BINNENVAART
Deployment in Inland
Waterway Transport

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Breakthrough LNG Deployment in Inland Waterway Transport

1.1 Execution of ex-ante cost/benefit analyses for the best available LNG technologies for vessels

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1 Introduction

The uptake of LNG in IWT experiences various bottlenecks and under which the lack of information concerning the costs and benefits of LNG. This analysis aims to fill up the information gap and contribute to the uptake of LNG in IWT by providing the necessary insight into the costs and benefits from a ship owners' point of perspective, and by providing insight into the environmental benefits for the society, resulting from emission reduction by using LNG as compared to conventional diesel fuel. Consequently, this analysis covers the effects on both the users (vessel-owners) as non-users (the society).

2 Approach

The required data for this analysis is provided by experts[1] in field involved in the Action, existing studies within the Action and other studies (see references for an overview). The calculations are based on a couple of assumptions, these assumptions were determined during expert meetings. The relevant assumptions are:

- LNG is not a suitable alternative for diesel for all vessel types. Therefore a selection has been made concerning the suited vessel types based on their characteristic. For this purpose the general costs structures overview has been used which is drafted in the study "Analysis of the costs and benefits of the application of after-treatment"[2] which is in turn based on the analysis of Rijkswaterstaat to the general cost structure for Western European vessels (see table 1 in the appendix)[3]. In this overview the IWT fleet is classified into a number of fleet families and corresponding representative vessel types within each fleet family (see table 2 in Appendix). From this overview the following representative vessels with corresponding characteristics have been selected:

[1] Beneficiaries involved in the Action are: ENGIE LNG Solutions, Scheepswerf Gebroeders Kooiman, Pon Power, Trifleet Leasing, Koedood Dieselservice, Dolderman, Pitpoint, Cryonorm Systems, Wartsila Netherlands and Stichting Projecten Binnenvaart (SPB)
[2] http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_11_14_PROMINENT_D2.2_Ex-ante-cost-benefit-analysis-of-business-cases-for-standard-after-treatment-configurations.pdf
[3] http://www.rws.nl/zakelijk/werken-aaninfrastructuur/steunpunt-economische-expertise/kengetallen/overige-documenten/index.aspx

Table 3: vessel types suited for LNG

	Passenger vessels	Push boats		Motorvessel dry cargo >=110m length		Motorvessel liquid cargo >=110m length			Coupled convoys
	hotel/cruise vessels	500-2000 kW	>=2000 kW	M8	M9		M11	M12	mainly class Va + Europe II lighter
Fleet family	1	3b	4a	5a	5b	6a	6b	6c	10
Vessel type representative vessels	PAX 135m	PushBII-1	Push B4	MVS110m	MVS 135m	MTS 110m	MTS 135m	MTS 135M	C3L/B
Length	135		116,5	110	135	110	135	135	110 + 80
Width	11,45	11,4	15 / 11,4	11,4	11,45	11,4	11,45	17	11,4
Draught	2		1,72 / 4	3,5	3,3	3,5	4	3,8	3,4
Max payload (t)			11200	3043	3300/268 teu	2908	4290 (5320 m^3)	6228	5500
Operational hours/year*	4318	4313	8064	4318	7898	4318	7898	7898	8064
engines	2,0	2,0	3,0	1,0	2,0	1,1	2,0	2,0	2,0
Installed kW	1492	1249	4080	1527	1492	1550	2347	2370	2351

Source: derived from http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_11_14_PROMINENT_D2.2_Ex-ante-cost-benefit-analysis-of-business-cases-for-standard-after-treatment-configurations.pdf

The remaining fleet families with representative vessel types excluded from this overview are considered to be less suitable for LNG in most cases, either due to vessel specific technical reasons and/or given the average operational characteristics like the yearly fuel consumption.[4] Most of the excluded vessel types are those which are smaller in size as compared to the vessel types mentioned in table 3 above, a second and even more important difference is the fuel consumption while the excluded vessels have a relatively low average annual fuel consumption making it very difficult to earn the investment back.

- This analysis illustrates the LNG investment costs for both existing as well as newbuild vessels for abovementioned vessel types. However in reality it may appear to be difficult, but not impossible, for certain existing vessels to be equipped with LNG installations. As such, some of the vessel types mentioned above are suitable for LNG once it especially concerns a newbuild; it will be difficult to equip an existing push boat with an LNG installation due to technical reasons concerning the general layout of such relative small

[4] However, there could be some cases in which an vessel, belonging to a vessel type excluded in this analysis, is yet suited for LNG due to, for example, an annual fuel consumption far beyond the average. Such cases are possible, however based on average values the excluded vessels are assumed to be unsuitable for LNG in most cases.

platforms. Whereas a newbuild push boat can be designed taking into account the LNG-installation and the general arrangement in relation to location of LNG related installations, ventilation, and safety regions on board.

- The calculations are based on the assumption of the presence of a repowering moment, i.e. a moment that an ship owner with an existing conventionally driven vessel needs to carry out a repowering operation. In such a case the ship owner would have to replace its existing installation with a new, most likely diesel, installation anyhow and therefore only the additional costs of an LNG-installation as compared to a conventional diesel-installation will be relevant. Consequently, the calculations are based on the additional costs of an LNG-installation as compared to a diesel-installation.
- The costs are based on the most effective economic solution and limited economies of scale resulting from equipping 5 vessels with LNG technology at a time. Deviating and alternative solutions may be realized with relatively higher investment costs.
- External costs of emissions (PM and NOx) per ton are an average of the costs for Germany, Belgium and the Netherlands. These three countries together form also the location of the Action. The costs of PM, NOx and CO2 (equivalent) are derived from the 'Handbook on estimation of external costs in the transport sector'.[5]
- The environmental benefit calculations are based on pollutant (PM and NOx, PN is not taken into account) and CO2 emission reduction. Pollutant emission reduction is based on a reduction from CCNR-2 limits towards EU NRMM Stage V limits for engines above 300kW. While it is assumed to have a repowering moment the benchmark for environmental benefit calculations will be CCNR-2, which is currently together with EU NRMM Stage IIIA, a near equivalent, the applicable emission standard for IWT. A vessel will have to meet this standard, or better, after a repowering moment anyway. EU NRMM Stage V on the other hand is the coming emission standard, as of 2019/2020, for IWT in EU member states and relevant from an ex-ante point of perspective.[6] It appeared from consultations with experts that the coming Stage V standard can be met with LNG without after treatment systems (SCR, DPF) which would be required to install for diesel powered Stage V engines.

[5] https://www.cupt.gov.pl/files/CUPT/analizakoszt/metodologia/wytycznepodr/metodologies/External%20Costs%20of%20Transport%20in%20Europe%20Update%20Study%20for%202008%20CE%20Delft%20INFRAS%20Fraunhofer%20ISI%20wrzesien%202011.pdf

[6] 2019 for propulsion (IWP) and auxiliary (IWA) engines below 300kW and 2020 for IWP and IWA engines above 300kW

- This analysis assumes a reduction of Green House Gases (GHG), expressed in CO2 equivalent, of up to 10% per vessel as result of a switch from diesel to LNG.[7]
- The used scenarios for the LNG fuel price are derived from the study 'Quantitative analysis LNG potential West-European IWT fleet', sub-report of 'Scenarios for the deployment of LNG in Inland Waterway Transport'. These studies are performed within activity 4.3 Consultation of stakeholders and research the market potential of LNG vessels.[8]
- The economic lifetime of the LNG installation is assumed to be 10 years with a residual value of 30%.[9] A value of 4% is taken into account as discount rate.

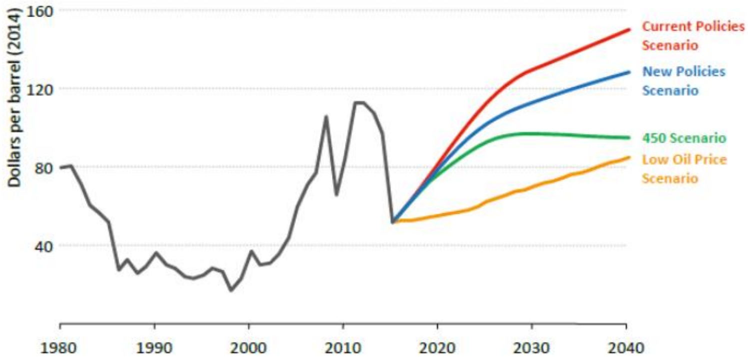
[7] 10% according to consultation with Pitpoint, http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_09_11_PROMINENT_D-1.2.-best-available-technologies_final.pdf
[8] Available on https://lngbinnenvaart.eu/downloads/
[9] According to consultation with Wartsila

3 Benefits

3.1 Financial benefits

The financial benefits in this analyses covers savings on fuel costs and port dues. The change in fuel costs resulting from the switch from diesel to LNG forms the core of this chapter, while it plays the key role for the return on investment. For this purpose a bandwidth is used for the price difference between diesel and LNG in the long term (spread). Long-term prospects are used while prices do strongly fluctuate on the short term, making it in turn difficult to paint a reliable picture of the potential fuel cost savings. The study 'Quantitative analysis LNG potential West-European IWT fleet' provides 4 scenarios for the price difference. The price difference is, among others, based on the LNG and oil price scenarios as included in the "World Energy Outlook 2015", considering a situation where LNG has always a limited price advantage relative to diesel.[10] The expected development of oil prices plays a key role for all four scenarios, which is presented in the figure below.

Figure 1: Average IEA crude oil import price by scenario



Source: World Energy Outlook 2015

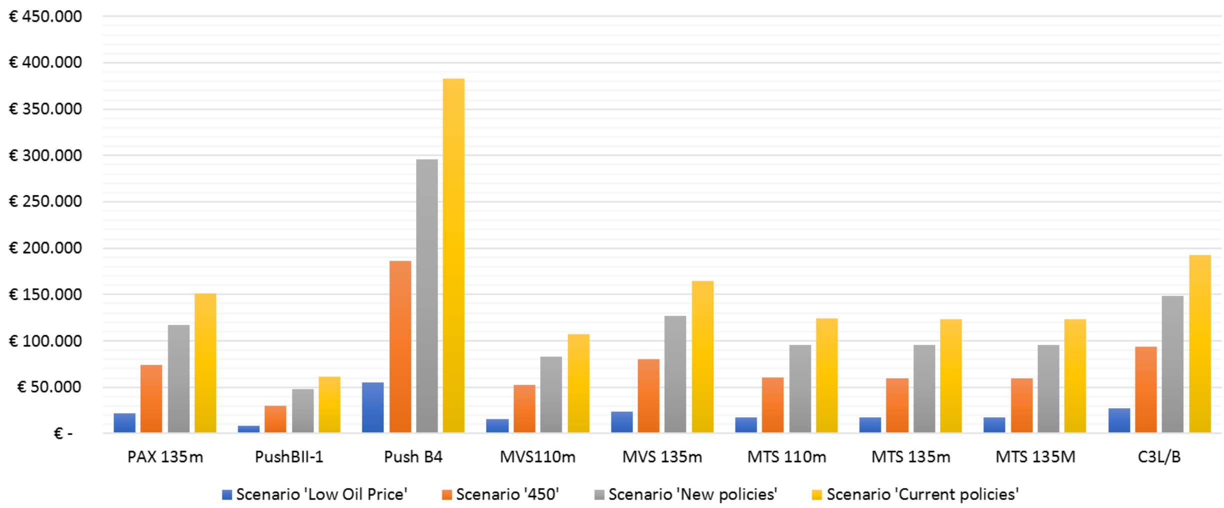
[10] The used scenarios for the LNG fuel price are derived from the study 'Quantitative analysis LNG potential West-European IWT fleet', sub-report of 'Scenarios for the deployment of LNG in Inland Waterway Transport'. These studies are performed within activity 4.3 Consultation of stakeholders and research the market potential of LNG vessels.

The price difference is expressed in an price advantage of LNG over diesel per liter in euros, resulting in the following four scenarios:

Scenario 'Low Oil Price'	€ 0,05
Scenario '450'	€ 0,17
Scenario 'New policies'	€ 0,27
Scenario 'Current policies'	€ 0,35

Based on these 4 scenarios the change in annual average fuel costs for a 100% switch to LNG is being calculated for the representative vessel types.[11] [12] The resulting annual average price advantage of LNG as compared to diesel is visualized in figure 2.

Figure 2: Price advantage LNG-Diesel according to 4 scenarios



Source: own elaboration

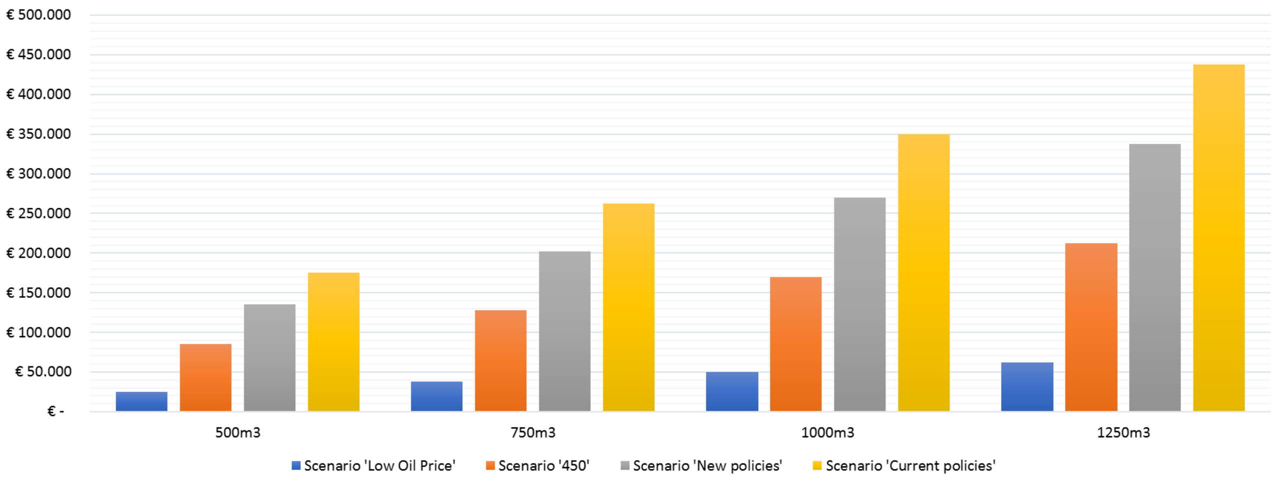
It can be seen from figure 2 that the vessel type Push B4 has the most significant potential savings on fuel costs, due to its relatively high fuel consumption as compared to the remaining vessel types. Coupled convoys (C3L/B) is on the second place concerning the amount of potential savings on fuel costs, whereas the motor cargo dry vessel (135m) comes as third. However, the potential savings on fuel costs are based on the average fuel consumption as included in the general cost structure in table 1 of the appendix.

[11] Based on the average fuel consumption as included in general cost structure for Western European vessels (see table1).
[12] The price advantage for a duel-fuel driven vessel will be relatively lower, depending on the exact fuel mix.

It is discussed in the 'analysis of the potential and sailing profiles of LNG using vessels in Europe' for activity 4.1, that the potential LNG fleet has a yearly fuel consumption of at least 500 m^3. This volume was taken as a threshold, while – according to first calculations – in order to earn back the LNG investment a vessel had to consume in the first place at least 500 m^3 of gasoil per year. This can be seen as a rough threshold, while it can be either higher of lower depending on the price difference between LNG and diesel. However, the higher the annual fuel consumption the shorter the payback period, making it therefore valuable to take the group with a relatively high fuel consumption into account.

Figure 3 in the appendix contains a boxplot which illustrates the fuel consumption of the IWT fleet with a high fuel consumption, i.e. more than 500 m^3 annually. It can be seen from the figure that the average fuel consumption of this fleet is much higher as compared to the average fuel consumption as mentioned in the general cost structure (table 1). Figure 4 below illustrates the potential annual savings on fuel costs for four fuel consumption categories (500 m^3, 750 m^3, 1000 m^3 and 1250 m^3 annually), being more in line with the fuel consumption of the potential LNG fleet.

Figure 4: Price advantage LNG-Diesel for four different fuel consumption categories



Source: own elaboration

It can be seen from both figure 2 and 4 that there is a significant potential on fuel cost savings, provided that the diesel price, and in turn the oil price, is relatively high. On the other hand, both figures also provide that the diesel price can form a major barrier for the uptake of LNG in IWT. This will be the case when the scenario 'low oil price' will sustain on the long term, which will make it difficult to realize a positive business case for investing in LNG driven inland vessels.

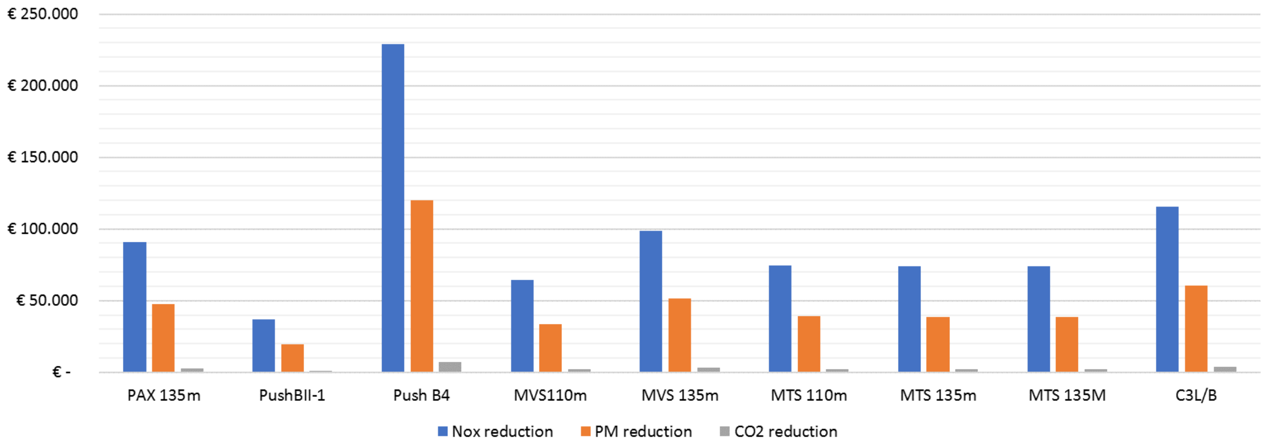
Savings can also be realized on port dues once a vessel obtains a Green Award due to a cut in emissions as result of sailing on LNG. Ports which are connected to Green Award provide reduction on port dues to certified clean ships.[13] Incentive providers for IWT consist of ports located in the Netherlands and Belgium, each port manages their own discount rate. However, the discount rate on port dues across all incentive providers is on average 13,55%.[14] Based on this average discount rate the maximum savings on port dues are calculated and illustrated in table 4 in the Appendix.[15] The granted discount for 'cleaner' vessels is a shot in the right direction, however it does not significantly contribute to a positive business case while the provided discount on port dues is marginal in comparison to the annual total costs as displayed in table 1. In order to have a notable effect the port dues should be significantly lower and also more ports, across more countries, should be connected to the initiative.

[13] http://www.greenaward.org/greenaward/467-english.html
[14] http://www.greenaward.org/greenaward/file.php?id=1721&hash=fbdfbf7b23272986132c90a5edf51c8b
[15] This is an average value; vessels may call on a select number of ports with a relatively higher discount percentage or vessels may also call on ports which are not connected to Green Award initiative and consequently does not provide an incentive.

3.2 Environmental benefits

Operating on LNG as compared to diesel creates significant positive externalities due to emission reduction. This sub-chapter translates the potential emission reduction to environmental benefits, i.e. benefits for the society, in euro's. Table 5 in the appendix contains the results of the environmental benefit calculations and figures 5 and 6 below visualize the environmental benefits (expressed in euros) based on the average fuel consumption (see table 1 in appendix) and four fuel categories as also used in figure 4. It can be seen from figure 5 that vessel type Push B4 may realize by far most emission reduction as compared to the remaining vessel types, due to its relatively high annual fuel consumption, which also indicates that these two factors are strongly correlated to each other as also can be seen in table 6 of the appendix.[16] Figure 5 shows also significant differences across NOx, PM and CO2. This can be related to the realized emission reduction in weight and to the emission cost. The largest reduction in weight is realized for CO2 whereas NOx comes as second and PM in third. However, when expressed in euros CO2 reduction results by far in the smallest benefits. This can be linked to the CO2 price which is significantly lower as compared to the price of PM and NOx.

Figure 5: Annual environmental benefits in euros for representative vessels

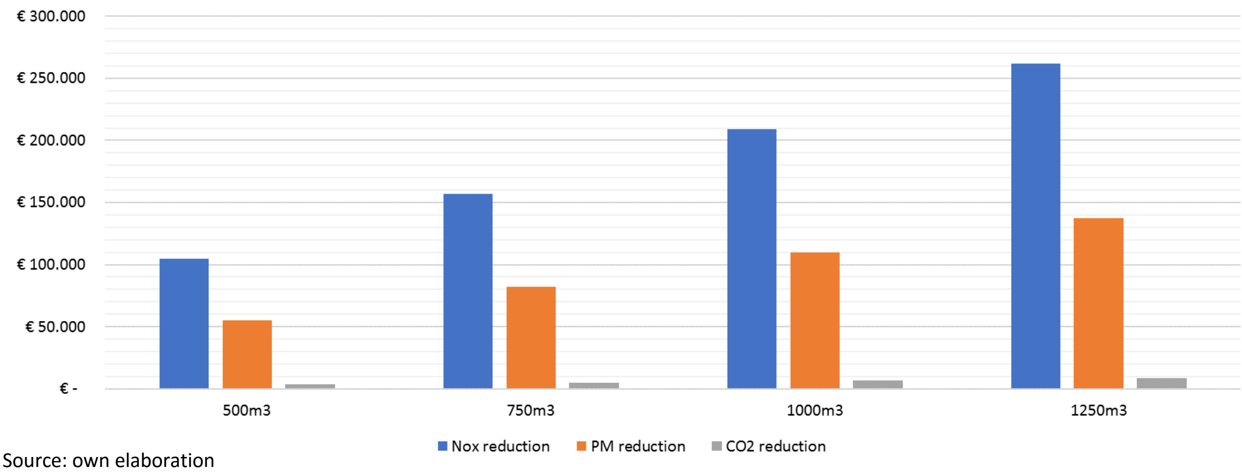


Source: own elaboration

[16] Correlation between between total consumed fuel and total environmental benefits is positive and relationship is also significant at the 5% significance level.

The environmental benefit is also identified, and illustrated in figure 6 below, for the four fuel categories which are more in line with the fuel consumption of the potential LNG fleet. It can be seen from both figures that the realizable emission reduction is relatively larger for higher fuel consumption categories.

Figure 6: Annual environmental benefit in euros for four fuel consumption categories



Source: own elaboration

Concluding, realizable environmental benefits are in all cases significant especially when considering that the illustrated environmental benefits are annual and benefits will be realized during the whole lifetime of the LNG installation.

4 Costs

Concerning the costs this analysis puts the focus mainly on investment costs for an LNG-installation, which consists basically out of three major hardware components and the installation costs. The three hardware components are the engine, tank (appendages included) and tank connection space. This analysis classifies the engines into three categories, namely mono-fuel gas engines, dual-fuel engines and a dual-fuel refit engines.

Mono-fuel engines

Mono-fuel engines, or also referred as 100% gas engines, use gas as single fuel. Manufacturers of mono-fuel engines and their suppliers for IWT are AGCO/Sandfirden, Caterpillar/Pon Power, Guascor/Sandfirden, Jenbacher/Jenbacher, Man Rollo/Man Rollo, Mitsubishi/Koedood, Scania/Sandfirden.[17] It is common for vessels to deploy mono-fuel gas engines in a gas-electric configuration. This configuration basically consists of e-engines, gas generator sets and frequency controllers, being a more extensive configuration as compared to dual fuel/dual fuel refit.[18]

Dual-fuel engines

Dual-fuel engines run on a fuel mix of LNG and diesel, though the emphasis is on using LNG. The Dual-Fuel engine can nevertheless run fully on diesel. There are different engines available regarding the fuel mix, a common type is the dual-fuel engine of Wärtsilä with a fuel mix of up to 99-95% LNG and 1-5% diesel. Diesel is actually only necessary for the fuel injection.[19] Another provider of dual-fuel engines is ABC, engines of ABC operate with nearly 90% of gas content in the fuel mix.[20] Caterpillar/Pon Power was a third provider of dual-fuel engines for IWT, however Caterpillar altered its strategy towards an engine mix consisting of pure gas and diesel only engines with an average fuel mix will of 85% LNG and 15% diesel for IWT. The objective is to maximize the consumption of gas, but always have diesel available as redundancy in challenging

[17] According to consultation with Koedood
[18] http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_11_14_PROMINENT_D2.2_Ex-ante-cost-benefit-analysis-of-business-cases-for-standard-after-treatment-configurations.pdf
[19] http://www.groenervaren.nl/15-nieuwe-shell-tankers-op-lng-krijgen-wartsila-motoren/
[20] https://www.mkc-net.nl/library/documents/207/download/

conditions.[21]

Dual-fuel refit engines

The last category of dual-fuel refit engines concerns the case in which an existing diesel engine of the type Caterpillar 3500[22] will be refitted to a dual fuel LNG engine with a fuel mix of 98% LNG and 2% diesel. This solution is being provided by ArenaRed and Dolderman.[23]

The LNG tank and tank connection space are the other two major components of the hardware. The LNG tank is the tank in which the fuel is stored, an average tank size of 40 m^3 is considered to be the standard for inland vessels.[24] The tank connection space is a space surrounding all tank connections, vaporizers, valves, etc., forming part of the fuel gas supply system.[25]

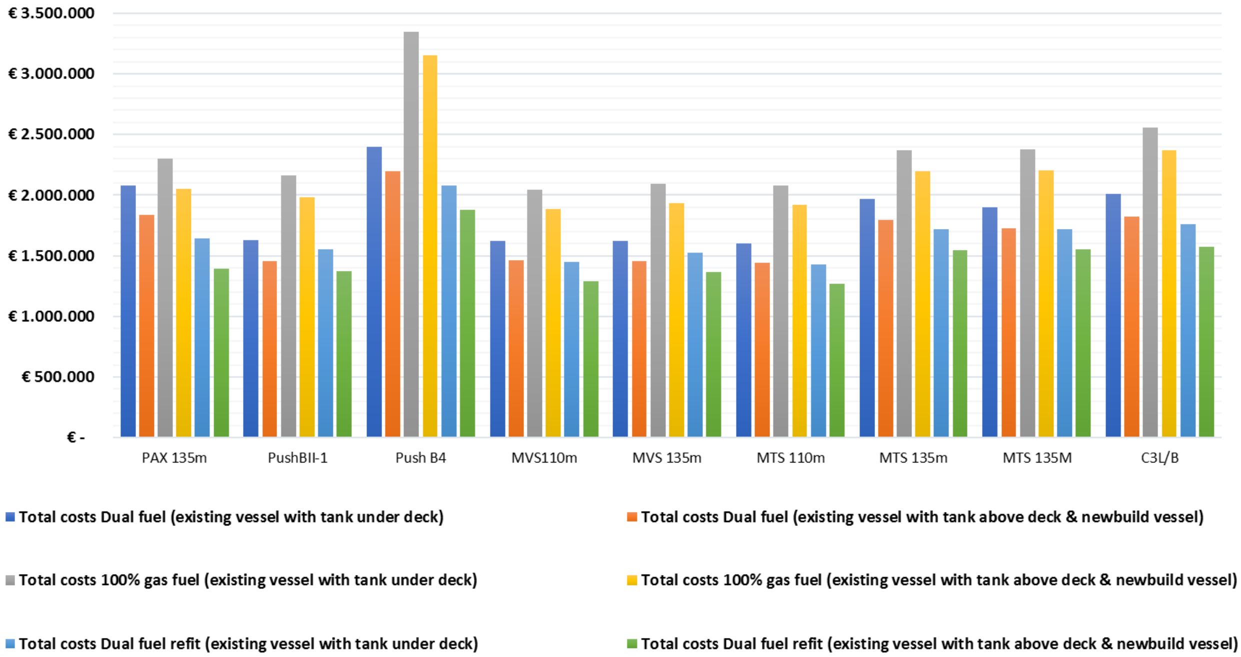
The costs for an LNG engine depend on the type of engine and the required power in kW, the costs are therefore divided according to the representative vessels and engine type. The costs for an LNG tank and tank connection space remains the same for all selected representative vessels due to the chosen standard tank capacity of 40 m^3 and the corresponding tank connection space. However, the installation costs will strongly vary between existing vessels with an LNG tank above deck and vessels with a tank underdeck. This difference in installation costs applies to existing vessels, placing an LNG tank underdeck in an existing vessel will significantly drive up the installation costs as compared to the situation in which an LNG tank will be installed above deck. This is mainly due to the necessary welding and cutting activities underdeck in order to free up the required space for the LNG tank. The mentioned difference in installation costs is not relevant for new build vessels while the vessel will be designed according to the preferences for placing an LNG tank above or underdeck. The installation costs of an LNG-installation is estimated to be the same for existing vessels with an LNG tank above deck as for new build vessels. Consequently, the installation costs can be divided into two categories, namely the categories 'existing vessel with tank above deck & newbuild vessel' and 'existing vessel with tank under deck'.

[21] According to consultation with Pon Power
[22] According to consultation with Dolderman the engine type Caterpillar 3500 is a very commonly used engine type in the IWT fleet
[23] http://www.verbrandingsmotor.nl/lidbedrijf/arenared-bv
[24] According to consultation with Cryonorm
[25] http://www.lng-info.de/fileadmin/Normen/Draft_IGF-Code_26.04._2013_rev.12.07.2013.pdf

An additional cost component for existing vessels only are the costs of idling due to the needed installation time in the shipyard (see table 11 in appendix). The additional installation time for LNG is estimated to be around 4 weeks.[26] During the estimated 4 weeks the vessel is not being put to productive use, while fixed costs are ongoing. Therefore the idling costs are estimated to be at least equal to the fixed costs over the estimated additional installation time.

Figure 7 provides a clear visualization of the investment costs for the mentioned configurations and representative vessels.

Figure 7: Total investment costs for various configurations and representative vessel types[27]



Source: own elaboration

At first sight it stands out that the vessel type 'Push B4' has on average relatively higher investment costs as compared to the other vessel types, which is mainly due to the fact that this vessel type is the only one in the overview with 3 installed engines due to the relatively high installed power (in kW's) on board, whereas the other vessels have 1 or 2 installed engines on

[26] According to consultation with Dolderman and Koedood; total installation time for LNG is around 8 weeks whereas total installation time for repowering lies around 4 weeks, resulting in a total additional installation time of 4 weeks for LNG.
[27] Idling costs for existing vessels are not included in the total costs

average with relatively less power on board. Therefore, the installed power for all selected representative vessels and total investment costs for all six categories are strongly correlated to each other (see table 7 in appendix)[28], while a higher installed power will require more engines on board, in turn significantly driving up the costs. Vessels with a relatively high installed power on board have also a relatively high annual fuel consumption on average (see table 1 and 6 in Appendix).[29] Therefore, once the switch to LNG is a fact these vessels may also realize the highest savings on operational costs due to relatively larger savings on the fuel consumption as discussed in chapter 3.

Figure 7 also shows a significant gap between 100% gas driven vessels and dual fuel/dual fuel refit vessels. This can be related to the fact that a 100% gas installation is relatively more extensive and expensive as compared to a dual fuel and dual fuel refit installation, while the price for a 100% gas installation covers multiple complementary components; gas generator sets, e-engines and frequency controllers. There are however additional advantages for a 100% gas driven vessel as compared to a dual fuel/dual fuel refit vessel:

- Next to the propulsion e-engines can also provide electricity for, under which, the 'hotel' facilities on board.
- In most cases there will be 2 or 3 gas generators on board, which will make it possible to match the available power to the needs in a more optimal way.
- A diesel fuel tank becomes unnecessary and can be left out in the design in case of a new build vessel.

Table 11 in the appendix clearly illustrates the specific investment costs for an LNG-installation in different configurations and vessel types. Table 11 also illustrates the annual leasing costs for a standard 40' LNG tank container with an approximate capacity of 40 m^3.[30] Leasing an LNG tank may be a suitable alternative for buying it, especially in order to balance the Capex and Opex. A major barrier, however, for the lease concept of fuel tank containers is the (existing) mortgage loan for an inland vessel. This actually applies for leasing of equipment in general. Most inland

[28] There is a positive and significant relationship (at the 5% significance level) between installed power and total investment costs (see table 8 and 9 in Appendix).
[29] There is a positive and significant relationship (at the 5% significance level) between installed power in kW's and total average fuel consumption (see table 10 in Appendix)
[30] According to consultation with Trifleet

vessels have an ongoing mortgage loan and leasing equipment may result in conflicts between stakeholders once the relevant inland shipping company goes bankrupt. In such a case it will become nearly impossible for the lessor to claim its equipment due to the mortgage law which gives the first mortgagee (usually the bank) the right to put a claim on the vessel including its equipment.[31] An uptake of leasing concepts in IWT requires in first instance a solution for abovementioned issue.

[31] https://www.eicb.nl/wp-content/uploads/2016/08/EICB001-18_rapporten-LNG_02_dynamisch.pdf

5 Business Case

The business case for the investment in an LNG installation strongly depends on the specific LNG configuration, fuel consumption and fuel price. This analysis puts the focus on the business case for a dual-fuel LNG driven vessel of the representative vessel type ‘110 metre motor vessel dry cargo’ (MVS110m), the so called “workhorse” in European IWT.[32]

The business economic impact of a switch to LNG will be discussed by means of the Net Present Value (NPV) and Internal Rate of Return (IRR). The NPV determines the present value of an investment by the discounted sum of all cash inflows and outflows as result of the investment, the NPV would need to be positive in order to be considered a profitable investment. The elements affecting the cash flows in this case are the savings on fuel costs and port dues, idling costs in case of an existing vessel, the initial investment at time zero and the salvage value at the last period. The IRR is another metric which measures the profitability of potential investments. It is the rate at which the NPV of all cash flows resulting from an investment equal zero, the resulting IRR value illustrates the attractiveness of the investment. Once the value exceeds a company’s required rate of return, the investment becomes desirable. On the other hand, the investment becomes undesirable once the value falls below the required rate and alternative (investment) opportunities should be considered.

The Net Present Value (NPV) and Internal Rate of Return (IRR) are calculated for three LNG configurations depending on four fuel price scenarios and five fuel consumption categories. The relevant configurations are:

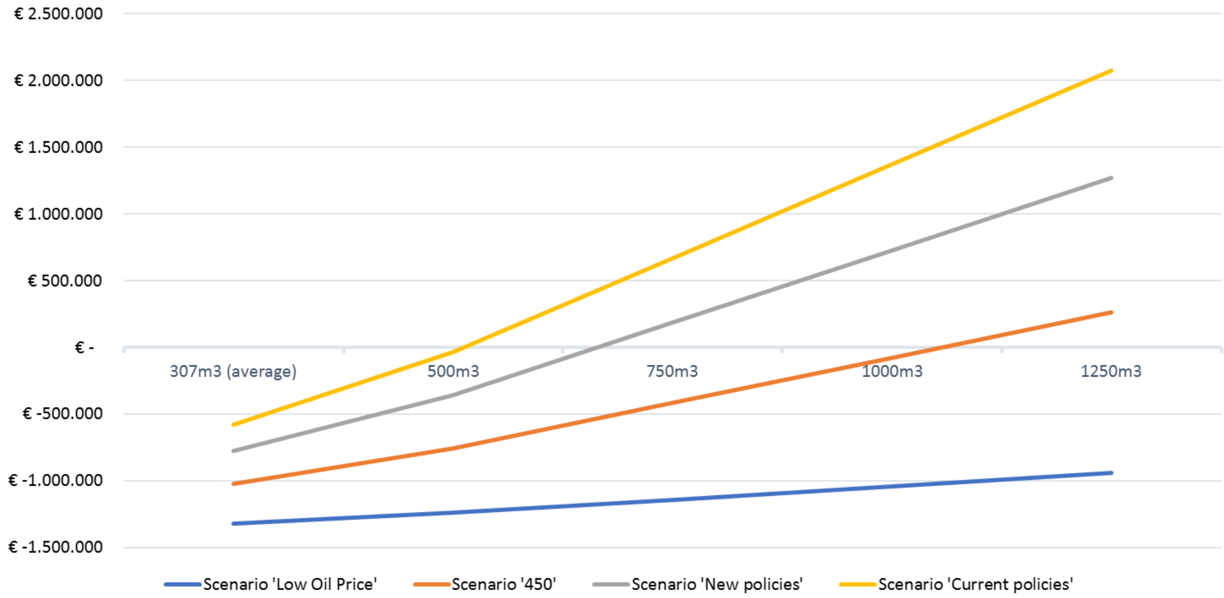
- Existing vessel with a dual fuel installation and tank under deck
- Existing vessel with a dual fuel installation and tank above deck
- New build vessel with a dual fuel installation

Despite installation costs are estimated to be the same for existing vessels with an LNG tank above deck as for new build vessels, these two categories are taken separately due to the idling

[32] Dual fuel installation with a fuel mix of up to 99% LNG and 1% diesel.

costs which only apply to existing vessels. The relevant fuel price scenarios are the four scenarios discussed in the previous sections, these are the scenarios 'Low Oil Price', '450', 'current policies' and 'new policies'. The five fuel consumption categories consist of the average fuel consumption (see table 1 in appendix) and the four fuel consumption categories (500 m^3, 750 m^3, 1000 m^3 and 1250 m^3) as illustrated in figure 4. The economic lifetime of the LNG installation is assumed to be 10 years with a residual value of 30%.[33] A value of 4% is taken into account as discount rate. The resulting NPV and IRR for the three configurations are presented in the figures below. The figures present on the vertical axis the outcome of the NPV and the IRR as function of the annual fuel consumption, expressed in five fuel consumption categories. The four lines present the outcomes at different fuel price scenarios.

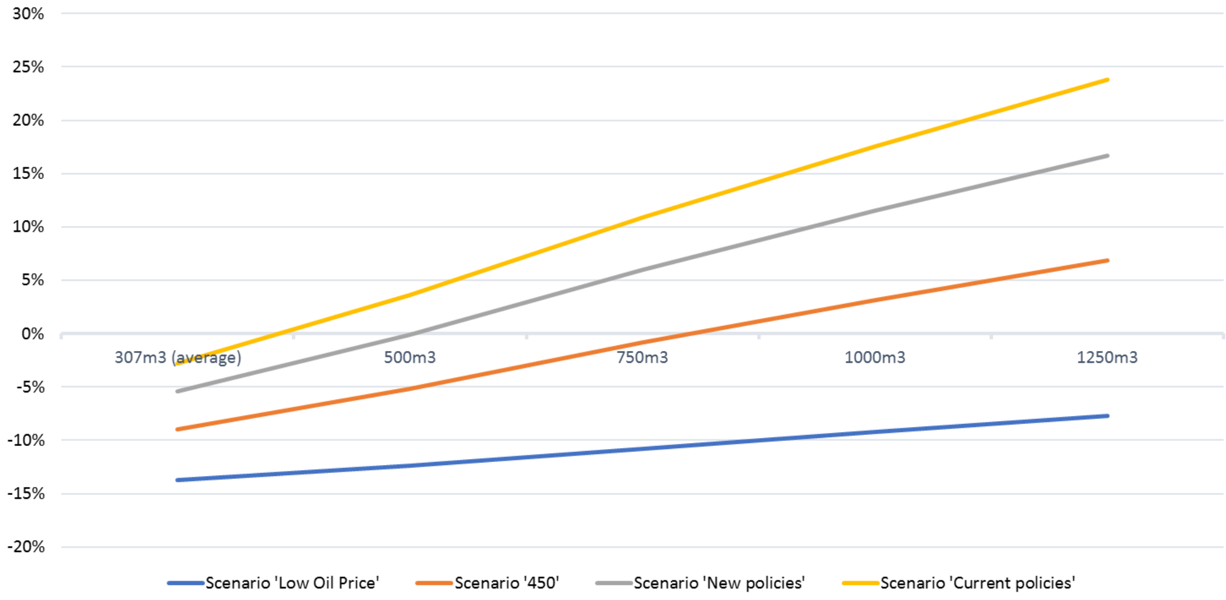
Figure 8: NPV Existing vessel with a dual fuel installation and tank under deck



Source: own elaboration

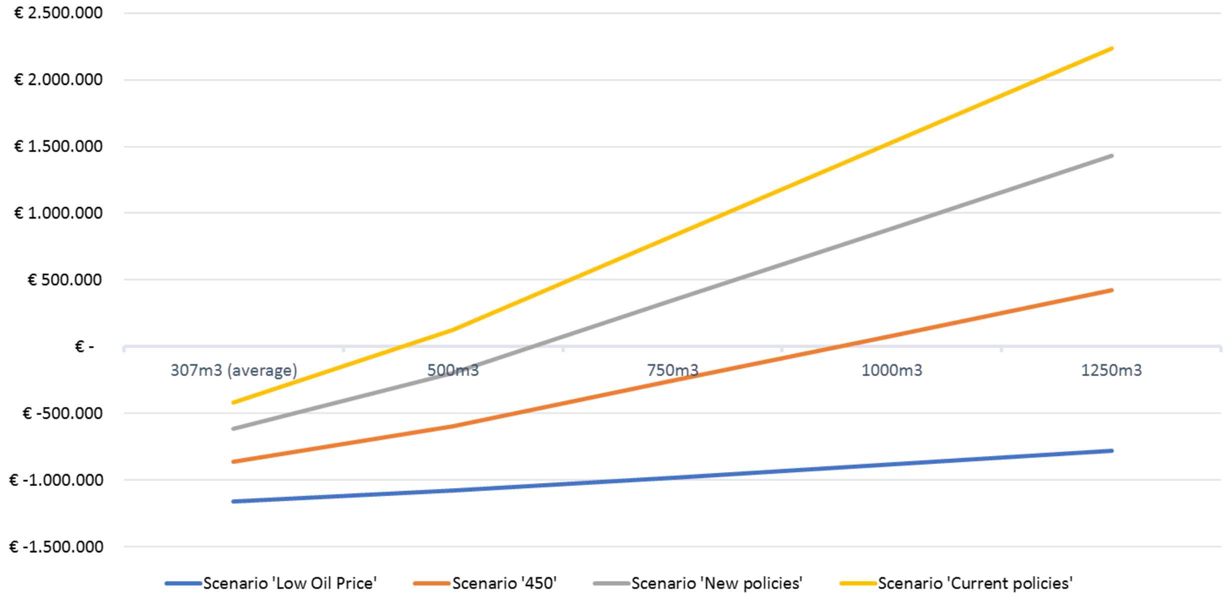
[33] According to consultation with Wärtsilä

Figure 9: IRR Existing vessel with a dual fuel installation and tank under deck



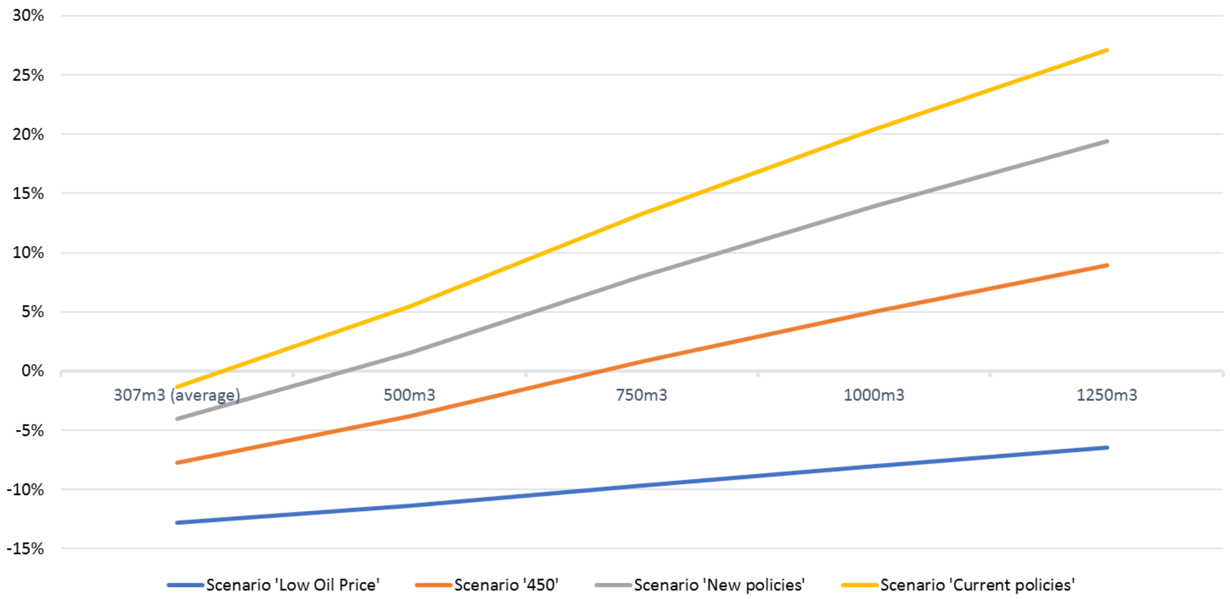
Source: own elaboration

Figure 10: NPV Existing vessel with a dual fuel installation and tank above deck



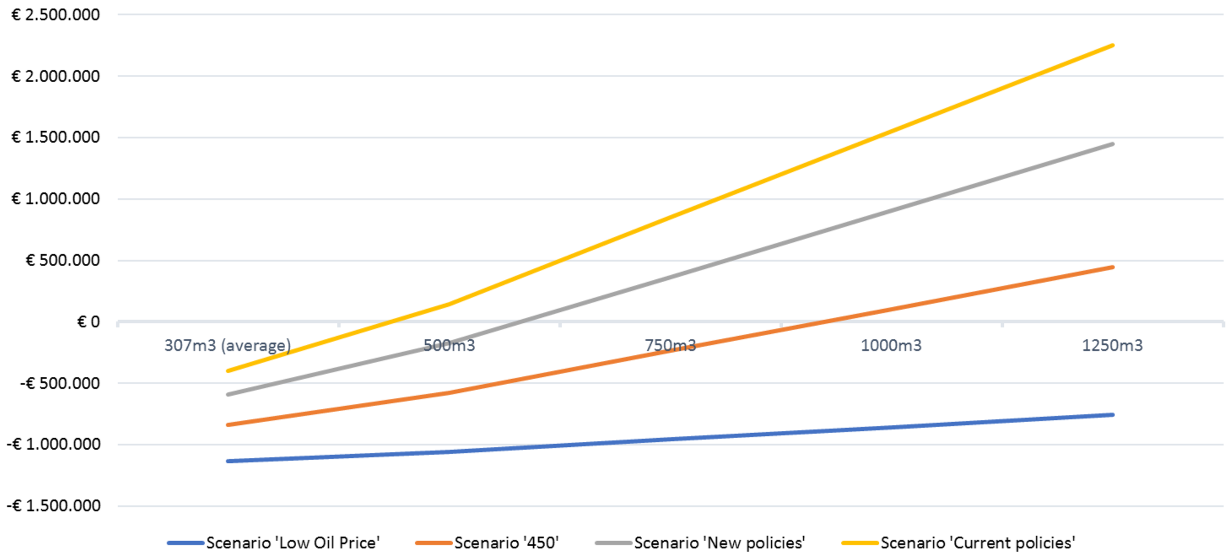
Source: own elaboration

Figure 11: IRR Existing vessel with a dual fuel installation and tank above deck



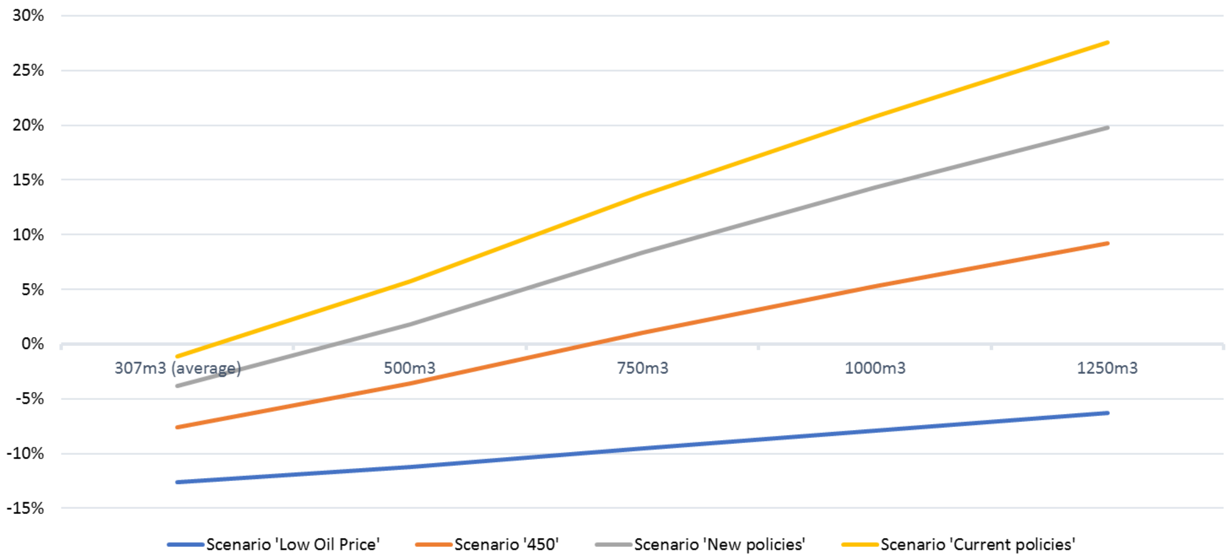
Source: own elaboration

Figure 12: NPV New build vessel with a dual fuel installation



Source: own elaboration

Figure 13 : IRR New build vessel with a dual fuel installation



Source: own elaboration

The NPV values for all three configurations share some similarities. Given the 4 fuel price scenarios the average fuel consumption of 307 m^3 is not sufficient to realize a positive business case due to negative NPV values, indicating an unprofitable investment. A second similarity is the unability to realise a positive business case within the fuel price scenario ‘low oil price’, given the investment costs an price advantage of LNG over diesel of € 0,05 per liter appears to be insufficient for all five fuel consumption categories.

Positive NPV’s are realisable within the remaining three fuel price scenarios, a positive business case is achievable with a relatively small annual fuel consumption given the fuel price scenario ‘Current policies’ due to the relatively large price delta (€ 0,35 per liter) between LNG and diesel. It can also be seen form the figures that NPV values are relatively more optimistic for (i) existing and (ii) newbuild vessels with a dual fuel installation and tank above deck as compared to (iii) existing vessels with a dual fuel installation and tank under deck, due to relatively higher installation costs for the latter. The variance in NPV values between the first two configurations, arising from the idling costs which is not relevant for newbuild vessels, is very marginal.

Concerning the IRR it can be seen from the figures that the rates are strongly in line with the NPV. IRR values higher than the discount rate of 4% correspond with a positive NPV. Quite high rates are possible within the scenarios ‘Current policies’ and ‘New policies’ which include a relatively large price difference between LNG and diesel, contrary a small price difference which applies in the scenario ‘low oil price’, hinders a positive business case.

Important to note is that these observations apply to this specific example, the business case will strongly diverge depending on the specific vessel type and its characteristics, and the type of LNG configuration.

6 Conclusion

This analysis addressed the ex-ante costs and benefits for the best available LNG technologies individually and together in different configurations. The potential savings on fuel costs, resulting from the switch of diesel to LNG, forms the core of the financial benefits in this analysis. The fuel cost savings, and also the business case, strongly depend on the LNG fuel price on the one hand, an external factor from the ship owners point of perspective, and the fuel consumption of the relevant vessel on the other hand.

Benefits for the society in the form of environmental benefits due to emission reduction are significant and may in some cases reach nearly a half million euros annually achieved by one vessel. Most benefits are made on reducing NOx, whereas benefits rising from CO2 reduction are relatively marginal.

The total cost is defined for six different LNG configurations for inland vessels and it appeared that costs strongly vary among the different configurations and representative vessel types, depending on factors like whether it concerns an existing vessel or newbuild, place of the LNG tank, the installed power on board, LNG engine type, etc. Vessels with relatively high investment costs also benefit on average the most from lower fuel costs resulting from the switch to LNG, while it appeared that higher investment costs can mainly be related to a higher installed power and the requirement for more engines but this means at the same time a relatively higher fuel consumption on average and consequently higher savings on fuel costs.

The business case strongly depends on the investment costs, the fuel price and the fuel consumption. Given the investment costs and fuel savings it is possible to realise a positive business case, without any subsidy, during the economic lifetime of the LNG-installation (10 years).

7 Limitations & Further Research

This subchapter will discuss the limitations of this research which can in turn be included as recommendations for further research on this topic. There are some limitations associated with the conducted analyses, these are:

- Factors like installed power (in kW), fuel consumption, operational hours, etc. which are included in the general cost structure are average values for the representative vessel types within each fleet family. In reality there will be vessels belonging to particular fleet families with different values as compared to the average values mentioned in the general cost structure.
- The engine costs are based on the installed kW, as included in the general cost structure. However, in reality there will not always be engines available for the exact amount of kW's as mentioned in the dataset. The mentioned engine costs are therefore indicative and in reality there will only be engines available in a certain power range.
- The included costs and benefits are mostly aggregated values, consisting of values provided by the various experts involved in the Action.
- The actual total investment costs will eventually strongly depend on a variety of factors. The used model does not include all relevant factors, some factors are excluded due to their specific characteristics. These are among others: the personal preferences of a ship owner, the operational profile of the vessel, characteristics of the cargo area, trim position of the vessel in combination with an empty/full tank and cargo, etc.

8 References

8.1 Literature

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8.2 Discussion partners

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9 Appendix

LNG BINNENVAART Deployment in Inland Waterway Transport

Table 1: general cost structure of IWT

			Passenger vessels	Push boats		Motorvessel dry cargo >=110m length		Motorvessel liquid cargo >=110m length			Coupled convoys
			hotel/cruise vessels	500-2000 kW	>=2000 kW	M8	M9		M11	M12	mainly class Va + Europe II lighter
Fleet family			1	3b	4a	5a	5b	6a	6b	6c	10
Vessel type representative vessels			PAX 135m	PushBII-1	Push B4	MVS110m	MVS 135m	MTS 110m	MTS 135m	MTS 135M	C3L/B
Length			135		116,5	110	135	110	135	135	110 + 80
Width			11,45	11,4	15 / 11,4	11,4	11,45	11,4	11,45	17	11,4
Draught			2		1,72 / 4	3,5	3,3	3,5	4	3,8	3,4
Max payload (t)					11200	3043	3300/268 teu	2908	4290 (5320 m3	6228	5500
Operational hours/year*			4318	4313	8064	4318	7898	4318	7898	7898	8064
engines			2,0	2,0	3,0	1,0	2,0	1,1	2,0	2,0	2,0
Installed kW			1492	1249	4080	1527	1492	1550	2347	2370	2351
Payload					11200	2039	187 TEU / approx. 1960 ton	1948	2917	4750	3795
Insurance value			€ 7.000.000	€ 1.400.000	€ 9.300.000	€ 2.457.200	€ 3.576.667	€ 5.027.240	€ 9.065.668	€ 11.100.817	€ 3.635.758
Residual value (in EURO)			€ 210.000	€ 99.926	€ 453.264	€ 111.723	€ 137.114	€ 136.550	€ 207.833	€ 248.815	€ 184.500
Depreciation period			25,0	15,4	10,0	18,2	16,8	17,1	16,7	16,7	15,7
Share of borrowed capital (in %)			65%	65%	65%	65%	65%	65%	65%	65%	65%
Share of equity			35%	35%	35%	35%	35%	35%	35%	35%	35%
5-year average interest % on borrowed capital			4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%	4,00%
Interest % on equity			4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%	4,0%
Insurance costs per year			€ 161.000	€ 31.446	€ 106.732	€ 50.449	€ 72.170	€ 82.960	€ 106.136	€ 109.317	€ 67.531
Depreciation per year			€ 271.600	€ 84.604	€ 884.619	€ 128.832	€ 205.187	€ 285.605	€ 531.359	€ 648.620	€ 219.329
Interest costs			€ 144.200	€ 29.999	€ 195.065	€ 51.378	€ 74.276	€ 103.276	€ 185.470	€ 226.993	€ 76.405
Repair and maintenance			€ 50.000	€ 50.768	€ 151.789	€ 20.616	€ 28.429	€ 27.773	€ 36.610	€ 40.388	€ 72.053
Port Dues			€ 50.000	€ 16.142	€ 89.834	€ 13.903	€ 27.087	€ 13.957	€ 47.268	€ 49.722	€ 32.463
Other fixed costs			€ 811.028	€ 50.941	€ 181.809	€ 16.542	€ 21.516	€ 22.710	€ 25.297	€ 29.674	€ 93.004
Total fixed costs per year			**€ 1.487.828**	**€ 263.899**	**€ 1.609.849**	**€ 281.720**	**€ 428.664**	**€ 536.281**	**€ 932.139**	**€ 1.104.714**	**€ 560.785**
Total labour costs per year			**€ 1.429.672**	**€ 310.133**	**€ 610.746**	**€ 171.686**	**€ 451.196**	**€ 219.353**	**€ 469.743**	**€ 469.743**	**€ 475.698**
Total fuel costs per year (average)	Price per 100l										
Low	€ 23,65		€ 103.703	€ 42.168	€ 261.888	€ 73.515	€ 112.879	€ 85.049	€ 84.333	€ 84.333	€ 131.967
Average	€ 49,25		€ 215.956	€ 87.812	€ 545.370	€ 153.092	€ 235.064	€ 177.111	€ 175.620	€ 175.620	€ 274.815
High	€ 67,81		€ 297.340	€ 120.905	€ 750.894	€ 210.785	€ 323.649	€ 243.856	€ 241.803	€ 241.803	€ 378.380
Total costs											
Low			€ 3.021.203	€ 616.199	€ 2.482.483	€ 526.921	€ 992.739	€ 840.684	€ 1.486.215	€ 1.658.790	€ 1.168.450
Average			€ 3.133.456	€ 661.844	€ 2.765.965	€ 606.498	€ 1.114.924	€ 932.745	€ 1.577.502	€ 1.750.077	€ 1.311.298
High			€ 3.214.840	€ 694.936	€ 2.971.489	€ 664.191	€ 1.203.509	€ 999.490	€ 1.643.685	€ 1.816.260	€ 1.414.862
Total kg fuel average	**200**		363.947	147.988	919.101	258.002	396.149	298.482	295.969	295.969	463.140
Total kg fuel CCR1	**195**	98%	354.848	144.288	896.123	251.552	386.245	291.020	288.569	288.569	451.562
Total kg fuel CCR2	**210**	105%	382.144	155.388	965.056	270.902	415.956	313.406	310.767	310.767	486.297
Total kWh			1.733.080	704.705	4.376.670	1.228.582	1.886.423	1.421.341	1.409.374	1.409.374	2.205.429
Estimated sailing hours			2904	2890	7258	1943	3238	1943	3238	3238	5645
Share sailing hours compared to operational hours			67%	67%	90%	45%	41%	45%	41%	41%	70%
Average share of total power used (kW)			40%	20%	15%	41%	39%	47%	19%	18%	17%

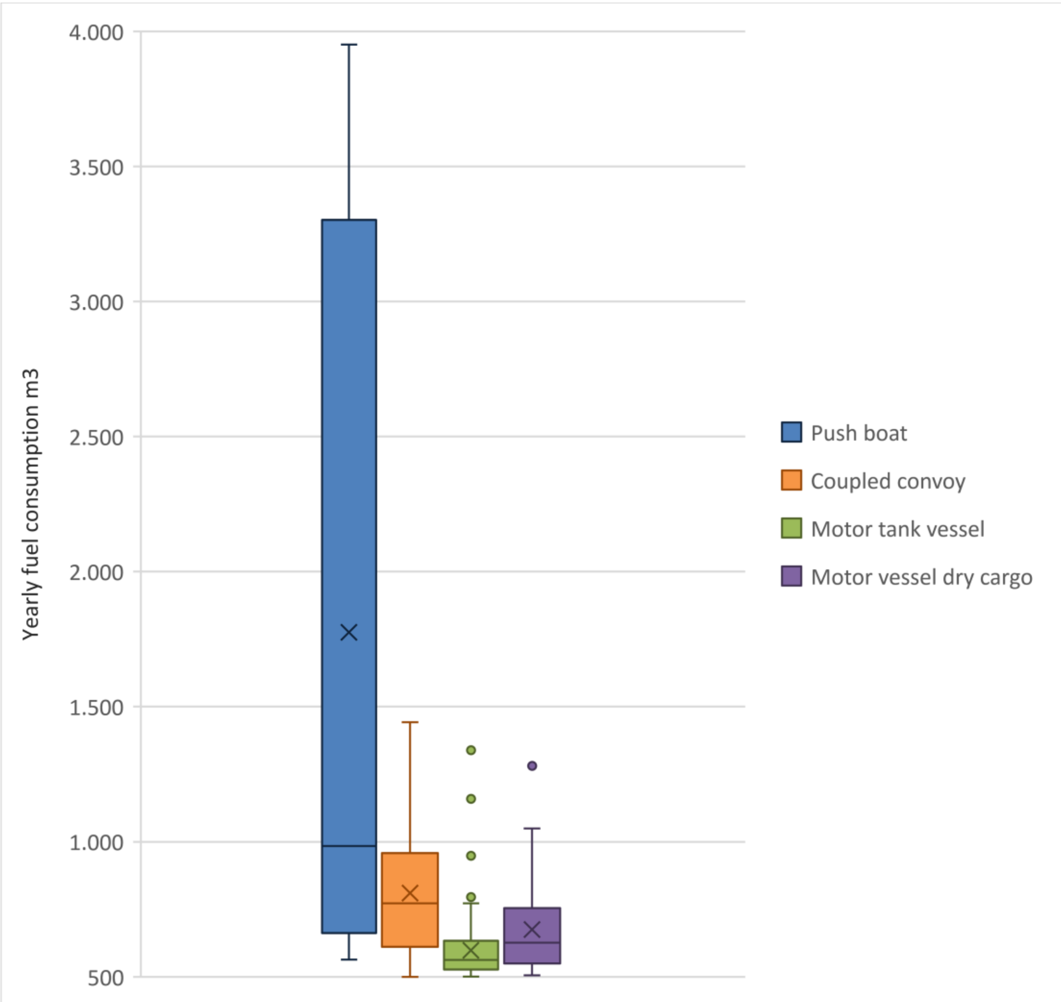
Source: derived from http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_11_14_PROMINENT_D2.2_Ex-ante-cost-benefit-analysis-of-business-cases-for-standard-after-treatment-configurations.pdf

Table 2: overview of vessel types

Fleet family	Vessel type
Passenger vessels (hotel/cruise)	PAX 135m
Push boats <500 kW	PB <500 kW B04
Push boats 500-2000 kW	PushB2L 500-2000kW
Push boats 500-2000 kW	PushBII-1, 500-2000kW
Push boats >=2000 kW	Push B4 > 2000 kW
	Push B6 > 2000 kW
Motor vessel dry cargo >=110m length	MVS 110m
	MVS 135m
Motor vessel liquid cargo >=110m length	MTS 110m
	MTS 135m (M11)
	MTS 135M (M12)
Motor vessel dry cargo 80-109m length	MVS 80m
	MVS 86m
	MVS 105m
Motor vessel liquid cargo 80-109m length	MTS 86m
Motor vessels <80 m. length	MVS 67m
	MVS 55m
	MVS 50m
	MVS 38,5m
Coupled convoys	C3L/B
Danube barges	Push Barge, 4 units, Danube
	Push Barge, 8/9 units, Danube

Source: http://www.prominent-iwt.eu/wp-content/uploads/2015/06/2015_11_14_PROMINENT_D2.2_Ex-ante-cost-benefit-analysis-of-business-cases-for-standard-after-treatment-configurations.pdf

Figure 3: Boxplot of yearly fuel consumption (in cubic meters) with the mean (X), 25% - 75% interval (and median), maximum and minimum, and outliers for vessels with a yearly consumption of ≥500 m^3



Source: activity 4.1 analysis of the potential and sailing profiles of LNG using vessels in Europe

Table 4: Financial benefits

			Passenger vessels	Push boats		Motorvessel dry cargo >=110m length		Motorvessel liquid cargo >=110m length			Coupled convoys
			hotel/cruise vessels	500-2000 kW	>=2000 kW	M8	M9		M11	M12	mainly class Va + Europe II lighter
Fleet family			1	3b	4a	5a	5b	6a	6b	6c	10
Vessel type representative vessels			PAX 135m	PushBII-1	Push B4	MVS110m	MVS 135m	MTS 110m	MTS 135m	MTS 135M	C3L/B
Benefits LNG (additional benefits as compared to diesel)											
Financial benefits											
Change in annual average fuel costs for a 100% switch to LNG (4 scenarios according to the study 'quantitative analysis LNG potential West-European IWT fleet')	Price advantage LNG-Diesel per liter in euro										
Scenario 'Low Oil Price'	€ 0,05		€ 21.663	€ 8.809	€ 54.708	€ 15.357	€ 23.580	€ 17.767	€ 17.617	€ 17.617	€ 27.568
Scenario '450'	€ 0,17		€ 73.656	€ 29.950	€ 186.008	€ 52.215	€ 80.173	€ 60.407	€ 59.898	€ 59.898	€ 93.731
Scenario 'new policies'	€ 0,27		€ 116.983	€ 47.568	€ 295.425	€ 82.929	€ 127.334	€ 95.941	€ 95.133	€ 95.133	€ 148.866
Scenario 'current policies'	€ 0,35		€ 151.644	€ 61.662	€ 382.959	€ 107.501	€ 165.062	€ 124.367	€ 123.320	€ 123.320	€ 192.975
Estimated annual savings on port dues	13,55% on average		€ 6.775	€ 2.187	€ 12.173	€ 1.884	€ 3.670	€ 1.891	€ 6.405	€ 6.737	€ 4.399

Source: own elaboration

Table 5: Environmental benefits LNG

			Passenger vessels	Push boats		Motorvessel dry cargo >=110m length		Motorvessel liquid cargo >=110m length			Coupled convoys		Fuel consumption category			
			hotel/cruise vessels	500-2000 kW	>=2000 kW	M8	M9		M11	M12	mainly class Va + Europe II lighter		**500m3**	**750m3**	**1000m3**	**1250m3**
			1	3b	4a	5a	5b	6a	6b	6c	10					
			PAX 135m	PushBII-1	Push B4	MVS110m	MVS 135m	MTS 110m	MTS 135m	MTS 135M	C3L/B					
Environmental benefit (annual) in kg																
Nox reduction	0,0052 g/kWh (CCR2 to NRMM Stage V)		9.012	3.664	22.759	6.389	9.809	7.391	7.329	7.329	11.468					
PM reduction	0,000185 g/kWh (CCR2 to NRMM Stage V)		321	130	810	227	349	263	261	261	408					
CO2 reduction	max 10% reduction (2,64kg CO2 emission per liter diesel)		114.383	46.511	288.860	81.086	124.504	93.809	93.019	93.019	145.558					
Environmental benefit (annual) in euros	€/ton												Environmental benefit (annual) in euros			
Nox reduction	€ 10.067		€ 90.724	€ 36.890	€ 229.112	€ 64.314	€ 98.751	€ 74.405	€ 73.778	€ 73.778	€ 115.451		€ 104.697	€ 157.045	€ 209.394	€ 261.742
PM reduction	€ 148.373		€ 47.571	€ 19.343	€ 120.135	€ 33.723	€ 51.780	€ 39.014	€ 38.686	€ 38.686	€ 60.537		€ 54.898	€ 82.347	€ 109.796	€ 137.245
CO2 reduction	€ 25		€ 2.860	€ 1.163	€ 7.222	€ 2.027	€ 3.113	€ 2.345	€ 2.325	€ 2.325	€ 3.639		€ 3.300	€ 4.950	€ 6.600	€ 8.250

Source: own elaboration

Table 6: Regression output for correlation and significance values for relationship between total consumed fuel and total environmental benefits.

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	1
R-kwadraat	1
Aangepaste kleinste kwadraat	1
Standaardfout	1,61566E-11
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*Gemiddelde kwadraten*	*F*	*Significantie F*
Regressie	1	58289451350	58289451350	2,23302E+32	1,5873E-111
Storing	7	1,82724E-21	2,61035E-22		
Totaal	8	58289451350			

	Coëfficiënten	*Standaardfout*	*T- statistische gegevens*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 95,0%*	*Hoogste 95,0%*
Snijpunt	-5,82077E-11	1,12848E-11	-5,158076388	0,001312243	-8,48919E-11	-3,15234E-11	-8,48919E-11	-3,15234E-11
Total kg fuel average	0,387844786	2,59545E-17	1,49433E+16	1,5873E-111	0,387844786	0,387844786	0,387844786	0,387844786

Source: own elaboration

Table 7: correlation between installed power (kW) and total investment costs

		Installed kW
1	Total costs Dual fuel (existing vessel with tank under deck)	0,84
2	Total costs Dual fuel (existing vessel with tank above deck & newbuild vessel)	0,88
3	Total costs 100% gas fuel (existing vessel with tank under deck)	0,96
4	Total costs 100% gas fuel (existing vessel with tank above deck & newbuild vessel)	0,97
5	Total costs Dual fuel refit (existing vessel with tank under deck)	0,93
6	Total costs Dual fuel refit (existing vessel with tank above deck & newbuild vessel)	0,96

Source: own elaboration

Table 8: Regression output for correlation and significance values for relationship between installed power (kW) and total investment costs (1st part)

1

Installed kW	**Total costs Dual fuel (existing vessel with tank under deck)**	
1492	€	2.082.500
1249	€	1.630.000
4080	€	2.397.670
1527	€	1.623.558
1492	€	1.618.835
1550	€	1.601.662
2347	€	1.966.712
2370	€	1.899.070
2351	€	2.009.751

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,840140999
R-kwadraat	0,705836897
Aangepaste kleinste kwadraat	0,663813597
Standaardfout	159678,9546
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*niddelde kwadra*	*F*	*Significantie F*
Regressie	1	4,28262E+11	4,28262E+11	16,79632231	0,004582648
Storing	7	1,78482E+11	25497368545		
Totaal	8	6,06744E+11			

	Coëfficiënten	*Standaardfout*	*tatistische gegev*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 95,0%*	*Hoogste 95,0%*
Snijpunt	1330541,416	141976,9888	9,371528632	3,27648E-05	994819,1851	1666263,647	994819,1851	1666263,647
Installed kW	263,0272997	64,17911536	4,098331649	0,004582648	111,2678071	414,7867923	111,2678071	414,7867923

2

Installed kW	**Total costs Dual fuel (existing vessel with tank above deck & newbuild vessel)**	
1492	€	1.835.000
1249	€	1.452.500
4080	€	2.200.170
1527	€	1.463.558
1492	€	1.458.835
1550	€	1.441.662
2347	€	1.794.212
2370	€	1.726.570
2351	€	1.824.751

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,879590878
R-kwadraat	0,773680112
Aangepaste kleinste kwadraat	0,741348699
Standaardfout	131448,8062
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*niddelde kwadra*	*F*	*Significantie F*
Regressie	1	4,13476E+11	4,13476E+11	23,92967241	0,001769611
Storing	7	1,20952E+11	17278788650		
Totaal	8	5,34427E+11			

	Coëfficiënten	*Standaardfout*	*tatistische gegev*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 95,0%*	*Hoogste 95,0%*
Snijpunt	1158546,594	116876,4271	9,912577098	2,26685E-05	882177,7603	1434915,428	882177,7603	1434915,428
Installed kW	258,4467461	52,83268617	4,89179644	0,001769611	133,5172951	383,3761971	133,5172951	383,3761971

3

Installed kW	**Total costs 100% gas fuel (existing vessel with tank under deck)**	
1492	€	2.340.500
1249	€	2.206.500
4080	€	3.424.500
1527	€	2.081.500
1492	€	2.138.000
1550	€	2.123.000
2347	€	2.418.000
2370	€	2.423.000
2351	€	2.610.500

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,956526345
R-kwadraat	0,914942649
Aangepaste kleinste kwadraat	0,902791598
Standaardfout	129470,4257
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*niddelde kwadra*	*F*	*Significantie F*
Regressie	1	1,26218E+12	1,26218E+12	75,29741319	5,40541E-05
Storing	7	1,17338E+11	16762591137		
Totaal	8	1,37952E+12			

	Coëfficiënten	*Standaardfout*	*tatistische gegev*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 95,0%*	*Hoogste 95,0%*
Snijpunt	1492322,055	115117,3693	12,96348295	3,7806E-06	1220112,731	1764531,378	1220112,731	1764531,378
Installed kW	451,5508354	52,03752372	8,677408207	5,40541E-05	328,5016448	574,600026	328,5016448	574,600026

Source: own elaboration

Table 9: Regression output for correlation and significance values for relationship between installed power (kW) and total investment costs (2nd part)

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Installed kW	Total costs 100% gas fuel (existing vessel with tank above deck & newbuild vessel)	
1492	€	2.093.000
1249	€	2.029.000
4080	€	3.227.000
1527	€	1.921.500
1492	€	1.978.000
1550	€	1.963.000
2347	€	2.245.500
2370	€	2.250.500
2351	€	2.425.500

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,967353521
R-kwadraat	0,935772835
Aangepaste kleinste kwadraat	0,926597525
Standaardfout	110117,855
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*middelde kwadrat*	*F*	*Significantie F*
Regressie	1	1,2367E+12	1,2367E+12	101,9881513	2,00493E-05
Storing	7	84881593940	12125941991		
Totaal	8	1,32158E+12			

	Coëfficiënten	*Standaardfout*	*tatistische gegeve*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*agste 95,0*	*Hoogste 95,0%*
Snijpunt	1320327,233	97910,21936	13,48508094	2,89565E-06	1088806,354	1551848,112	1088806	1551848,112
Installed kW	446,9702818	44,25922337	10,09891832	2,00493E-05	342,3138489	551,6267148	342,3138	551,6267148

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Installed kW	Total costs Dual fuel refit (existing vessel with tank under deck)	
1492	€	1.640.500
1249	€	1.553.000
4080	€	2.078.000
1527	€	1.451.000
1492	€	1.523.000
1550	€	1.426.000
2347	€	1.717.000
2370	€	1.722.000
2351	€	1.759.500

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,933818692
R-kwadraat	0,87201735
Aangepaste kleinste kwadraat	0,853734115
Standaardfout	76514,30809
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*middelde kwadrat*	*F*	*Significantie F*
Regressie	1	2,79227E+11	2,79227E+11	47,69491386	0,000230054
Storing	7	40981075400	5854439343		
Totaal	8	3,20208E+11			

	Coëfficiënten	*Standaardfout*	*tatistische gegeve*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*agste 95,0*	*Hoogste 95,0%*
Snijpunt	1216649,759	68031,95257	17,88350492	4,22033E-07	1055779,754	1377519,764	1055780	1377519,764
Installed kW	212,3854376	30,75308589	6,906150437	0,000230054	139,6659449	285,1049303	139,6659	285,1049303

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Installed kW	Total costs Dual fuel refit (existing vessel with tank above deck & newbuild vessel)	
1492	€	1.393.000
1249	€	1.375.500
4080	€	1.880.500
1527	€	1.291.000
1492	€	1.363.000
1550	€	1.266.000
2347	€	1.544.500
2370	€	1.549.500
2351	€	1.574.500

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,958008323
R-kwadraat	0,917779946
Aangepaste kleinste kwadraat	0,906034224
Standaardfout	58489,81947
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*middelde kwadrat*	*F*	*Significantie F*
Regressie	1	2,67313E+11	2,67313E+11	78,13738044	4,7945E-05
Storing	7	23947412870	3421058981		
Totaal	8	2,9126E+11			

	Coëfficiënten	*Standaardfout*	*tatistische gegeve*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*agste 95,0*	*Hoogste 95,0%*
Snijpunt	1044654,937	52005,65389	20,08733395	1,89704E-07	921681,1063	1167628,767	921681,1	1167628,767
Installed kW	207,804884	23,50[illegible]19	8,83953508	4,7945E-05	152,2159346	263,3938334	152,2159	263,3938334

Source: own elaboration

Table 10: Regression output for correlation and significance values for relationship between installed power (kW) and total fuel consumption

Installed kW	**Total kg fuel average**
1492	363947
1249	147988
4080	919101
1527	258002
1492	396149
1550	298482
2347	295969
2370	295969
2351	463140

SAMENVATTING UITVOER

Gegevens voor de regressie	
Meervoudige correlatiecoëfficiënt R	0,876764918
R-kwadraat	0,768716721
Aangepaste kleinste kwadraat	0,735676252
Standaardfout	113151,4503
Waarnemingen	9

Variantie-analyse

	Vrijheidsgraden	*Kwadratensom*	*niddelde kwadra*	*F*	*Significantie F*
Regressie	1	2,97879E+11	2,97879E+11	23,26591471	0,001913784
Storing	7	89622754907	12803250701		
Totaal	8	3,87502E+11			

	Coëfficiënten	*Standaardfout*	*tatistische gegev*	*P-waarde*	*Laagste 95%*	*Hoogste 95%*	*Laagste 95,0%*	*Hoogste 95,0%*
Snijpunt	-67802,58351	100607,5111	-0,673931626	0,521979102	-305701,544	170096,3771	-305701,544	170096,3771
Installed kW	219,3644444	45,47850403	4,823475377	0,001913784	111,8248708	326,9040179	111,8248708	326,9040179

Source: own elaboration

Table 11: additional costs of LNG

		Passenger vessels	Push boats		Motorvessel dry cargo >=110m length		Motorvessel liquid cargo >=110m length			Coupled convoys
		hotel/cruise vessels	500-2000 kW	>=2000 kW	M8	M9		M11	M12	mainly class Va + Europe II lighter
Fleet family		1	3b	4a	5a	5b	6a	6b	6c	10
Vessel type representative vessels		PAX 135m	PushBII-1	Push B4	MVS110m	MVS 135m	MTS 110m	MTS 135m	MTS 135M	C3L/B
Costs LNG (additional costs as compared to diesel)										
Mono fuel engine (incl. gas generator sets, e-engines and frequency controllers)		€ 946.500	€ 895.825	€ 1.920.425	€ 807.825	€ 861.500	€ 871.000	€ 1.085.000	€ 1.085.000	€ 1.227.500
Dual fuel engine		€ 730.000	€ 365.000	€ 967.670	€ 388.558	€ 383.835	€ 391.662	€ 681.712	€ 609.070	€ 682.251
Dual fuel engine (refit solution)		€ 288.000	€ 288.000	€ 648.000	€ 216.000	€ 288.000	€ 216.000	€ 432.000	€ 432.000	€ 432.000
LNG tank	1 tank (40m3)	€ 165.000	€ 165.000	€ 165.000	€ 165.000	€ 165.000	€ 165.000	€ 165.000	€ 165.000	€ 165.000
Tank connection space	for 1 tank (40m3)	€ 377.500	€ 377.500	€ 377.500	€ 377.500	€ 377.500	€ 377.500	€ 377.500	€ 377.500	€ 377.500
including 1x water/glycol heating system, 1x bunkerskid, Class costs, engineering+project management, piping										
Total Installation costs (existing vessels with tank above deck & newbuild vessels)		€ 562.500	€ 545.000	€ 690.000	€ 532.500	€ 532.500	€ 507.500	€ 570.000	€ 575.000	€ 600.000
Installation costs LNG tank on deck		€ 52.500	€ 52.500	€ 57.500	€ 55.000	€ 55.000	€ 55.000	€ 57.500	€ 57.500	€ 57.500
Installation costs engine(s) and belongings		€ 170.000	€ 170.000	€ 247.500	€ 170.000	€ 170.000	€ 170.000	€ 202.500	€ 202.500	€ 202.500
Ventilation (tank+tcs)		€ 65.000	€ 50.000	€ 60.000	€ 45.000	€ 45.000	€ 45.000	€ 50.000	€ 50.000	€ 50.000
Monitoring/control of LNG related installations		€ 90.000	€ 90.000	€ 100.000	€ 90.000	€ 90.000	€ 90.000	€ 100.000	€ 100.000	€ 100.000
Electrical installation		€ 145.000	€ 132.500	€ 175.000	€ 122.500	€ 122.500	€ 122.500	€ 135.000	€ 140.000	€ 140.000
Class, hazid, administration for LNG retated items; above standand class costs for tankers, ADN vessels and passenger ships		€ 40.000	€ 50.000	€ 50.000	€ 50.000	€ 50.000	€ 25.000	€ 25.000	€ 25.000	€ 50.000
Total Installation costs (existing vessels with tank under deck)		€ 810.000	€ 722.500	€ 887.500	€ 692.500	€ 692.500	€ 667.500	€ 742.500	€ 747.500	€ 785.000
Installation costs LNG tank under deck		€ 290.000	€ 220.000	€ 240.000	€ 205.000	€ 205.000	€ 205.000	€ 215.000	€ 215.000	€ 227.500
Installation costs engine(s) and belongings		€ 170.000	€ 170.000	€ 247.500	€ 170.000	€ 170.000	€ 170.000	€ 202.500	€ 202.500	€ 202.500
Ventilation (tank+tcs)		€ 75.000	€ 60.000	€ 75.000	€ 55.000	€ 55.000	€ 55.000	€ 65.000	€ 65.000	€ 65.000
Monitoring/control of LNG related installations		€ 90.000	€ 90.000	€ 100.000	€ 90.000	€ 90.000	€ 90.000	€ 100.000	€ 100.000	€ 100.000
Electrical installation		€ 145.000	€ 132.500	€ 175.000	€ 122.500	€ 122.500	€ 122.500	€ 135.000	€ 140.000	€ 140.000
Class, hazid, administration for LNG retated items; above standand class costs for tankers, ADN vessels and passenger ships		€ 40.000	€ 50.000	€ 50.000	€ 50.000	€ 50.000	€ 25.000	€ 25.000	€ 25.000	€ 50.000
Total costs Dual fuel (existing vessel with tank under deck)		**€ 2.082.500**	**€ 1.630.000**	**€ 2.397.670**	**€ 1.623.558**	**€ 1.618.835**	**€ 1.601.662**	**€ 1.966.712**	**€ 1.899.070**	**€ 2.009.751**
Total costs Dual fuel (existing vessel with tank above deck & newbuild vessel)		**€ 1.835.000**	**€ 1.452.500**	**€ 2.200.170**	**€ 1.463.558**	**€ 1.458.835**	**€ 1.441.662**	**€ 1.794.212**	**€ 1.726.570**	**€ 1.824.751**
Total costs 100% gas fuel (existing vessel with tank under deck)		**€ 2.299.000**	**€ 2.160.825**	**€ 3.350.425**	**€ 2.042.825**	**€ 2.096.500**	**€ 2.081.000**	**€ 2.370.000**	**€ 2.375.000**	**€ 2.555.000**
Total costs 100% gas fuel (existing vessel with tank above deck & newbuild vessel)		**€ 2.051.500**	**€ 1.983.325**	**€ 3.152.925**	**€ 1.882.825**	**€ 1.936.500**	**€ 1.921.000**	**€ 2.197.500**	**€ 2.202.500**	**€ 2.370.000**
Total costs Dual fuel refit (existing vessel with tank under deck)		**€ 1.640.500**	**€ 1.553.000**	**€ 2.078.000**	**€ 1.451.000**	**€ 1.523.000**	**€ 1.426.000**	**€ 1.717.000**	**€ 1.722.000**	**€ 1.759.500**
Total costs Dual fuel refit (existing vessel with tank above deck & newbuild vessel)		**€ 1.393.000**	**€ 1.375.500**	**€ 1.880.500**	**€ 1.291.000**	**€ 1.363.000**	**€ 1.266.000**	**€ 1.544.500**	**€ 1.549.500**	**€ 1.574.500**
additional installation time		4 weeks	4 weeks	4 weeks	4 weeks	4 weeks	4 weeks	4 weeks	4 weeks	4 weeks
Idling costs		€ 114.059	€ 20.231	€ 123.413	€ 21.597	€ 32.862	€ 41.112	€ 71.459	€ 84.689	€ 42.991
Annual lease costs of LNG tank	40' LNG tank	€ 18.250	€ 18.250	€ 18.250	€ 18.250	€ 18.250	€ 18.250	€ 18.250	€ 18.250	€ 18.250
Depreciation time	10 years									
Residual value LNG installation	30%									
Annual depreciation costs Dual fuel (existing vessel with tank under deck)		€ 170.075	€ 135.775	€ 194.462	€ 134.424	€ 134.093	€ 132.141	€ 159.945	€ 155.360	€ 164.233
Annual depreciation costs Dual fuel (existing vessel with tank above deck & newbuild vessel)		€ 145.325	€ 118.025	€ 174.712	€ 118.424	€ 118.093	€ 116.141	€ 142.695	€ 138.110	€ 145.733
Annual depreciation costs 100% gas fuel (existing vessel with tank under deck)		€ 185.230	€ 172.933	€ 261.155	€ 163.773	€ 167.530	€ 165.695	€ 188.175	€ 188.675	€ 202.400
Annual depreciation costs 100% gas fuel (existing vessel with tank above deck & newbuild vessel)		€ 160.480	€ 155.183	€ 241.405	€ 147.773	€ 151.530	€ 149.695	€ 170.925	€ 171.425	€ 183.900
Annual depreciation costs Dual fuel refit (existing vessel with tank under deck)		€ 119.380	€ 112.150	€ 133.912	€ 104.590	€ 110.180	€ 100.195	€ 122.875	€ 123.375	€ 122.850
Annual depreciation costs Dual fuel refit (existing vessel with tank above deck & newbuild vessel)		€ 94.630	€ 94.400	€ 114.162	€ 88.590	€ 94.180	€ 84.195	€ 105.625	€ 106.125	€ 104.350
Benefits LNG (additional benefits as compared to diesel)										
Financial benefits										
Change in annual average fuel costs for a 100% switch to LNG (4 scenarios according to the study 'quantitative analysis LNG potential West-European IWT fleet')	Price advantage LNG-Diesel per liter in euro									
Scenario 'Low Oil Price'	€ 0,05	€ 21.663	€ 8.809	€ 54.708	€ 15.357	€ 23.580	€ 17.767	€ 17.617	€ 17.617	€ 27.568
Scenario '450'	€ 0,17	€ 73.656	€ 29.950	€ 186.008	€ 52.215	€ 80.173	€ 60.407	€ 59.898	€ 59.898	€ 93.731
Scenario 'new policies'	€ 0,27	€ 116.983	€ 47.568	€ 295.425	€ 82.929	€ 127.334	€ 95.941	€ 95.133	€ 95.133	€ 148.866
Scenario 'current policies'	€ 0,35	€ 151.644	€ 61.662	€ 382.959	€ 107.501	€ 165.062	€ 124.367	€ 123.320	€ 123.320	€ 192.975
Estimated annual savings on port dues	13,55% on average	€ 6.775	€ 2.187	€ 12.173	€ 1.884	€ 3.670	€ 1.891	€ 6.405	€ 6.737	€ 4.399

Source: own elaboration