to 30% more efficient vessels by 2025.

The baseline for the 30% increase in energy efficiency is the fleet from 1999-2008 (which is high speed with lots of horsepower). Therefore, DNV GL has accounted a digressive factor for more efficient vessels built after that period, based on the following considerations.

Based on EEDI requirements, an analysis of fuel efficiency of the currently deployed fleet in the area in scope across different age clusters and additional analysis such as a study on historical trends in ship design efficiency by the research organization CE Delft (/3/), and expert opinions on vessel designs (increase in energy efficiency is happening faster than required), the fuel demand of today's newbuildings compared to vessels that reach their expected replacement age is estimated. E.g. what is the fuel demand to deliver the same transport work of a container newbuilding in 2016 compared to a vessel built in 1992 as the average replacement age is expected to be 24 years in the basic scenario for this segment.

The estimated development in fuel efficiency in comparison to the transport work includes expected progress in engine and hull design, development of vessel sizes in the segments (larger vessels are usually more efficient) as well as changes in size of installed engines. On the other hand, we have accounted for new ultimate consumers which are a main driver in the cruise segment where many vessels have become more luxury and include additional new features in the hotel operation.

Potential energy efficiency measures for existing vessels, e.g. retrofits, have not been accounted for separately as they are not impacting the potential LNG demand in the model.

The table below gives an overview on the assumed difference in fuel demand of a 2016 newbuilding compared to a vessel that reaches its assumed replacement age in 2016 by segment. These values have varied slightly across the scenarios to reflect today's knowledge and the uncertainty of forecasts for the future.

The efficiency advance of a vessel with a 2016 design then continuously decreases in the model going forward as vessels that replace older tonnage in the future become younger, e.g. a container vessel that enters the market in 2036 replaces a 2012 newbuilding based on an expected replacement age of 24 years which is almost as efficient as a 2016 newbuilding.

Table 11: Fuel demand of newbuildings vs. replacement in 2016 by vessel segment

	Basic scenario				Low scenario				High scenario			
	2016	**2025**	**2030**	**2050**	**2016**	**2025**	**2030**	**2050**	**2016**	**2025**	**2030**	**2050**
Vessel segment												
1) Container ships	75%	85%	95%	100%	75%	85%	95%	100%	80%	90%	100%	100%
2) Tankers	80%	90%	95%	100%	80%	90%	95%	100%	90%	95%	100%	100%
3) Bulk carriers	85%	90%	95%	100%	85%	90%	95%	100%	90%	95%	100%	100%
4) General cargo	80%	85%	95%	100%	80%	85%	90%	100%	90%	95%	100%	100%
5) Car carriers	80%	85%	95%	100%	80%	85%	90%	100%	90%	95%	100%	100%
6) Passenger ship	85%	90%	95%	100%	85%	90%	95%	100%	90%	95%	100%	100%
7) Ro-Ro	80%	85%	95%	100%	80%	85%	90%	100%	90%	95%	100%	100%
8) Ro-Pax	80%	85%	95%	100%	80%	85%	90%	100%	90%	95%	100%	100%
9) Other	80%	90%	100%	100%	80%	90%	95%	100%	90%	95%	100%	100%

Efficiency used in the modelling focusses on efficiency gains by design of more efficient newbuildings. Additional operational efficiency gains have a more limited influence on the overall efficiency gain and are neglected in this model. Main operational fuel reduction measures, e.g. slow steaming, have been realized in the past and cannot account to a great extent for future efficiency gains.

2.3 Assessment of relevance of LNG as marine ship fuel

The next step to determine the relevant LNG demand is the estimation of the LNG market penetration for the various vessel segments. The LNG demand is defined for the three scenarios. Note that this LNG demand is not a prediction of the future, but rather an estimate of what the future might look like based on DNV GL's expertise given a set of identified trends and drivers.

2.3.1 Introduction

One of the main drivers for the diffusion of LNG as a maritime fuel is the current focus on regulating ships' airborne emissions. Shipping companies are obliged to use marine fuel with low sulphur content or need to ensure through technical measures equivalent limits of SOX emissions. Possible solutions include the use of LNG, the use of conventional low-sulphur marine fuels such as Low Sulphur Heavy Fuel Oil (LSHFO), Marine Diesel Oil (MDO) and Marine Gas Oil (MGO) or the use of Heavy Fuel Oil (HFO) in combination with application of exhaust gas scrubbers.

Based on screening of existing projects the likelihood that existing vessels install an engine retrofit to become LNG ready is very low, as alternative options to comply with regulation such as installation of a scrubber or switch to low sulphur fuels exist and are much less complex to implement. In the model LNG is therefore only considered as an option for newbuildings.

The expected LNG penetration of newbuildings is one of the key determining factors for the LNG market potential. Each vessel owner has to make an individual decision on the choice of the technical option as to meet regulatory requirements. This decision is based on an evaluation of technical and economical (CAPEX and OPEX) pros and cons which in turn depends on the operational profile of each vessel. General factors that influence this decision are the type of regulation in place and how strongly this regulation is enforced, as well as economic factors such as the oil price development and especially the development of the price difference between HFO and LNG (so-called fuel price spread). Key factors at individual vessel level are the operational profile, e.g. if vessel is deployed on global our regional trade, and share of fuel consumption in ECAs. In addition, soft factors such as green image play a role on segment level, e.g. in cruise segment.

A 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.

Provided that the different options have the same benefits for newbuildings as well as for retrofits or existing fleet, every shipping company comes to a decision based on their assumptions about investment and ongoing costs and further softer factors.

2.3.2 Approach

The below mentioned LNG uptake percentages are ultimately estimated based on the Shipping 2020 simulation model DNV GL had originally developed in 2012 to determine which technologies are likely to be implemented in the period leading up to 2020. The model, which has been revised and updated in 2015, takes into account a broad range of (quantitative and qualitative) variables, such as investment horizons, fuel burdens, operational patterns and risk appetite (some ship owners decide to invest in technology while other do not, for the same parameter set) within the industry. The model does not try to optimize the best path ahead, but simulates how each ship owner individually will seek to comply with regulations and increase energy efficiency. The 2015 update of the original 2012 model takes new insights regarding technology uptake, megatrends and external drivers into account, as well as the results of a ship owner survey.

The 2012 model simulates newbuilding (and retrofit technology) decisions for a representative set of ships, using regulatory compliance and net present value (NPV) as the main decision criteria. It initially generates a sample of individual ships that is representative for the operating fleet at the end of 2011. Each ship is given specific technical characteristics and owner preferences drawn from statistical distributions representing the diversity of the world fleet and its owners. The model then steps through each year until 2020. In each year, newbuildings are added to the fleet and older ships are scrapped. For each ship, the model simulates the decision to install one or more technologies. The resulting technology uptake from a simulation run is a result of these decisions. For each scenario, a large number of simulation runs are undertaken to see the effect on technology uptake of fuel prices and technology costs.

The 2012 model simulates uncertainty in prices for HFO, low sulphur heavy fuel oil (LSHFO), MGO and LNG. This is done by utilising a relative simple mean reversion stochastic model that simulates uncertainty around the fuel price trends defined for each scenario. Uncertainty in fuel oil prices is assumed to be linked to the crude oil price. There are mainly two possibilities for simulating LNG price uncertainty in the model (a combination of both is used for the weakly coupled scenario):

1. As fully linked to crude oil price;

2. As a separate gas market with no oil link.

Historical spot price data for Brent crude and Henry Hub natural gas is used to parameterise the stochastic model.

The 2015 update is adjusted for new insights in fuel prices uncertainty. Fuel price trends are based on forecasts by the EIA (US Energy Information Administration) and the IEA (International Energy Agency) and analysis undertaken by DNV Research & Innovation. The uncertainty in fuel prices was analysed based on data from historical prices, available from the EIA (crude oil and LNG/NG) and Clarkson (HFO/ MGO).

The ship owner’s share of fuel costs and economic preferences are based on a survey conducted by DNV GL and verified by experience data from relevant projects in DNV GL. The world fleet composition is based on the updated IMO GHG study and IHS Fairplay World Fleet Database. The volume of newbuildings and scrapped vessels are based on forecasts developed by the Institute of Shipping Analysis (SAI).

Regarding the technologies uptake, we have also been forced to make some simplifications as, based on the survey, different stakeholders claim different effects and operational characteristics. The technology costs and other assumptions are based on a wide range of sources, ranging from DNV GL experience data to manufacturers and literature research.

The technologies have been quantified in terms of:

1. Costs/CAPEX and assumed energy and emission reduction effect

2. Regulatory compliance

3. Compatibility and overlap between technologies

A base estimate for technology investment cost (CAPEX) is specified for each fleet segment, with an uncertainty factor that is given per technology. CAPEX uncertainty varies from +/-5% to +/-30 percent. The possible constraint on technology uptake resulting from lack of yard and/or maker capacity is not included in the analysis.

The main assumptions in order to define the different forecast scenarios are listed in the below table.

Table 12 Assumptions in the forecast scenarios

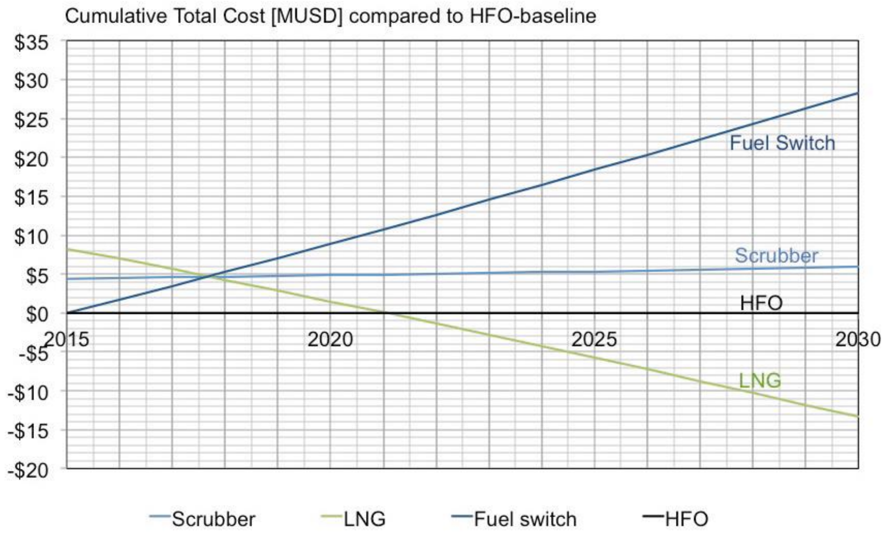
	Low Scenario	Basic Scenario	High Scenario
LNG fuel price delivered free on board	LNG 110% of HFO price (+ scrubber)	LNG at 70-80% of HFO price (+ scrubber)	LNG at 50% of HFO price (+ scrubber)
Oil and Gas price coupling	coupled	weakly coupled (oil link contracts and spot markets in place)	decoupled
Economic growth	Low 1% year on year	Medium & in line with EU 2% year on year	Higher than EU 3% year on year
Sulphur regulations	Low regulatory push: Global sulphur cap of 0.50%, originally planned for 2020 is postponed until 2025 and the EU sulphur directive comes into force in 2020. No new ECA's are planned.	Global sulphur cap of 0.50%, originally planned for 2020 is maintained and the EU sulphur directive comes into force in 2020. In this scenario proper enforcement of the emission regulations (ECA) can be expected	High regulatory push: Both the global sulphur cap and the EU sulphur directive come into force in 2020, new ECA zones are being established in the Mediterranean and in China
Access to capital	Low/limited	Medium	High
New technology uptake	Slow (S-curve: mainly Laggards)	Average (S-curve: mainly Late majority)	Quick (S-curve: mainly Early majority)

The assumptions are discussed in more detail below:

LNG FUEL PRICE – It is assumed that the price for LNG as a bunkering fuel will be determined by the regional natural gas price, marked up with a logistics cost of supplying LNG as a bunker fuel. The mark-up will of course not only include potential liquefaction and transportation costs but will most also depend on the number of handlers in the LNG supply chain and their respective handling fees, which are hard to predict since this is just an emerging market.

We furthermore consider the price spread between traditional bunker fuels and natural gas as a fundamental driver for using natural gas as a nontraditional transportation fuel, and the difference in prices should be sufficient to drive the conversion of diesel into LNG products, while emission rules of course also incentivise use of LNG in the marine sector.

DNV GL developed a so-called ECA simulation tool combining our technical advisory with stochastic simulation of lifecycle costs and payback time, to compare different ship fuel strategies (see illustration):



Storylines for future scenarios:

With an LNG price 10% above heavy fuel oil (HFO) + scrubber, the only driver to select LNG is compliance and avoidance of opex & capex costs for installing scrubbers. Payback times are relatively long, leading to a low expected LNG penetration for new buildings.

If the LNG price goes down to 20% below HFO + scrubber, the uptake of LNG is expected to increase, with payback times decreasing and investment risks equally decreasing.

In the extreme case of an LNG price 50% below HFO, the LNG share of newbuildings could peak to percentages as significant as 30% from 2020 onwards. (These vessels will have either pure gas fuelled engine or dual-fuel engine).

OIL AND GAS PRICE COUPLING- The price of natural gas differs across global markets, unlike the price of oil which is the same worldwide. The mechanism behind the pricing of natural gas is complex; many factors affect the (changes in the) cost of natural gas in different geographical locations.

In regions where there is no domestic supply of gas, typically the prices are related to the price of oil, as it is seen as a substitute fuel (this is the current case in Asia with its huge amounts of imported gas). In regions where there is high domestic supply, typically the gas prices are established by the market laws of demand and supply and not linked to the price of oil (This e.g. explains the recent drop in gas prices in the US since the supply of shale gas has been discovered there).

In Europe the mechanism for the pricing of gas is somewhat “mixed”: rather than the price of gas being solely related to the price of oil (as in Asia), or solely determined by the market (as in US), gas prices are typically indexed to a “basket” of energy alternatives such as coal, oil, and petroleum products. This results in natural gas prices that are cheaper than Asia (solely indexed to oil prices) and more expensive than those of the US (where there is a vast domestic supply of natural gas), and less linked to oil than in Asia but more than in US.

Storylines for future scenarios:

- Oil and gas price coupled: in this scenario we consider the EU gas price coupled to the world oil price. This could be the case if the EU is dependent on high amounts of import from a limited number of suppliers. In this case, prices themselves act to balance supply and demand; and overall economic conditions influence demand for natural gas, with limited short-term alternatives to natural gas as a fuel. End-consumers often fail to influence the price, and there is little transparency regarding margins, putting the end-consumer at a disadvantage in the contract negotiation.
- Oil and gas prices weakly coupled: in this scenario we consider the EU gas price weakly coupled to the world oil price. This reflects best the current situation where part of the import contracts is long-term and oil-indexed, but a share is spot market-based. In such a setting, the market is more open, with opportunities for different alternative gas suppliers to sell more and end-customers to pay less.
- Oil and gas prices decoupled: in this scenario we consider the EU gas price decoupled from the world oil price. This reflects a situation with a gas hub price based on supply and demand with flexible (even divertible) and spot LNG supply abundantly available.

ECONOMIC GROWTH - Energy economic theories hold that rates of energy consumption and energy efficiency are linked causally to economic growth. A fixed relationship between historical rates of global energy consumption and the historical accumulation of global economic wealth has been observed. Based on this overall insight, specifically for the construction of future shipping energy demand scenarios, different approaches can be used, e.g. extrapolating from historical demand, GDP growth or both historical use and future trends. Historically there has been a strong correlation between growth in GDP and shipping. However, analysts indicate that the recent greater emphasis on sustainability supports a steadier (lower) level of growth in shipping demand in the future.

We have therefore decided to consider fleet growth fixed (external) and only relatively consider the economic growth of the Iberian Peninsula in relation to the overall anticipated EU growth for the future scenarios:

- Low scenario: GDP growth in Iberian region lower than EU average, in the order of 1% year on year
- Basic scenario: GDP growth in Iberian region in line with EU, in the order of 2% year on year
- High scenario: GDP growth in Iberian region higher than EU, in the order of 3% year on year

SULPHUR REGULATIONS – International shipping is a heavily regulated industry. Additional regulations are becoming effective, with significant economic and operational implications. Key environmental regulations coming into force in this decade address emissions of sulphur oxides (SOx), nitrous oxides (NOx), particulate matter (PM) and greenhouse gases (in particular CO2), as well as ballast water management. New international regulations addressing ships' energy efficiency entered into force on January 1, 2013, while stricter sulphur requirements enter into force for specific sea areas in 2015 and globally in 2020, and demanding ballast water treatment requirements are expected to enter into force before the middle of the decade. Compliance is made challenging by a number of factors, including financial constraints, technological immaturity and uncertainty regarding enforcement and the consequences of non-compliance. The cost of compliance will be high for the maritime industry, and the business consequences of wrong decisions severe. In the longer run, the ability to navigate these regulatory waters is likely to be a key commercial differentiator.

Storylines for future scenarios:

In the low scenario we consider low regulatory and stakeholder pressure, and we see a negative trend with regard to the further development of global regulation. In this story there has been a tendency to see more regional and local regulatory initiatives, but some of these are also losing momentum. One example of this is that the EU's plan for implementing ECA-like requirements in all EU waters is put on hold and the discussions seem to lose ground and fade out. The 0.5% sulphur global cap planned for 2020 is postponed until 2025. The proposed plan of having the shipping industry contribute to the United Nations Framework Convention on Climate Change (UNFCCC)-agreed Green Climate Fund is also shelved. The Ballast Water Management Convention (BWMC) has not entered into force. The US decides not to progress with its own ballast water cleaning standards, planned to be stricter than IMO standards, but enforces the IMO requirements in their own waters. There has been no success in implementing MBMs, mainly due to major disagreements on the applicability of these mechanisms. The EU has also been unsuccessful in implementing regional mechanisms to reduce CO_2 emissions from shipping. In such a world, where there is low regulatory pressure, emissions are "free" and only a few players are driving developments that exceed the level of environmental regulations in place, branding themselves above the minimum standards.

In the basic scenario we consider that, while environmental regulations in the maritime industry have historically lagged behind those of other industries, this situation is now changing. An increased focus on both global and local environmental issues in general, combined with the growing realisation of the actual pollution burden imposed by shipping, has led to an upsurge in both international and national regulations. Some are ready for implementation and will enter into force in the near future, while others are still being developed and will have an impact only in the intermediate term. The key issues having a significant regulatory impact this decade are, broadly speaking, SOx, NOx, particles, greenhouse gases (in particular CO_2) and ballast water management. From a "beyond 2020" perspective, there are a number of emerging issues that appear likely to result in regulatory initiatives: key among these are black carbon, hull bio-fouling and underwater noise. In the absence of IMO progress, the EU will be proposing a regional mechanism to reduce CO_2 emissions from shipping. In this scenario proper enforcement of the EU sulphur directive and the emission regulations (ECA) is expected.

In the high scenario we consider a legally binding agreement on global cuts in CO_2 emissions that includes all countries, including the US and China. The EEDI scheme has been further developed beyond its 2013 introduction and is mandatory for existing ships. We expect to observe a forced phase-out of energy-inefficient ships, similar to what we saw for single hull crude oil tankers. There are major commercial implications for shipping companies and yards and these are strong drivers for innovation and technology development in the shipping industry. In 2025, ECAs cover all coastal areas worldwide. There are no 'sanctuaries' to be found for ships emitting SOx, NOx and PM. The transition to low sulphur fuels, in particular LNG, is shipping's strongest trend. The BWMC has been ratified to a level covering 80% of merchant shipping, and is a strong driver for technology uptake in this area. In a world where there is high regulatory and stakeholder pressure combined with strong growth in seaborne trade, shipping thrives through a high degree of innovation and technology development. We see an increased focus on environmental performance by charterers, forcing ship owners to implement environmentally friendly technology.

ACCESS TO CAPITAL – Shipping is a traditional capital intensive industry. The capex cost for machinery-related costs is in addition about 20 to 30% higher (MEC analysis 2015, DMA 2012) for new build LNG fuelled vessels compared to HFO fuelled vessels. The price difference between diesel engines and gas engines is small. The extra cost is due to increased piping and fuel tank costs. The machinery related cost accounts for 10-15% of the total ships costs (exact percentage depends on the ship type).

Storylines for future scenarios:

- Low scenario: Low capital availability in the market for this capital intensive sector puts limitations on the funding of new technology. An important percentage of new building is being delayed. Shipping owners are struggling to find the funds required to pay the shipyard upon delivery. Shipping companies are experiencing balance sheet issues, leading to increased cost of capital. Limited risk capital is available.
- Basic scenario: There is limited capital available for technology, R&D and education due to the weak state of the industry and the low regulatory and stakeholder pressure. Banks favor certain owners and are only willing to lend if they can see real and tangible cashflow from the projects of their clients.
- High scenario: Credit lines from banks and private equity are open and available to small and large shipping companies. Bankers overcome their traditional barriers to technology investment, which will drive the industry in future. Bankers are more far-seeing and have a "tech-economic thinking".

NEW TECHNOLOGY UPTAKE – History shows that major technology updating in shipping is driven primarily by regulatory changes and because of major accidents. Technology uptake also depends on the degree to which a technology is implemented, as financial and information costs tend to decrease as technologies mature. And finally, shipping is a rather conservative industry where very few companies can be considered as early adopters for new technologies.

The uptake of new technology typically follows an S-shaped curve (see figure below), with a slow initial acceptance followed by an accelerating pace, when the majority starts implementing and before it eventually slows down, as the market becomes saturated. The technologies we are considering here are typically implemented rather slowly due to a range of barriers such as lack of capital, split incentives on fuel savings (it's the owner who has to invest the capex while the potential opex savings are for the charterer), yard and designer capacity, and uncertainty connected to new technology.

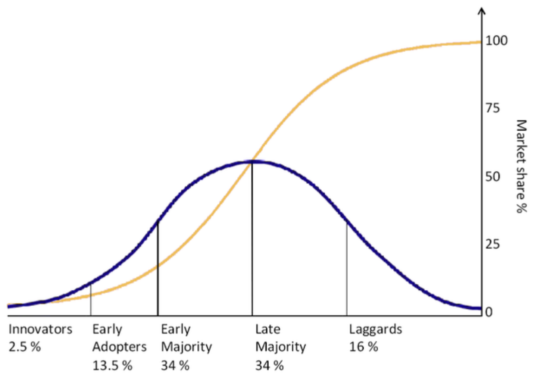


Figure 4: Typical technology uptake curve

Table 13 below shows the expected LNG penetration by vessel segment for the next generations of vessels in the newbuilding year clusters 2016-20, 2021-25, 2026-30, 2031-35 and 2036-50 in the basic scenario. High penetration is expected especially for the Passenger and the Ro-Ro/Ro-Pax segments. To reflect the high uncertainty driven by many factors involved the LNG penetration is varied across the three scenarios, see Table for scenario "Low" and Table for scenario "High".

The values in Table 13 to Table 15 represent DNV GL best insights for a set of scenarios (base, low, high with each their increasing/decreasing variables as defined in Table) based on the 2015 update of the 2012 model (accounting for new insights regarding technology uptake, megatrends and external drivers as well as the results of a ship owner survey).

Table 13: Expected LNG penetration of new buildings in the future – Basic scenario (DNV GL in-house library)

	Basic scenario				
	2016-20	**2021-25**	**2026-30**	**2031-35**	**2036-50**
Vessel segment					
1) Container ships	4%	7%	12%	15%	20%
2) Tankers	4%	8%	13%	16%	19%
3) Bulk carriers	4%	7%	12%	15%	19%
4) General cargo	4%	7%	12%	15%	20%
5) Car carriers	4%	7%	12%	15%	20%
6) Passenger ship	10%	25%	30%	35%	40%
7) Ro-Ro	10%	25%	30%	35%	40%
8) Ro-Pax	10%	25%	30%	35%	40%
9) Other	4%	5%	8%	10%	15%

Table 14: Expected LNG penetration of new buildings in the future – Low scenario (DNV GL in-house library)

	Low scenario				
	2016-20	**2021-25**	**2026-30**	**2031-35**	**2036-50**
Vessel segment					
1) Container ships	2%	4%	7%	10%	15%
2) Tankers	2%	6%	9%	13%	15%
3) Bulk carriers	2%	4%	7%	10%	15%
4) General cargo	2%	4%	7%	10%	15%
5) Car carriers	2%	4%	7%	10%	15%
6) Passenger ship	5%	10%	15%	20%	25%
7) Ro-Ro	5%	10%	15%	20%	25%
8) Ro-Pax	5%	10%	15%	20%	25%
9) Other	2%	2%	4%	6%	10%

Table 15: Expected LNG penetration of new buildings in the future – High scenario (DNV GL in-house library)

	High scenario				
	2016-20	**2021-25**	**2026-30**	**2031-35**	**2036-50**
Vessel segment					
1) Container ships	6%	11%	15%	19%	24%
2) Tankers	5%	11%	16%	21%	25%
3) Bulk carriers	5%	11%	15%	19%	24%
4) General cargo	6%	11%	15%	19%	24%
5) Car carriers	6%	11%	15%	19%	24%
6) Passenger ship	15%	30%	40%	45%	50%
7) Ro-Ro	15%	30%	40%	45%	50%
8) Ro-Pax	15%	30%	40%	45%	50%
9) Other	5%	8%	10%	13%	18%

2.4 Regional share

As highlighted above the analysis is based on the fair share principle and does not account for actual bunkering. Note that local variations (e.g. due to bunker attractiveness of specific locations) will be accounted for in chapter 4.

2.5 Calculation method to evaluate future LNG demand

2.5.1 Calculation method

In this chapter the calculation method for the evaluation of the future LNG demand is described. Based on the current energy demand (chapter 2.1), taking into account different factors (as presented in the previous chapters 2.2, 2.3 and 2.4) such as fleet growth, fleet renewal, efficiency, etc. the LNG demand is forecasted until 2050. The forecast is given per corridor and per shipping segment. In addition, the forecast is made per corridor and per port.

The following formula (LNG demand) is executed for aggregated vessels per year of construction for every individual segment in every single corridor:

$$\text{LNG demand} = \text{FOC} \times \text{Growth} \times \text{Fleet renewal} \times \text{Efficieny}_{NB} \times \text{LNG}_{penetration} \times \text{Regional share}$$

With

- FOC: Current energy demand, aggregated value per corridor and per vessel segment
- Growth: Segment specific transport growth, e.g. 1% yearly for container vessels (Table 9:)
- Fleet renewal: Specific yearly fleet renewal rate of each vessel segment. The model screens for every year (2016 – 2050) the age structure of the segment fleet. According to the assumed renewal age it is checked, what the percentage of vessels is leaving the operating fleet (share of energy demand) (Table)
- Efficiency_{NB}: Efficiency gain for newbuildings. The share of new vessels replacing old tonnage and supplying additional demand caused by transport growth is multiplied by the appurtenant efficiency gain (Table)

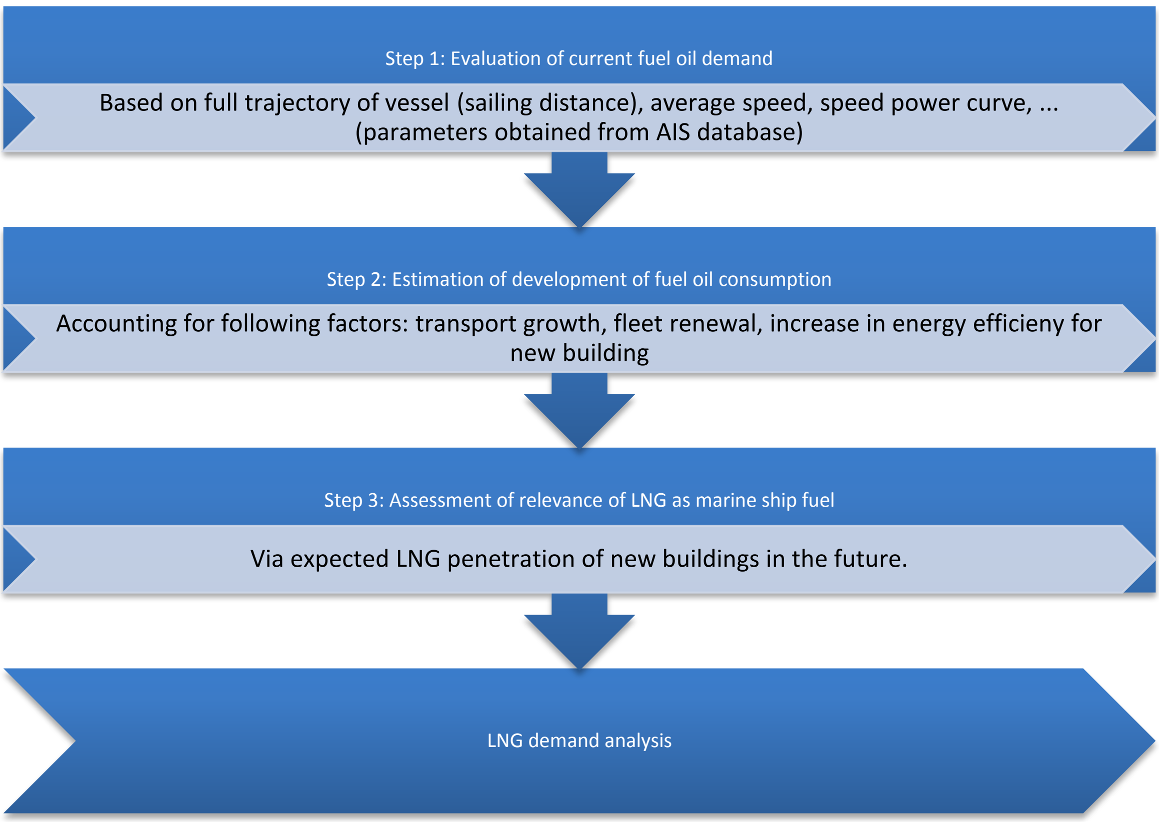
- $LNG_{penetration}$: Factor applied to the share of new tonnage, as the model considers LNG only as an option for newbuildings (Table -Table)
- Regional share: not accounted for yet, "Fair share" vs actual bunkering behaviour, factor = 1

Allocation of the LNG demand on port level is conducted by using the current share per shipping segment for each port (based on fair share principles) and the forecast of future LNG demand per segment and per corridor.

While the previous results for energy demand were given in [kt HFO_{eq}/a], for the following tables the LNG demand is given in [kt LNG_{eq}/a]. Conversion is carried out by applying the caloric factors of 40.4 MJ/kg for HFO and 48.0 MJ/kg for LNG.

2.5.2 Illustrative example

In the below paragraph, the methodology is illustrated by means of a simplified example. The analysis follows the steps as shown in below figure.



As an example, we assume 2 container vessels A & B, both sailing between P1 and P2. For reasons of simplification only one trip per vessel is assumed. Container vessel A, built in 1992, has a fuel consumption of 100 kton/a and container vessel B built in 1993 has a fuel consumption of 200 kton/a. Both vessels are only calling 2 ports, i.e. P1 and P2. Based on the fair share principle, 50% of the bunker demand will be in the project area (P1), leading to a total annual bunker demand in P1 of 150 kton/a.

From Table can be deducted that the fleet renewal rate is 24 years for container ships (basic scenario), leading to the following conclusions:

- Container vessel A (built in 1992) will be replaced in 2016
- Container vessel B (built in 1993) will be replaced in 2017

The LNG demand 2016 in P1 for the Basic scenario can now be calculated as follows:

- Container vessel A: 50 kton (FOC) X 75% (Efficiency for Newbuilds - Table) X 4% (LNG penetration - Table) = **1,5 kton HFO eq.**
- Container vessel B: 0 kton LNG (still running on conventional fuel, as this vessel is not being replaced in 2016)

The LNG demand 2017 in P1 for the Basic scenario can be calculated as follows:

- Container vessel A: **1,5 kton HFO eq**. (same vessel as in 2016)
- Container vessel B: 100 kton (FOC) X 75% (Efficiency for Newbuilds) X 4% (LNG penetration) = **3 kton HFO eq.**

The final LNG demand is obtained by comparing the calorific values of HFO_{eq} (40.4 MJ/kg) and LNG (48 MJ/kg). Note that the example makes abstraction of the shipping growth rate. The LNG demand hence is related to the individual vessels, but the results can of course be aggregated to the port or corridor level.

3 TOP DOWN RESULTS

The future LNG demand scenarios indicate that aggregated over all corridors LNG driven ships calling ports in Spain and Portugal are using 0.2-0.6 million tonnes of LNG in the year 2030 and 1-2 million tonnes of LNG in the year 2050. For reference, the LOT3 report (Analysis of the LNG market development in the EUR, CE Delft, 2015) indicates that LNG ships in the EU will be using 1-5 million tonnes of LNG in the year 2030.

3.1 Timeline

The model considers four time frames, developing linearly between 2016, 2020, 2025, 2030 and 2050. Detailed yearly fluctuations were not included in the model as they are not realistic to forecast.

3.2 Results by corridor

Estimation results show for the basic scenario the highest demand of LNG in the Mediterranean corridor with 0.7 million tonnes of LNG in the year 2050, closely followed by the GS & Islands corridor with 0.6 million tonnes of LNG in the year 2050 and finally the Atlantic corridor with 0.4 million tonnes of LNG in the year 2050. It is possible to see that information in the following table:

Table 16: Corridor results – Basic scenario (10^3 m^3)

Corridor	2020	2025	2030	2050
Atlantic	10,8	28,4	78,1	362,5
Mediterranean	26	116	314	1.489
GS & Islands	28	110	279	1.274
Total	**64,8**	**254,4**	**671,1**	**3.125,5**

Details for the reference years 2020, 2025, 2030 and 2050 for the Atlantic corridor differentiated by segment are shown in Table 17.

Table 17: Atlantic corridor – Basic scenario (10^3 m^3)

[10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	3	14	39	139
Tankers	3	10	43	213
Bulk carriers	2	9	22	172
General cargo	1	7	16	74
Car carriers	1	4	9	38
Passenger ship	3	11	24	90
Ro-Ro	0	2	8	25
Ro-Pax	0	1	4	23
Other	2	5	8	31
Sum	15	63	174	806

Details for the reference years 2020, 2025, 2030 and 2050 for the Mediterranean corridor differentiated by segment are shown in Table 18.

Table 18: Mediterranean corridor – Basic scenario (10^3 m^3)

[10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	6	29	86	379
Tankers	4	16	65	331
Bulk carriers	2	8	20	142
General cargo	1	6	11	47
Car carriers	1	6	14	66
Passenger ship	6	25	55	257
Ro-Ro	1	5	9	62
Ro-Pax	3	16	45	165
Other	2	6	9	39
Sum	26	116	314	1.487

Details for the reference years 2020, 2025, 2030 and 2050 for the GS & Islands corridor differentiated by segment are shown in Table 19.

Table 19: GS & Islands corridor – Basic scenario (10^3 m³)

[10^3 m³ LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	5	20	53	307
Tankers	2	8	35	164
Bulk carriers	0	1	3	18
General cargo	1	5	11	45
Car carriers	0	1	3	7
Passenger ship	7	28	58	257
Ro-Ro	1	3	5	36
Ro-Pax	4	23	80	297
Other	8	21	30	142
Sum	28	110	279	1.274

Corresponding tables for the scenarios "Low" (A-18L, A-19L, A-20L) and "High" (A-18H, A-19H, A-20H) can be found in the Appendix.

3.3 Development over time

Across all scenarios there is a significant increase in LNG demand to be noted. Comparing the three corridors and their LNG demand over time, it appears that the Mediterranean corridor with the highest LNG demand stays ahead over the other two corridors in all scenarios.

As the deployed fleet is very young in some segments, e.g. with an average age per vessel of just about 10 years for the tanker segment in all corridors in scope, for the bulker segment in the Atlantic and in the Mediterranean corridor, or for the Ro-Ro segment in the Atlantic corridor, the replacement of existing tonnage takes a significant amount of time and therefore the uptake of LNG demand is starting slowly.

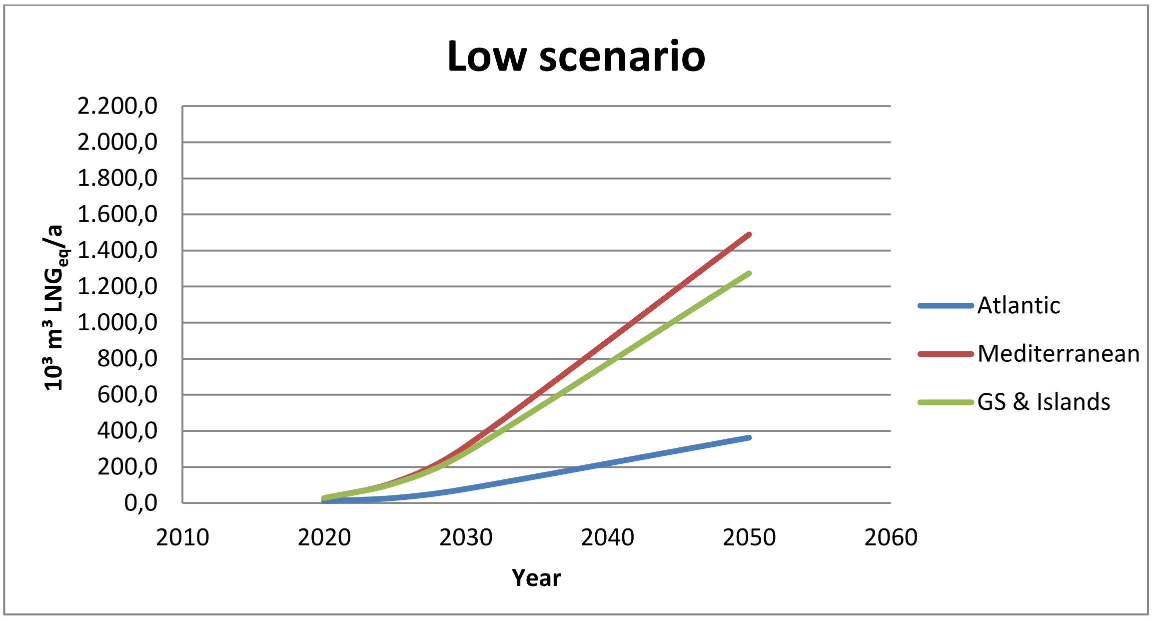


Figure 5: Energy demand by corridor – Basic scenario

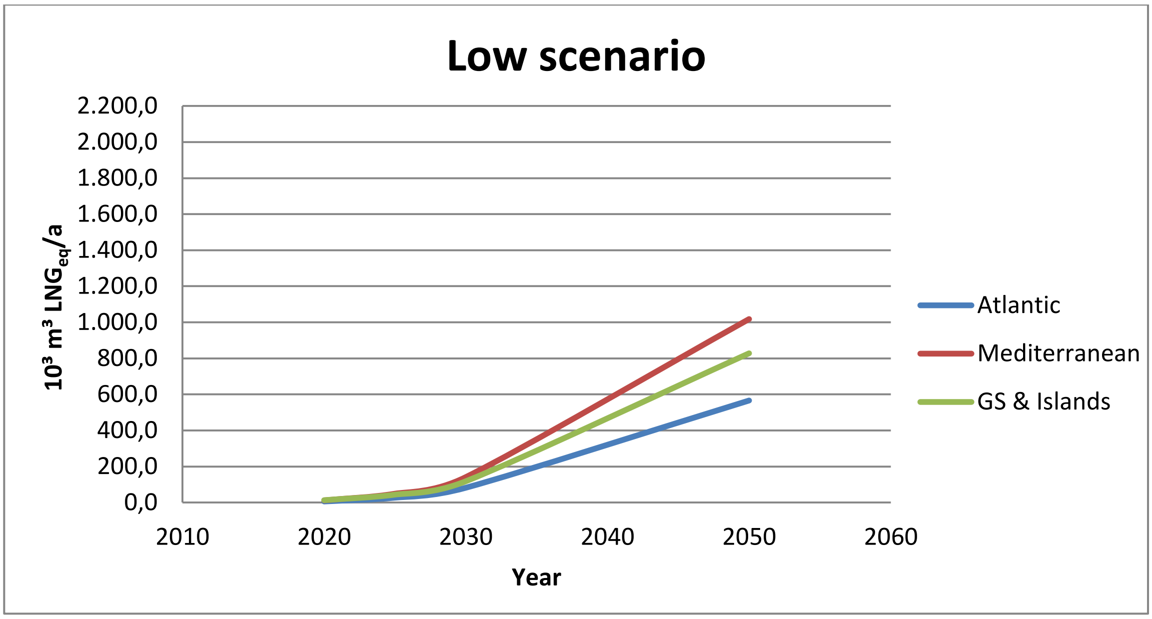


Figure 6: Energy demand by corridor – Low scenario

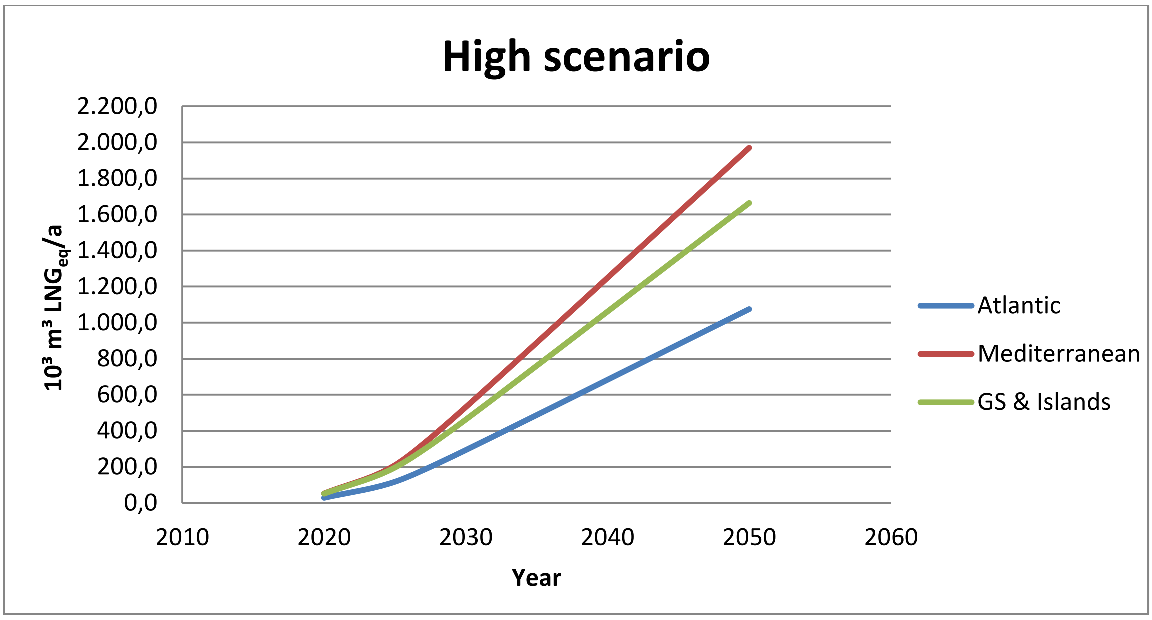


Figure 7: Energy demand by corridor – High scenario

4 REGIONAL SHARE - EXTRAPOLATION OF RESULTS TO ACTUAL BUNKERING DATA

4.1 Introduction

As highlighted above in chapter 2.4 the analysis is based on the fair share principle and does not account for actual bunkering. Analysis of the bunker data has shown that important local variations exist (e.g. due to bunker attractiveness of specific locations and the fact that some ports have specific anchorage areas where bunkering is performed). As example one can refer to the port of Algeciras where a theoretical bunker volume of 756 kton (HFOeq) is calculated whereas the real average bunker volume over the period 2012-2014 equals 3027 kton. This can be explained by the fact that a significant part of bunker operations is out of the zone which is identified as port area (bunkering at anchor in the bay and therefore not counted as a port call) and due to the attractiveness of that port. Similar trends are observed for the ports of Las Palmas and Ceuta.

In this chapter the values are updated for some key ports based on the actual bunker demand. It relates to the most important Spanish ports as the deviations are minor for Portugal.

4.2 Actual bunker data

The total tons/year bunkered in main Spanish ports was delivered by Puertos del Estado to Enagas and is shown in Table 20. To calculate the average yearly bunker supply (in tons/year) for every port, 3 reference years (i.e. 2012, 2013 and 2014) were considered.

Table 20 - Average current bunker supplied per port, based on client data, average of 2012-2014

Port	Average yearly bunker supply (tons/year)
Algeciras	3 027 190
Ceuta	589 978
Barcelona	724 823
Valencia	373 967
Santa Cruz de Tenerife	695 774
Las Palmas	2 015 681
Baleares (P. de Mallorca + Ibiza)	4 907
Bilbao	62 960
Tarragona	63 202
Huelva	105 881
Cartagena	4 403
Vigo	95 365
Santander	8 712
Castellon de la Plana	5 297
Malaga	24 201

Port	Average yearly bunker supply (tons/year)
Gijon	77 250
Aviles	6 578
Cadiz	16 906
Motril	22 630
A Coruña	38 980
Alicante	3 243
Ferrol	4 779
Almeria	25 125
Melilla	311
Marín y Ría de Pontevedra	16 232
Pasajes	9 205
Sevilla	9 796
Vilagarcía	1 082
SPAIN total	**8 034 458**

4.3 Conversion

The via AIS obtained forecast has been updated – by means of a correction factor – to the actual bunker data obtained from the Client, still accounting for the bunkering behaviour split between vessels types as per AIS model. Via this correction factor the calculated bunker demand is set to the level of the actual bunker demand, keeping all the remaining parameters and hence the relative ratios fixed.

4.4 Results by corridor

Estimation results show for the basic scenario the highest demand of LNG in the GS & Islands corridor with 1.7 million tonnes of LNG in the year 2050, followed by the Mediterranean corridor with 0.4 million tonnes of LNG in the year 2050 and finally the Atlantic corridor with 0.24 million tonnes of LNG in the year 2050.

Table 20: Corridor results – Basic scenario (10^3 m^3)

Corridor	2020	2025	2030	2050
Atlantic	10	45	121	541
Mediterranean	17	76	205	944
GS & Islands	81	305	791	3725
Total	**108**	**426**	**1117**	**5210**

Details for the reference years 2020, 2025, 2030 and 2050 for the Atlantic corridor differentiated by segment are shown in Table 21.

Table 21: Atlantic corridor – Basic scenario (10^3 m³)

[10³ m³ LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	2	13	36	128
Tankers	2	6	26	130
Bulk carriers	1	5	13	98
General cargo	1	4	10	45
Car carriers	0	3	5	24
Passenger ship	2	9	20	75
Ro-Ro	0	1	5	16
Ro-Pax	0	0	1	5
Other	1	3	5	20
Sum	10	45	121	541

Details for the reference years 2020, 2025, 2030 and 2050 for the Mediterranean corridor differentiated by segment are shown in Table

Table **22**: Mediterranean corridor – Basic scenario **(10^3 m³)**

[10³ m³ LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	4	21	62	273
Tankers	2	8	31	158
Bulk carriers	1	3	9	60
General cargo	1	3	6	24
Car carriers	1	5	12	55
Passenger ship	4	17	37	172
Ro-Ro	1	3	6	41
Ro-Pax	2	14	40	145
Other	1	2	4	16
Sum	17	76	205	944

Details for the reference years 2020, 2025, 2030 and 2050 for the GS & Islands corridor differentiated by segment are shown in Table 23.

Table 23: GS & Islands corridor – Basic scenario (10^3 m³)

[10³ m³ LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	19	77	206	1190
Tankers	8	30	134	636
Bulk carriers	1	5	12	60
General cargo	4	19	42	171
Car carriers	0	4	10	27
Passenger ship	10	39	79	352
Ro-Ro	2	10	17	114
Ro-Pax	9	54	190	709
Other	28	67	100	466
Sum	81	305	791	3725

Corresponding tables for the scenarios "Low" (A-26L, A-27L, A-28L) and "High" (A-26H, A-27H, A-28H) can be found in the Appendix.

4.5 Development over time

The development over time for the different scenarios is expressed in Figure 8 to Figure 10. Across all scenarios there is a significant increase in LNG demand to be noted. Comparing the three corridors and their LNG demand over time, it appears that the GS & Islands corridor with the highest LNG demand stays largely ahead over the other two corridors in all scenarios.

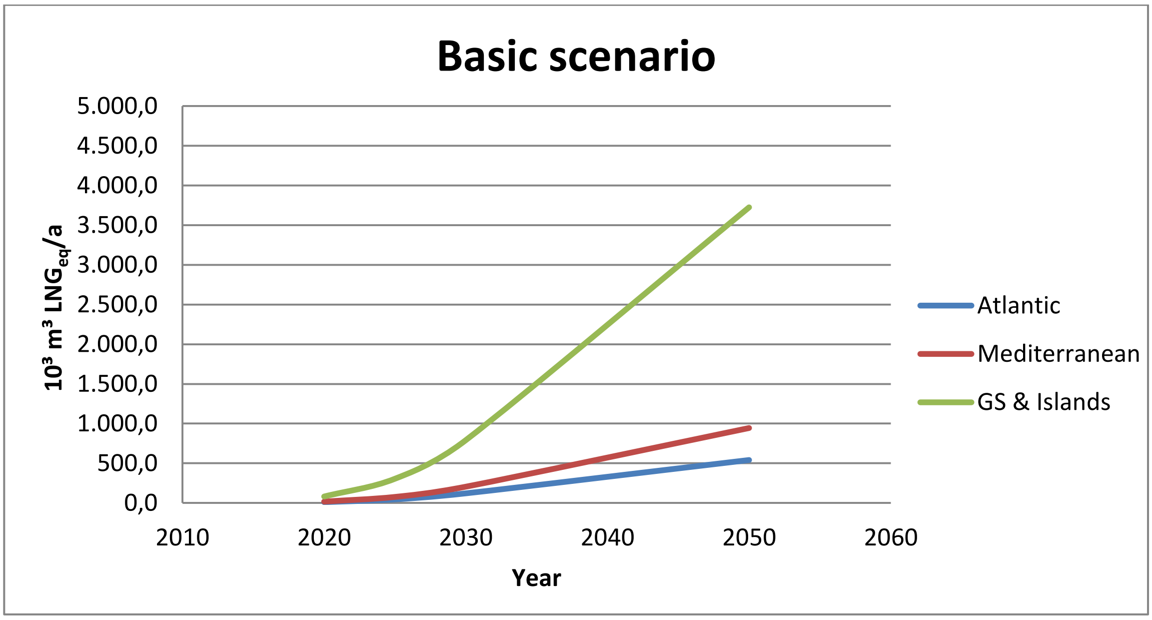


Figure 8: Energy demand by corridor – Basic scenario

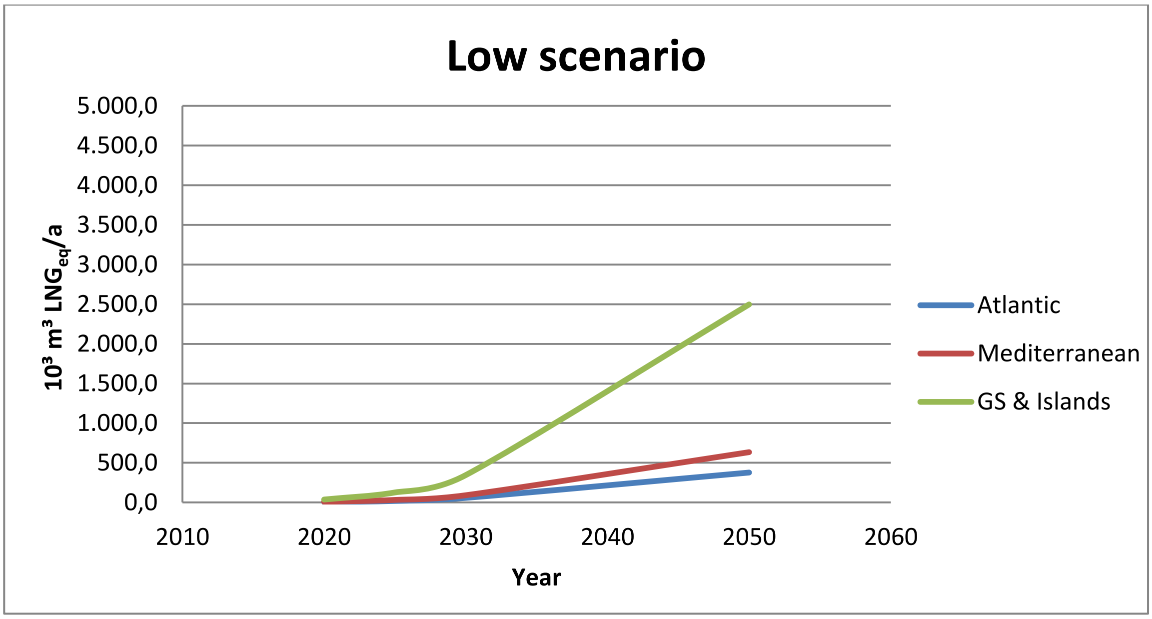


Figure 9: Energy demand by corridor – Low scenario

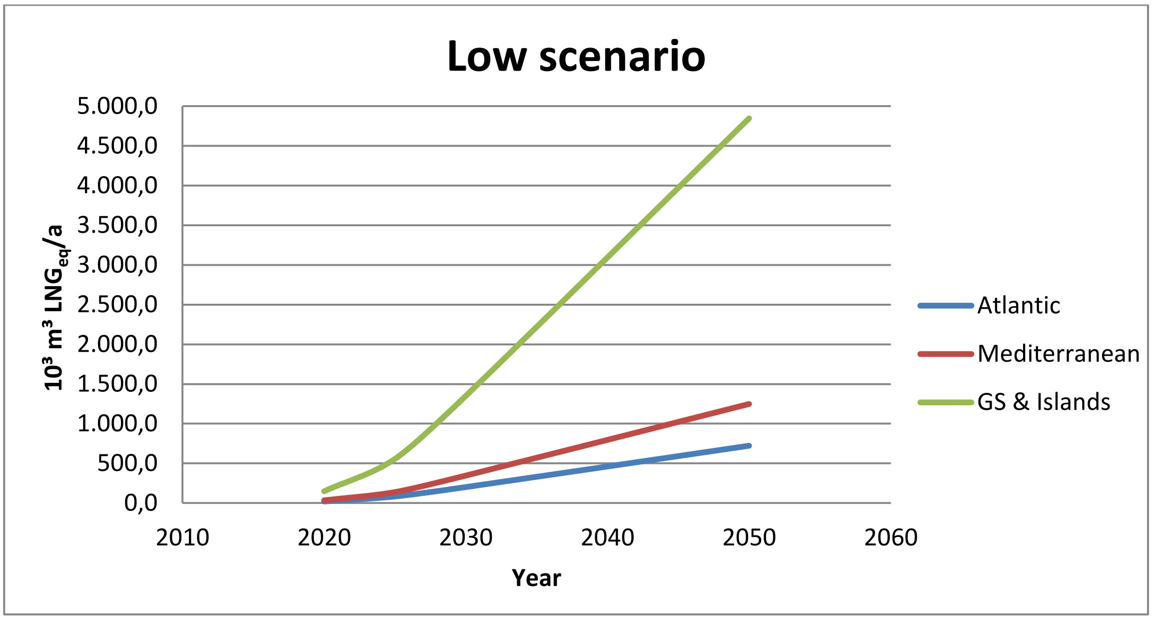


Figure 10: Energy demand by corridor – High scenario

5 SENSITIVITY

We can assume a status quo of vessels approaching selected ports in the defined corridors “Atlantic”, “Mediterranean” and “GS & Islands” and the associated annual fuel consumption of these vessels. The error margin is likely to be around 5%, so this has little impact on the demand forecast. The development of consumption as a combination of changing transportation needs and rising energy efficiency gained from newbuildings and improvement of operation has a greater uncertainty. We estimate the error margin of the baseline scenario to be about 10% and compensate for this by the two additional scenarios.

The estimation of the LNG share in the future consumption holds a significantly higher uncertainty. The LNG penetration rates depend on a variety of uncertain parameters. From a shipping company perspective this includes availability of LNG, future pricing of LNG compared to HFO and compared to conventional low-sulphur marine fuels as well as technical and financial development of required technologies. The error margin of the LNG market penetration is expected to be at 50% across all segments.

The final uncertainty is the proportion of the relevant LNG demand, which is covered in the individual corridors and in the individual ports, respectively. Differentiating how many times vessels called ports in the observation period and the likelihood of changing transport patterns, we estimate the margin of error here to be at 25%.

6 REFERENCES

/1/ DNV GL Maritime Global Scenario planning 2015, DNV GL

/2/ Global Shipping Fleet Forecast, Clarkson Research

/3/ Historical trends in ship design efficiency, 2015 . s.l.: CE Delft

7 LIST OF FIGURES AND TABLES

8 APPENDIX

8.1 Basic calculations

8.1.1 Low Scenario

LOW SCENARIO (10^3 m^3 LNGeq/a)				
Corridor	**2020**	**2025**	**2030**	**2050**
Atlantic	6	27	82	566
Mediterranean	12	49	141	1.018
GS & Islands	13	44	118	828
Total	**31**	**120**	**341**	**2.412**

LNG FORECAST PER VESSEL SEGMENT FOR THE SPECIFIED CORRIDORS

Vessel segment	2020	2025	2030	2050
Container ships	1	6	19	93
Tankers	1	6	21	171
Bulk carriers	1	4	12	129
General cargo	0	3	8	51
Car carriers	0	2	5	24
Passenger ship	1	4	10	53
Ro-Ro	0	0	3	14
Ro-Pax	0	0	1	13
Other	1	2	4	18
Sum	6	27	82	566

A-18L: Atlantic corridor – Low scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	2	13	40	265
Tankers	2	10	30	265
Bulk carriers	1	4	11	106
General cargo	0	3	6	33
Car carriers	1	3	7	44
Passenger ship	3	9	22	152
Ro-Ro	0	2	4	37
Ro-Pax	1	5	17	95
Other	1	2	4	22
Sum	**12**	**49**	**141**	**1.018**

A-19L: Mediterranean – Low scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	2	9	27	217
Tankers	1	5	15	133
Bulk carriers	0	1	2	13
General cargo	0	2	5	31
Car carriers	0	0	2	4
Passenger ship	3	11	24	151
Ro-Ro	0	1	2	21
Ro-Pax	2	7	28	173
Other	4	8	14	85
Sum	**13**	**44**	**118**	**828**

A20L: GS & Islands corridor – Low scenario [10^3 m^3 LNG_{eq}/a]

8.1.2 High Scenario

HIGH SCENARIO (10^3 m^3 LNGeq/a)				
Corridor	**2020**	**2025**	**2030**	**2050**
Atlantic	28	117	293	1.075
Mediterranean	52	209	531	1.970
GS & Islands	51	196	462	1.664
Total	**131**	**522**	**1.286**	**4.709**

LNG FORECAST PER VESSEL SEGMENT FOR THE SPECIFIED CORRIDORS

Vessel segment	2020	2025	2030	2050
Container ships	6	28	63	184
Tankers	4	19	75	289
Bulk carriers	3	15	34	228
General cargo	4	14	32	98
Car carriers	2	9	15	50
Passenger ship	5	17	36	120
Ro-Ro	0	5	11	35
Ro-Pax	0	1	13	30
Other	3	9	13	42
Sum	**28**	**117**	**293**	**1.075**

A-18H: Atlantic corridor – High scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	15	56	153	493
Tankers	6	28	113	448
Bulk carriers	3	14	30	189
General cargo	4	10	21	63
Car carriers	3	12	25	88
Passenger ship	11	40	87	338
Ro-Ro	2	8	14	80
Ro-Pax	6	30	72	221
Other	3	10	14	50
Sum	**52**	**209**	**531**	**1.970**

A-19H: Mediterranean corridor – High scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	11	38	99	385
Tankers	3	14	62	221
Bulk carriers	1	3	5	24
General cargo	3	9	22	60
Car carriers	0	3	3	10
Passenger ship	12	43	85	342
Ro-Ro	1	5	15	47
Ro-Pax	8	46	122	392
Other	12	35	48	182
Sum	**51**	**196**	**462**	**1.664**

A-20H: GS & Islands corridor – High scenario [10^3 m^3 LNG_{eq}/a]

8.2 Regional share update

8.2.1 Low Scenario

LOW SCENARIO (10^3 m^3 LNGeq/a)				
Corridor	**2020**	**2025**	**2030**	**2050**
Atlantic	4	19	58	377
Mediterranean	7	32	91	634
GS & Islands	37	126	345	2.497
Total	**48**	**177**	**494**	**3.508**

LNG FORECAST PER VESSEL SEGMENT FOR THE SPECIFIED CORRIDORS

Vessel segment	2020	2025	2030	2050
Container ships	1	5	18	85
Tankers	1	4	13	104
Bulk carriers	1	2	7	74
General cargo	0	2	5	31
Car carriers	0	1	3	15
Passenger ship	1	3	8	44
Ro-Ro	0	0	2	9
Ro-Pax	0	0	0	3
Other	1	1	2	12
Sum	4	19	58	377

A-26L: Atlantic corridor – Low scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	1	9	29	191
Tankers	1	5	14	126
Bulk carriers	0	2	4	45
General cargo	0	1	3	17
Car carriers	0	2	6	37
Passenger ship	2	6	15	102
Ro-Ro	0	1	3	24
Ro-Pax	1	5	15	83
Other	0	1	2	9
Sum	**7**	**32**	**91**	**634**

A-27L: Mediterranean corridor – Low scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	7	36	103	842
Tankers	3	18	59	513
Bulk carriers	1	2	6	45
General cargo	1	9	19	116
Car carriers	0	1	7	15
Passenger ship	4	14	33	206
Ro-Ro	1	3	7	67
Ro-Pax	5	17	66	414
Other	15	25	46	278
Sum	**37**	**126**	**345**	**2497**

A28L: GS & Islands corridor – Low scenario [10^3 m^3 LNG_{eq}/a]

8.2.2 High Scenario

LOW SCENARIO (10^3 m^3 LNGeq/a)				
Corridor	**2020**	**2025**	**2030**	**2050**
Atlantic	20	83	201	722
Mediterranean	34	138	346	1.248
GS & Islands	148	556	1.350	4.847
Total	**202**	**777**	**1.897**	**6.817**

LNG FORECAST PER VESSEL SEGMENT AND PER PORT FOR THE SPECIFIED CORRIDORS

Vessel segment	2020	2025	2030	2050
Container ships	6	25	58	169
Tankers	2	12	46	176
Bulk carriers	2	9	19	130
General cargo	2	8	20	59
Car carriers	1	5	9	31
Passenger ship	4	15	30	100
Ro-Ro	0	3	7	23
Ro-Pax	0	0	3	7
Other	2	6	8	26
Sum	**20**	**83**	**201**	**722**

A-26H: Atlantic corridor – High scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	11	41	111	356
Tankers	3	13	54	214
Bulk carriers	1	6	13	80
General cargo	2	5	11	32
Car carriers	2	10	21	73
Passenger ship	7	27	59	226
Ro-Ro	1	5	9	53
Ro-Pax	5	26	63	194
Other	1	4	6	21
Sum	**34**	**138**	**346**	**1248**

A-27H: Mediterranean corridor – High scenario [10^3 m^3 LNG_{eq}/a]

Vessel segment	2020	2025	2030	2050
Container ships	42	147	382	1494
Tankers	12	54	242	856
Bulk carriers	2	9	17	82
General cargo	12	36	83	228
Car carriers	1	11	13	38
Passenger ship	17	59	116	467
Ro-Ro	3	15	47	149
Ro-Pax	19	110	293	937
Other	40	116	158	597
Sum	**148**	**556**	**1350**	**4847**

A-28H: GS & Islands corridor – High scenario [10^3 m^3 LNG_{eq}/a]

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