WP 6: New scales and services

D6.4: Synthesis and impact assessment

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ABSTRACT

Inland waterway vessels are considered the cleanest land based transport mode in terms of its CO2 emissions on a per ton-km basis. However other modes are quickly catching up and speeding up is needed to maintain the IWT green character. For some emission categories (NOx, PM), road transport is already outperforming IWT. One reason for IWT to lag behind other modes is the long technical and economic lifetime of ships, which can easily extend 50 years. The replacement rate of the fleet is therefore rather low. This means, by modernising just through replacing older vessels by newer ones, the sector may become bypassed by other transport sectors soon. Therefore, action is needed targeting the existing IW fleet. To improve the performance of the inland waterway sector especially the existing fleet should be modernized. Currently there is insufficient knowledge about how to modernize the inland waterway fleet efficiently.

The MoVe IT! project aims to develop concrete applications that can be installed on existing ships. WP 6 focuses on the most common old vessels in the fleet. WP6 can be split in two clusters. The first cluster analyses the options to improve the competitive position of relatively small vessels in the fleet (CEMT II and III) by lengthening them (with a goal to reach CEMT IV). The second cluster assesses new market opportunities for single hull tankers. This report is the last step of the first cluster where the economic and environmental feasibility of the lengthening steps are assessed.

Lengthening of small inland vessels (by contemporary standards) is found to be economically feasible. It seems that vessels that fall within the CEMT II and III class can benefit of this retrofit option, as is shown from the business cases for the MV Hendrik and the MV Rheinland conducted in this task. Based on the analysis done and also in line with the results of the lengthening done in WP 7.2, inland vessels already need to have a critical mass to ensure that the lengthening will be economically feasible. If a vessel is too small, as is the case for e.g. the MV Rheinland, lengthening will be less feasible, especially when the vessel is only lengthened with 6 metres. To make lengthening a feasible option the benefits need to outweigh the investment costs.

From an economic and environmental perspective it seems feasible to install a propeller in nozzle instead of a naked propeller. The propeller in nozzle is able to reduce the fuel consumption and therefore the impact of CO_2 emissions. To have full economical and environmental effects, the speed should be reduced, but speed reduction has a cost too and is not as easy as it sounds.

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1 Executive Summary

1.1 Problem Definition

Inland shipping is considered the cleanest land based transport mode in terms of its CO2 emissions on a per ton-km basis. However other modes are quickly catching up in terms of energy efficient and clean technologies take-up and speeding up of the IWT sector is needed to maintain its leading position. For some emission categories (NOx, PM), road transport is already outperforming IWT. One reason for IWT to lag behind other modes is the long technical and economic lifetime of ships, which can easily extend 50 years. The replacement rate of the fleet is therefore rather low. This means, by modernising just through replacing older vessels by newer ones, the sector may be bypassed by other transport sectors, esp. the road sector, very soon. Therefore, action is needed targeting the existing IW fleet. To improve the performance of the inland waterway sector especially the existing fleet should be modernized. Currently there is insufficient knowledge about how to modernize the inland waterway fleet efficiently.

The MoVe IT! project aims to develop concrete applications that can be installed on existing ships. WP 6 focuses on the most common old vessels in the fleet. WP6 can be split in two clusters. The first cluster analyses the options to improve the competitive position of relatively small vessels in the fleet (CEMT II and III) by lengthening them. The second cluster assesses new market opportunities for single hull tankers. This report is the last step of the first cluster where the economic and environmental feasibility of the lengthening steps are assessed.

The aim of this task is twofold: on the one hand the consequences on the costs and benefits once the vessel is modernized need to be estimated and on the other hand the environmental impact of the modernizing needs to be assessed. In task 6.0 two possible vessels were chosen, the Hendrik and Rheinland, these vessels are used to carry out the first part of WP 6. For each of the two vessels several lengthening steps, the impact on manoeuvrability and the powering requirements were assessed.

Each lengthening step will impact the business case of the ship owner. Not only does the economic profile of the vessel change; there might also be an impact on the logistical operation of the vessel. To analyse the impacts of the retrofit options the current operational profile of the vessel is compared with the expected operational profile once a certain retrofit option is implemented. Also the payback period of the investment is considered.

Also the environmental impact will change once the vessel is lengthened. To assess the environmental impact the change in environmental performance is compared to the current performance of the vessels.

1.2 Technical approach

The aim of task 6.4 is to analyse the operational, logistics and economic effects of the proposed lengthening steps on the operator’s business. The effects of each option are compared with the reference situation which equals the current operating profile of the shipping company concerned. To establish current operating profiles, general assumptions are made which are verified with ship owners participating in the project.

For each of the five lengthening options, the main economic advantages and drawbacks were identified by the Move-IT WP6 partners jointly with the ship operators and checked with the technical partners to ensure consistency and reliability.

From tasks 6.1, 6.2 and 6.3 cost estimates for the lengthening, impacts on maintenance costs and effects on fuel consumption were provided. These estimates are the basis of the analyses made to assess the feasibility of each lengthening option. For each vessel several options are calculated, and the results are compared to the reference situation. The payback time of the investment is calculated as well as other indicators, i.e. the internal rate of return (IRR) and the net present value (NPV).

1.3 Results and Achievements

Lengthening of small inland vessels (by contemporary standards) is found to be economically feasible. It seems that vessels that fall within the CEMT II and III class can benefit from this retrofit option, as is shown from the business cases for the MV Hendrik and the MV Rheinland conducted in this task. Based on the analysis done and also in line with the results of the lengthening done in WP 7.2, inland vessels already need to have a critical mass to ensure that the lengthening will be economically feasible. If a vessel is too small, as is the case for e.g. the MV Rheinland, lengthening will be less feasible, especially when the vessel is only lengthened by only 6 metres. To make lengthening a feasible option the benefits need to outweigh the investment costs.

From an environmental perspective it seems desirable to install a propeller in nozzle instead of a naked propeller, which is commonly found on old inland ships. The propeller in nozzle is able to reduce the fuel consumption and therefore the amount of CO_2 emissions. To have more effect of the propeller in nozzle the vessel should also reduce its speed. In this case the implementation of the nozzle is most effective.

2 Introduction

2.1 Background

Due to the liberalization of the European continental transport market competition on the transport sector has increased considerably. This applies both the competition between modes (road, rail and IWT) and within the same mode (e.g. between vessel types and / or cargo markets).

On top of that, the fuel prices have increased during the last years. All modes mainly use fossil fuels (e.g. diesel, gasoline and gasoil) and the rising fuel prices have led to higher fuel bills. Due to the sharpened competition as a result of the economic crisis from 2009, freight rates and transported volumes have decreased. To stay competitive on the market, transport companies have to become more efficient. Especially IWT is losing more and more ground to the other modes like rail and in particular road transport.

In order to cope with the increased competition and cost increases, inland shipping, known as the cleanest and most fuel-efficient transport mode, needs to become more efficient than it already is, as to improve business operations. However inland vessels have a very long life span and remain in the market for a considerable time. The strategy of phasing out of existing inefficient vessels and replace them by new and more efficient ones is not easily done, takes too long, and is much too costly. Therefore it is important to modernize and improve the existing vessel fleet as well. The following table shows the average age per vessel class in Western Europe. On average the Eastern European fleet is of similar age, though in some places maintenance levels are low.

Table 2.1 Average age of Western European vessels

Tonnage of the vessel	Building year	Classification	Average age
0 – 650 tons	Ca. 1950	CEMT I and II	60 years
650 – 1500t tons	Ca. 1960-1970	CEMT III and IV	45 years
1500 – 3000 tons	Ca. 1995 (110 m ship)	CEMT V	25 years
3000 – 4000 tons	Ca. 2000 (135m)	CEMT VI	15 years
Over 4000 tons	Ca. 2005	>CEMT VI	5 years
Average age of pushing units (barge and pushers) is 20 years			

Currently there is insufficient knowledge about how to modernize the inland waterway fleet efficiently. The goal of the MoVe IT! project is to obtain the required knowledge. Objectives of the project are:

- Improve the hydrodynamic behaviour of the ships involved (WP2);
- Improving the operational performance (WP3);
- Improve the performance of engines (WP4);
- Improve the construction (also when integrating new structures in existing vessels to meet new requirements) (WP5);
- Finding new trades for existing vessel and/or improving their competitiveness by reconstruction of parts of the vessel (WP6).

WP6 can be split in two clusters. The first cluster analyses the options to improve the competitive position of the smaller vessels in the fleet (CEMT II and III) by lengthening them. The second cluster assesses new market opportunities. WP6 consists of seven tasks and an 8th task (task 0) that was added after the start of the project:

New scales

0. Added Task – concentrates on identification of vessels that should be lengthened (6.0);
1. Focus on ship structure, especially lengthening (6.1);
2. Impact of ship lengthening on manoeuvring (6.2);
3. Impact of ship lengthening and repowering on powering requirements (6.3);
4. Synthesizing the outcomes of the previous tasks and assessing the economic and environmental impacts (6.4).

New services

5. Evaluating technical solutions to adjust to climate change (6.5);
6. Evaluating possibilities for the transport of CO2 (6.6);
7. Evaluating new markets for single hull tankers (6.7).

2.2 Aim of task 6.4

The aim of this task is twofold: on the one hand the consequences on the costs and benefits once the vessel is modernized need to be estimated and on the other hand the environmental impact of the modernizing needs to be assessed. In task 6.1 two example vessels were selected, the Hendrik and Rheinland, which may be considered examples of the types of vessels that should be lengthened. These vessels are used to carry out the first part of WP 6 (tasks 6.2 to 6.4). For each of the two vessels several lengthening steps, their impact on manoeuvrability and the associated powering requirements were assessed.

Each lengthening step will impact the business case of the ship owner. Not only does the economic profile of the vessel change; there might also be an impact on the logistical operations of the vessel. To analyse the impacts of the retrofit options the current operational profile of the vessel is compared with the expected operational profile once a certain retrofit option is implemented. Also the payback period of the investment is considered.

Also the environmental impact will change once the vessel is lengthened. To assess the environmental impact the change in environmental performance is compared to the current performance of the vessels. As no details on the operating profile and current environmental performance were known to the Consortium some expert judgements were made in order to carry out both the economic and environmental assessment.

The result of task 6.4 is an overview of the impacts of the different lengthening steps considered. The approach chosen within WP6 is considered classical and while two typical class II and III vessels were chosen, it is assumed that the conclusions derived apply to other similar vessels as well. It is noted that apart from the technical characteristics also the operational profile has a large influence on the economic viability.

2.3 Structure of the report

Chapter 3 describes the methodology used to assess the economic feasibility of the proposed retrofit options. The main assumptions are presented as well as the evaluation criteria. The chapter also describes the methodology used to assess the environmental performance of the vessels considered.

The remaining of the report is divided into two parts that each have the same structure. Part A focuses on the larger inland vessel, Hendrik, and part B describes the smaller inland vessel assessed, the Rheinland. For both vessels a general description is provided (chapters 4 and 8), the proposed retrofit options are described (chapters 5 and 9), the economic assessment is described (chapters 6 and 10) and the environmental assessment is carried out (chapters 7 and 11). Chapter 12 provides the main research findings and in chapter 13 the literature used is presented.

3 Methodology

3.1 Methodology of economic assessment

The aim of task 6.4 is to analyse the operational, logistics and economic effects of the proposed lengthening steps on the operator's business. The effects of each option are compared with the reference situation which equals the current operating profile of the shipping company concerned. To establish current operating profiles general assumptions are made which are verified with ship owners participating in the project. The assumptions made for the two specific ships are discussed in chapters 6 and 11.

For each of the five lengthening options considered in the project[1] the main economic advantages and drawbacks were identified by the MoVe IT! WP6 partners jointly with the ship operators, and checked with the partners with technical expertise to ensure consistency and reliability.

From tasks 6.1, 6.2 and 6.3 cost estimates for the lengthening, impacts on maintenance costs and effects on fuel consumption were provided. These estimates are the basis of the analyses made to assess the feasibility of each lengthening option. For each vessel several options are calculated, so the results look similar to:

Table 3.1 Presentation of outcomes feasibility assessment

	Reference situation	**Retrofit option 1**	**Retrofit option 2**	**Retrofit option 3**
NPV				
IRR				
Payback period				

For each of the options the change in operating costs compared to the reference situation is calculated, as well as the payback time of the investment. For shipping companies the payback period is the most relevant indicator. This indicator shows when the ship owner has earned back his initial investment and when he starts to make money. The lower the payback period is the sooner the ship owner will have earned back his investment.

Another indicator used is the internal rate of return (IRR). This indicator measures and compares the profitability of different options or more specifically the IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment. The higher the IRR is the more profitable it is to invest in a retrofit option.

A last indicator used is the Net present value (NPV). This indicator is often used in policy related decisions and indicates the 'difference amount' between the sums of discounted: cash inflows and cash outflows. It compares the present value of money today to the present value of money in the future, taking inflation and returns into account. The higher the value of this indicator the more attractive it is to invest in the retrofit option.

[11] Two lengthening steps for fhe Rheinland and three lengthening steps for the Hendrik were considered.

General assumptions

Several general assumptions are made, which apply to all shipping companies and all retrofit options.

The **first assumption** relates to the time horizon used to calculate the effects. Apart from the investments costs, which occur only once, all other costs components are recurring. Some of them recur every year, e.g. the casco insurance premium and wages of employees, while other cost components only occur every two or three years, e.g. large maintenance costs. The time horizon chosen is set at 25 years.

The **second assumption** relates to the discount rate. All future costs or benefits are expressed in their present value, so all effects will be discounted to the year of investment. The year of investment is assumed to be 2016[2]. By discounting the costs and effects, costs and effects later in time count less heavily than costs and effects made earlier in time. The discount rate used in the analysis is 5.5%.

The **third assumption** relates to the prices used. All effects will be expressed in Euros, and data obtained in other currencies are converted to Euros. The effects will all be expressed in real prices and the price level used is price level 2013.

Main effects – direct effects:

- ***Investment costs***: One of the most important aspects in the economic evaluation is the investment costs needed to obtain the new retrofit option. For each of the options the partners with technical expertise have estimated the investment costs. It is assumed that the investment costs will all fall in one year and can be qualified as one-of costs;
- ***Maintenance costs:*** Closely related to the investment costs are the additional costs for maintenance. Installing a new engine or place a new rudder arrangement might cause an increase of the maintenance costs. It is assumed that maintenance related to the retrofit installation is needed every couple of years, and assumptions on this are made for each option. This means associated costs are included in the analysis using the assumed frequency (e.g. every 2 years, 3 years, etc.).

Main effects – operational profile

- ***Fuel consumption:*** Depending on the retrofit option chosen, fuel consumption of the vessel may increase or decrease. Most of the technical improvements suggested in the previous Work packages will result in a decrease of the fuel consumption of the vessel, resulting in a lower fuel bill, assuming that fuel prices remain constant. However some options, e.g. lengthening of the vessel, will increase the fuel consumption and therefore increase the fuel bill. For estimating the fuel prices the CBRB Gas oil circulars for inland shipping are used;

2 The MoVe-IT project ends in November 2014. It is assumed that companies need 2015 to ensure financing, make arrangements, e.g. reserve yard space and decide on the retrofit options. The first possible year of investment is 2016.

- ***Insurance costs:*** In inland shipping there two important types of insurances; the casco insurance or the hull and machinery insurance (H&M) and the protection and indemnity insurance (P&I). For the economic evaluation the casco insurance is the most important one, because the modernisation of the vessel will influence the height of the casco insurance. Insurance costs may increase if a technology is implemented that is much more expensive then the systems in place in the reference situation. On the other hand as it may concern a replacement by a newer and more reliable system, in some cases perhaps premiums can be reduced, because the chance of failure had reduced;
- ***Capital costs:*** The financial picture of the company can change due to the retrofitting of the vessel. To finance a retrofit option it is assumed that the shipping company has to obtain an additional loan from a bank or from another investor. The interest costs will probably increase and the company faces higher financing costs than before.

Additional effects

- ***Cargo volumes:*** Cargo carrying capacity can change due to the retrofit modernization of the ship. For most proposed retrofit options this effects will be limited, as cargo capacity or sailing speeds will not change. However in case the vessel is lengthened the ship's capacity will increase allowing larger volumes to be transported, resulting in a revenue increase (assuming sufficient demand). On the other hand some other retrofit options may cause a (slight) reduction of the cargo capacity of the vessel;
- ***Labour costs:*** labour costs could be affected by the modernisation of the vessel. This could concern the need for hiring additional personnel to comply with current legislation, or the need for additional training, which brings (temporary) additional costs. The first impact may occur when a vessel is lengthened, and if a threshold in manning regulations is passed, additional crew is required. On the other hand the retrofit option can require additional skills of the employees for which and additional training is required.

3.1.1 *Assessing different economic scenarios*

As assumptions are made which are uncertain, while the base case development may also be uncertain (e.g. how will the IW market develop, what will the level of fuel prices be in future years, etc.), for each ship/retrofit option combination, multiple scenarios will be tested. Generally we assess a baseline scenario (e.g. applying the middle assumptions on costs and impacts), a high, and a low scenario (using the range ends of costs and impacts estimated. These will be presented as sensitivity tests on the baseline scenario.

As the uncertainties on assumptions vary between the ships and retrofit options, no standard scenarios for all ships are developed, but the baseline and alternative scenarios are made for each ship/retrofit option specifically. However general inputs such as interest rates, residual values or fuel prices are applied similar for all ships.

3.2 Methodology for assessing environmental impacts

The second aim of task 6.4 is to assess the environmental impact of the retrofit options proposed in tasks 6.1 – 6.3. The emissions considered in the assessment are:

- Carbon dioxide (CO_2);
- Nitrogen oxide (NOx);
- Particular matter (PM);
- Hydrocarbon (HC);
- Carbon monoxide (CO);
- Sulphur dioxide (SO_2).

The emissions are related to the change in fuel consumption and are compared to the situation without any retrofit option. The emissions are presented as yearly values and values related to the transport performance in ton kilometres (tkm).

Fuel consumption is estimated for all lengthening options considered. Also a distinction is made between the fuel consumption in case the vessel uses a naked propeller and the fuel consumption in case the vessel has a propeller with nozzle.

The fuel consumption and therefore the emissions will increase due to lengthening of the vessel as the vessel requires more power to achieve the same performance. Taking only this aspect into account lengthening might not be a desirable option from an environmental point of view. However not only the fuel consumption of the vessel changes, but also the cargo carrying capacity will increase significantly. Due to this increase in cargo carrying capacity the relative values (kg emission / tkm) can be lower than without lengthening of the vessel. This can make lengthening, also from an environmental perspective, a more favourable option than doing nothing.

The total emissions per year are determined using the following equation:

$$E_{1year} = FC * EF$$

where FC is the total fuel consumption per year in kg and EF is the respective emission factor given in kg/fuel for CO_2 and g/fuel for all other emission factors. The factors used are based on the factors used in other studies. The factors are the same factors that are used in the environmental assessment in WP7. The following table shows the factors used in this study.

Table 3.2 Emission factors for inland waterway vessels

CO_2	NOx	PM	HC	CO	SO_2	Source
kg / kg fuel	g / kg/fuel	g / kg/fuel	g / kg/fuel	g / kg/fuel	g / kg/fuel	
3,175	57	0,83	3,4	6,5	0,02	VBD, 2001
3,173	46	2,116	5,1	19	0,02	TNO, 2010

Source: VBD (2001) and TNO (2010).

It is noted that the differences between TNO and VBD (now DST) data is large. Reasons for deviations are the uncertainty associated with PM measurements as well as the fact that the emission factors are average values over different power classes of engines. In this study the TNO figures will be the leading factors as the study is more recent. For more information on the methodology used, please see Deliverable 7.3 ‘Environmental impact’.

Part A: Hendrik

4 Description of the ship

The Hendrik (currently named Alk) was built in 1975 at the Dutch yard Joh. van Duijvendijk, located in Krimpen a/d IJssel. The length of the vessel was 70.0 metres and the vessel had two separate cargo holds with a length of 20.0 metres each. Both cargo holds are covered with sliding hatch covers to protect the cargo.

Between 1975 and 1990 the vessel was lengthened to 80.0 metres. It is unknown to the Consortium when this lengthening precisely took place. For research purposes this past lengthening is not considered in the analysis and the starting point of the lengthening assignment is the original length of the vessel, hence 70.0 metres. The vessel can be qualified as a CEMT III or CEMT IV vessel. Following table provides the original measurements of the vessel.

Table 4.1 Main characteristics of the Hendrik (1975)

Length	69.98 m
Beam	8.60 m
Draught	2.95 m
Displacement	1360 ton
Main engine	SKL 660 PK 6 NVD 48 – 2U

Source: http://www.debinnenvaart.nl/schip_detail/1649/.

Figure 4.1 Impression of the Hendrik

Source: www.debinnenvaart.nl (left) & www.binnenvaart.eu (right).

4.1 Operational profile

As the actual operating profile of the vessel is unknown to the MoVe IT! Consortium, several assumptions have been made which are used in the economic and environmental assessment. It is assumed that the vessel operates on the Rhine between Duisburg and Cologne, Germany. A one way trip has a length of approximately 100 km and so a round trip has a length of 200 km.

It is also assumed that the vessel performs maximum one round trip per week and does not sail the whole year round. In the calculations it is therefore assumed that the vessel operates 48 weeks per year and so the maximum number of trips performed equals 48. As the vessel is sailing on a short distance it is assumed that the vessel sails for one client only and is carrying cargo only one way and therefore the vessel is only loaded on 48 single trips and the other remaining 48 trips the vessel does not carry cargo.

5 Considered ship modifications

This chapter presents the outcomes of tasks 6.1 to 6.3 for the Hendrik. In task 6.1 several lengthening steps were considered and for each of the steps considered task 6.2 assessed the manoeuvrability of the vessel under different circumstances by carrying out several manoeuvrability tests. Task 6.3 assessed the power requirements once the vessel is lengthened taking into account different water depths and currents.

5.1 Ship structure

In task 6.1 the lengthening option of the Hendrik is analysed. Starting point of the analysis is the original length of the vessel (70.0 metres) instead of the current length (80.0 metres). The structure of the virtually lengthened vessel complies with current GL rules. Each lengthening step is 6.0 metres (which corresponds with the approximate length of one TEU) and in total 5 lengthening steps were considered.

The following table shows the maximum draft and total cargo capacity for each lengthening option. For each new option also the additional cargo capacity is presented.

Table 5.1 Max. draught and additional cargo for different lengthening steps

		Loa 70 m	Loa 76m	Loa 82m	Loa 88m	Loa 90m	Loa 95m
Max. draught	(m)	2.960	2.952	2.945	2.940	2.938	2.934
Total cargo in holds	(t)	1.114	1.241	1.373	1.502	1.545	1.653
Additional cargo in holds	(t)	-	128	259	388	432	539
Relative change	(%)	-	11.5	23.3	34.9	38.8	48.4

Source: Move-it WP 6, task 6.1 final report.

For each of the options a detailed cost estimate was made. The following table shows the overall costs per lengthening step and the costs per metre.

Table 5.2 Summary of costs per lengthening step for MV 'Hendrik'

		Loa 76m	**Loa 82m**	**Loa 88m**	**Loa 90m**	**Loa 95m**
Lengthening step ΔL	(m)	6.0	12.0	18.0	20.0	25.0
New hull section	(€)	35.000	88.000	126.000	142.000	178.000
Upgrade existing parts	(€)	18.000	18.000	18.000	18.000	18.000
Hatch cover	(€)	10.000	20.000	30.000	33.300	41.700
Total	**(€)**	**64.000**	**126.000**	**175.000**	**193.300**	**237.700**
Costs per meter of the new section (steel)	(€/m)	10.500	10.500	9.700	9.700	9.500
Costs for additional modification (structure)	(€/m)				1,000	1,900
Costs per meter of the new section (dry dock per week)	(€/m)	1,200	600	400	400	300
Total cost per m	**(€/m)**	**11,700**	**11,100**	**10,100**	**11,100**	**11,700**

Source: Move-it WP 6, task 6.1 final report.

In task 6.1 it was concluded that, although the lengthening steps Loa 90m and Loa 95m are technically feasible, they are too comprehensive as a retrofit option, because various additional changes in the structure of the forward and aft part of the vessel would be needed to meet GL requirements. Therefore these options are rather complex ones and are no longer considered in the remaining part of the analysis; see the task 6.1 report for further details.

5.2 Manoeuvrability

Manoeuvrability and the impact of lengthening of the vessel on the manoeuvrability is the main focus of task 6.2. To establish the effect of lengthening on a vessel's manoeuvrability four different tests were conducted:

1. Combined turning circle / pull-out manoeuvres;
2. Standard zigzag manoeuvres;
3. Evasive manoeuvres; and
4. Crash stop manoeuvres.

The analysis was carried out for three different lengths of the vessel. The first length is the original length of 70.0 metres and the tests were also done for lengths of 82 metres and 95 metres. All tests are carried out for different water levels, to establish the effects in deep water as well as shallow water. The depths considered were 3.5 m, 5 m, and 20 m. On top of that different speed levels were taken into account and each test was carried out for a speed of 10 km/h and 13 km/h.

The lengthening of the vessel was found to have no significant impact on the turning ability and directional stability of the vessel (the combined turning circle and pull-out manoeuvres). In shallow water the turning ability of the vessel is worse, but to improve the turning ability the vessel could decrease it approach speed. Further no improvements are needed. The same conclusions are drawn for the yaw checking ability and the initial turning ability (zigzag manoeuvres).

Lengthening of Hendrik has a small influence on the evasive manoeuvring ability. In shallow water the capabilities of the vessel are reduced and to solve the problem the rudder dimensions and characteristics could be improved. The lengthening does not affect the stopping ability (crash stop manoeuvres) of the vessel and no action is needed with regard to the stopping ability of the vessel.

5.3 Powering

In task 6.3 the influence of lengthening the vessel on the powering arrangement is analysed. The Hendrik is a single-propelled vessel, with a SKL 660 PK 6 NVD 48 – 2U engine. The vessel has one naked propeller with diameter of 1.5 metres.

It is estimated that the maximum speed of the vessel with its initially installed engine is 19.5 km/h, however the vessel hardly sails at maximum speed. In the analysis not only the effect of the lengthening on the required power is analysed, but also the water depth is considered.

The lengthening itself does not significantly influence the power needed to achieve a certain speed. Therefore the same power train (engine, gearbox and propeller) was considered for all lengthening steps. It should be noted that the power train is renewed in the analysis, but the technical specifications remain more or less the same.

Speed reductions of 1 to 2 km/h as result of the lengthening might occur in case the water depth changes. In shallow water (from deep to h= 5m and then from 5m to 3.5 m) the speed reduction of Hendrik is around 4 km/h. In very shallow water the maximum speed is even further reduced due to squat. The maximum allowed speed for the vessel is 13 km/h for h=5 m and 8 km/h for h=3.5 m.

The installation of a propeller in nozzle will improve the propulsive efficiency compared to the naked propeller. The expected improvement is around 10% which can increase the speed for 1 km/h.

6 Economic feasibility

6.1 Commercial / economic impacts

The options proposed might influence the logistical operation of the company. The main aim is to increase the cargo capacity of the vessel. On the one hand this option enables the company to transport the same amount of cargo with a lower draught. The vessel operates on the Rhine, a river with fluctuating water levels, and if the vessel is able to sail with a lower draught, the company is able to operate longer than it is nowadays. On the other hand the company can transport more cargo than before and increase its revenue per trip.

Lengthening of the vessel will have some impacts on the business case of the shipping company. First and foremost the fuel consumption of the vessel will change. Due to the lengthening it is expected that the vessel will consume more fuel if it wants to maintain the same operating speed. According to the findings in task 6.3 it is likely that the fuel consumption will increase, even in case a propeller in nozzle is installed. This is a result of the increased ship capacity. The following table provides an overview of the fuel consumption of the Hendrik under different relative speeds and retrofit options. The table shows the absolute increase in fuel consumption.

Table 6.1 Total fuel consumption of Hendrik in litre per year on Rhine

	Relative speed 10.0 km/h		Relative speed 14.4 km/h	
Ship's length (m)	**Naked propeller**	**Propeller in nozzle**	**Naked propeller**	**Propeller in nozzle**
69.98	30,049	24,530	59,726	47,563
76	32,962	26,676	65,898	52,827
82	35,936	28,823	72,070	58,274
88	39,095	30,969	78,243	63,538

Besides an increase in fuel consumption the vessel is able to carry more cargo due to lengthening of the cargo hold. In case the vessel is lengthened by 6 metres the cargo carrying capacity increases with 127 tons, in case the vessel is lengthened by 12 metres the cargo carrying capacity increases with 258 tons and in case of a lengthening step of 18 metres the additional cargo carrying capacity is 388 tons.

In the table below the fuel consumption per transported ton is presented. As the table shows the fuel consumption per ton decreases, once the vessel is able to transport more cargo, this is irrespective the speed that is sailed. In case a nozzle is installed the fuel consumption per ton is even further reduced.

Table 6.2 Fuel consumption of Hendrik in litre per ton transported

	Relative speed 10.0 km/h		Relative speed 14.4 km/h	
Ship's length (m)	**Naked propeller**	**Propeller in nozzle**	**Naked propeller**	**Propeller in nozzle**
69.98	0.75	0.61	1.489	1.186
76	0.74	0.60	1.475	1.182
82	0.73	0.58	1.459	1.180
88	0.72	0.57	1.447	1.175

6.2 *Input data and assumptions*

As described before, three lengthening steps are considered for Hendrik. The investment costs of lengthening only (so no installation of a propeller in nozzle) are about € 70,400.- for Loa 76m, € 133,400.- for Loa 82m and € 182,000.- for Loa 88m. In task 6.2 it was advised to improve or renew the rudder arrangement of the vessel in order to improve the manoeuvrability of the vessel. It is assumed that the rudder system will be renewed and that the investment costs are € 100,000 euros[3]. The rudder system is renewed in all options considered. In task 6.3 it was advised that for each lengthening step the main engine needs to be changed as well, to ensure enough powering to operate the vessel in the same way. Total costs for the new engine add up to € 232.800. The investments costs for the new engine consist of both the selling price of an engine as well as the installation costs. In task 6.3 it was also advised to change the propeller from a naked propeller to a propeller in nozzle. It is assumed that the additional investment for the new propeller and nozzle is € 57,500.[4]

For all three options it is considered that the time at yard is four weeks. The time at yard will not change due to lengthening as the lengthened part is pre-produced at the yard and once the vessel is in dry dock the total length of the new part is irrelevant for the time the vessel needs to be at the yard.

It is assumed that the additional insurance costs are the same for all lengthening steps and will increase the initial insurance costs by 10%.

Table 6.3 Overview of data input

	Loa 76m	**Loa 82m**	**Loa 88m**
Investment costs (lengthening and new engine)	€ 303,200	€ 366,200	€ 414,800
Investment costs rudder renewal	€ 100,000	€ 100,000	€ 100,000
Investment costs propeller and nozzle	€ 57,500	€ 57,500	€ 57,500
Time at yard	4 weeks	4 weeks	4 weeks
Maintenance costs	€ 0	€ 0	€ 0
Additional ship capacity (tons)	127	259	388
Δ insurance costs	+ 10%	+ 10%	+ 10%

6.2.1 *Specific assumptions*

1. It is assumed that the vessel transports bulk, e.g. agricultural products. For each of these commodities a transport price per ton of € 24, - is considered.[5]

2. In case of lengthening the fuel consumption will rise. As no information is available for the fuel consumption of the main and auxiliary engine it is assumed

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[3] Based on expert judgement. The price chosen allows for renewal of the entire rudder system.

[4] The costs for a new propeller are only considered in the option where the propeller is replaced and the costs are additional to the investment costs mentioned in table 6.2.

[5] Based on expert judgement.

that the fuel consumption used only compromises the main engine. The consumption of the auxiliary engines will not change as a result of the lengthening. Therefore, to calculate the fuel increase only the fuel consumption of the main engine is considered.

3. To lengthen the vessel, the vessel needs to go in dry-dock for 4 weeks. It is assumed that the vessel performs one round trip per week, for instance between Nurnberg and Regensburg in Germany. Therefore the vessel will miss 4 round trips and its related revenues.

4. Inland vessels are often not fully loaded. The Hendrik was compared with other vessels sailing on the Rhine and it is assumed that the load factor of the vessel is 75%. This is more or less equal to the load factors of similar vessels. It is assumed, that also when the vessel is lengthened, the vessel will not be fully loaded. According the task 6.1 the additional cargo capacity for Loa 76 m is 127 tons, for Loa 82 m is 259 tons and for Loa 88 m is 388 tons. For the additional capacity it is assumed that 75% will be used, equalling 95, 192 and respectively 289 tons (assuming there is sufficient demand).

6.3 Results of economic assessment

The economic assessment is carried out for two different relative speeds. The first table presents the results when a relative speed of 10.0 km/h is used, which is the lowest speed considered in the analysis. The upstream speed equals 5.0 km/h and the downstream speed 15.0 km/h. A distinction is made between the option of only lengthening the vessel with 6, 12 or 18 metres and the option of also changing the propeller from a naked propeller to a propeller in nozzle.

Table 6.4 Outcome of economic assessment for relative speed of 10.0 km/h

	Loa 76m		Loa 82m		Loa 88m	
	Naked propeller	Propeller in nozzle	Naked propeller	Propeller in nozzle	Naked propeller	Propeller in nozzle
NPV (x 1000)	€ 791	€ 801	€ 2,073	€ 2,091	€ 3,355	€ 3,383
IRR	23%	21%	53%	48%	93%	83%
Payback time	6 years	6 years	3 years	3 years	2 years	2 years

As the table shows most retrofit options are economically feasible with a maximum payback period of 5 years. Lengthening the vessel with only 6 metres has a payback period of six years. These options will not be feasible from a ship owner’s perspective and these options will probably not be chosen. According to interviews held with different ship owners their desirable payback period is between 3-4 years as a maximum. If this criterion is followed only the lengthening option of 76 m with a propeller in nozzle is not a feasible option for them. However it should be noted that one the economic climate is improving this might be a viable option as well.

The same analysis was carried out for the higher relative speed of 14.4 km/h. The upstream speed in this situation is 9.4 km/h and the downstream speed equals 19.4 km/h. The results are shown in the following table.

Table 6.5 Outcome of economic assessment for relative speed of 14.4 km/h

	Loa 76m		Loa 82m		Loa 88m	
	Naked propeller	Propeller in nozzle	Naked propeller	Propeller in nozzle	Naked propeller	Propeller in nozzle
NPV (x 1000)	€ 760	€ 835	€ 2,011	€ 2,093	€ 3,264	€ 3,356
IRR	22%	22%	51%	48%	89%	82%
Payback time	6 years	6 years	3 years	3 years	2 years	2 years

The results of this analysis are more or less similar to the results of the analysis with a relative speed of 10.0 km/h. Also in this analysis all options are economically feasible. However ship owners will probably not use for the lengthening options of 76 metres as the payback period is beyond their desired pay back periods.

6.4 Sensitivity analyses

The following tables show the outcome of the sensitivity analyses carried out for the lengthening options. All analyses are carried out for a relative speed of 10.0 km/h which is probably the speed most often used. The first analysis carried out focuses on lengthening the vessel by 6 metres and the installation of a propeller in nozzle. This option is chosen as it is the option with the longest payback period. Changes in fuel price, investment costs or transport prices might make this option a less desirable one. Each of these effects is considered separately and a worst case and best case scenario are presented.

Table 6.6 Outcome of sensitivity analysis Loa 76 m and propeller in nozzle (relative speed 10.0 km/h)

		Investment costs		Fuel price		Transport price	
	Base case	-20%	+20%	-10%	+10%	-25%	+25%
NPV (x 1000)	€ 801	€ 880	€ 723	€ 798	€ 805	€ 505	€ 1,098
IRR	21%	26%	18%	21%	21%	16%	26%
Payback time	6 years	5 years	7 years	6 years	6 years	8 years	5 years

The sensitive analysis shows that this retrofit option is most sensitive to changes in the investment costs and transport price. The option becomes less attractive once the investment costs increase by 20% or the transport prices drop by 25%. In these cases the payback period will be seven respectively eight years and ship owners indicated that the desirable payback period is 3 to 4 years. However if the investment costs decrease or the transport prices increase it become more attractive to invest in this option as the payback period is shortened to five years in both scenarios. It seems that this retrofit option is not very sensitive for changes in the fuel price as the pay back remains the same in both situations.

The same sensitive analysis was done for lengthening the vessel with 6 metres, but without changing the propeller arrangement.

Table 6.7 Outcome of sensitivity analysis Loa 76 m and naked propeller (relative speed 10.0 km/h)

		Investment costs		Fuel price		Transport price	
	Base case	**-20%**	**+20%**	**-10%**	**+10%**	**-25%**	**+25%**
NPV (x 1000)	€ 791	€ 859	€ 722	€ 793	€ 788	€ 494	€ 1,087
IRR	23%	28%	19%	23%	23%	17%	28%
Payback time	6 years	5 years	7 years	6 years	6 years	8 years	5 years

According to the sensitivity analysis carried out this option is also sensitive to increases in investments costs and decrease in transport prices. The conclusions are more or less the same as for the option reviewed above. The pay-back periods are the same as the ones found in the above mentioned sensitivity analysis. It seems that also this option is insensitive to changes in the fuel price.

7 Environmental feasibility

7.1 Input data and assumptions

The assessment of the environmental performance is carried out following the approach described in chapter 2. In the analysis a distinction is made between an average speed of 10.0 km/h per journey and an average speed of 14.4 km/h per journey. For each average speed a different speed upstream and downstream is used, resulting in different fuel consumption levels. The following table shows the fuel consumption upstream and downstream per relative speed and per lengthening step with and without the usage of a nozzle.

Table 7.1 Total fuel consumption of Hendrik in kg for operation of 100 km on Rhine

		Relative speed 10.0 km			Relative speed 14.4 km		
	Ship's length (m)	Upstream 5.0 km/h	Downstream 15.0 km/h	Total	Upstream 9.4 km/h	Downstream 19.4 km/h	Total
Propeller: naked	69.98	392	131	523	700	339	1,039
	76	430	143	573	772	374	1,146
	82	469	156	625	845	409	1,254
	88	510	170	680	917	444	1,361
Propeller: nozzle	69.98	320	107	427	558	270	827
	76	348	116	464	619	300	919
	82	376	125	501	683	331	1,014
	88	404	135	539	745	361	1,105

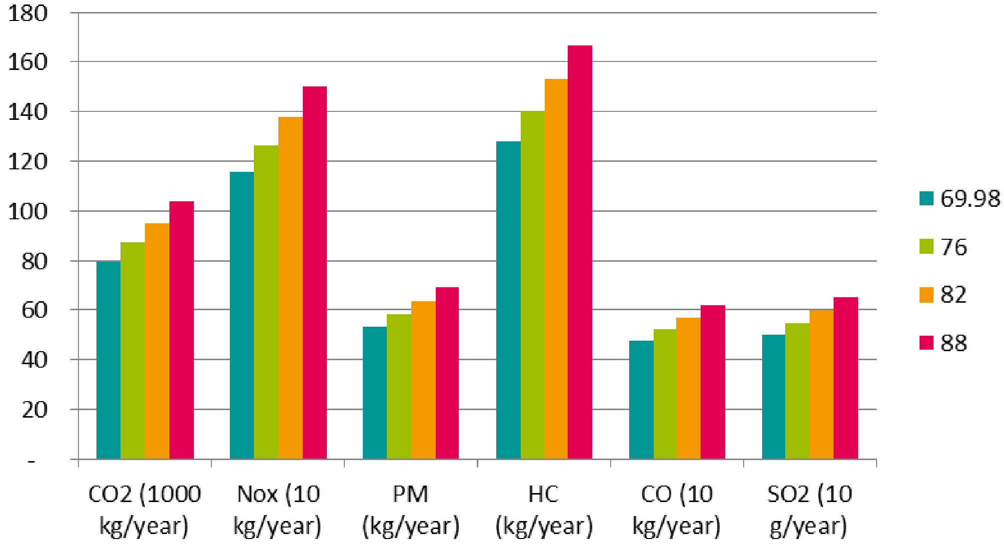
In the analysis the tonne kilometres per lengthening step per year are considered. The following data are used:

- 69.98 m: 10,694,000 tkm;
- 76 m: 11,913,600 tkm;
- 82 m: 13,171,200 tkm;
- 88 m: 14,419,200 tkm.

7.2 Results

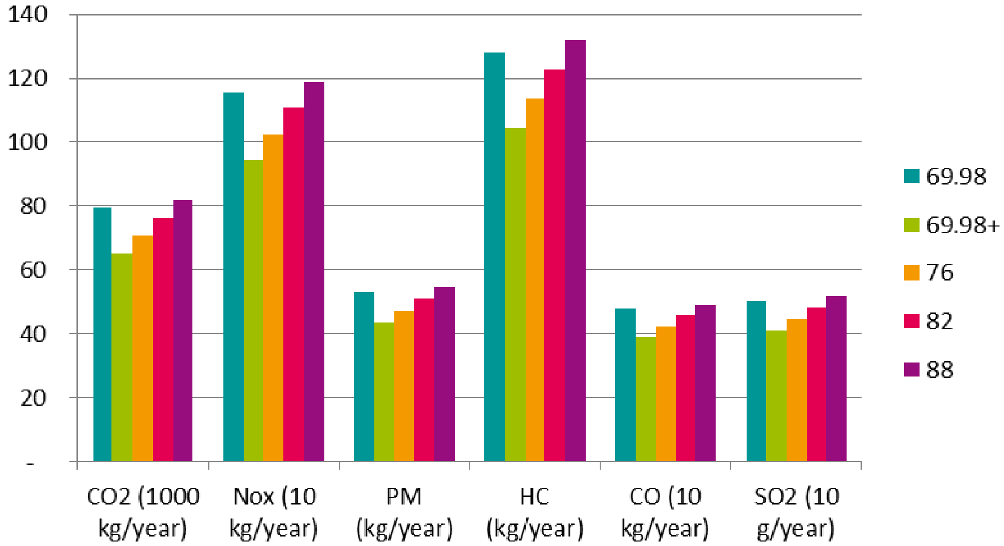
In the environmental assessment, a distinction is made between lengthening only and lengthening + replacement of the propeller. The figure below shows the results of the environmental assessment for the lengthening only options in case the vessel operates on the relative speed of 10.0 km/h. In these cases the vessel still uses its current 'naked' propeller. As the figure shows all emissions will increase in absolute numbers, due to the increased capacity and volumes transported. In table 7.2 the emissions per tonne kilometre are presented and this table shows a decrease in emissions.

Figure 7.1 Annual emissions of the Hendrik for an average speed of 10,0 km (naked propeller)



In the second step of the analysis the naked propeller is replaced for a propeller in nozzle. The figure shows the results of this analysis. For a good comparability also the current environmental performance of the vessel is presented (i.e. 69.98). The option 69.98+ indicates the installation of the propeller in nozzle.

Figure 7.2 Annual emissions of the Hendrik for an average speed of 10,0 km (propeller in nozzle)



As the figure shows the environmental performance of the vessel will improve once a propeller in nozzle is installed. The two figures only show the total emissions per year and therefore the absolute increase in emissions. However the cargo carrying capacity of the vessel also increases and therefore the relative values (kg emission/tkm) can be lower than without the retrofitting. Following table shows the change in emissions per tkm. For CO_2 the grams per tonne kilometre are presented, for all the other emissions the micrograms per tonne kilometres are calculated. Also in this table a distinction is made between the lengthening options with and without a propeller rearrangement.

Table 7.2 Emissions in g/tkm and mg/tkm for relative speed of 10.0 km/h

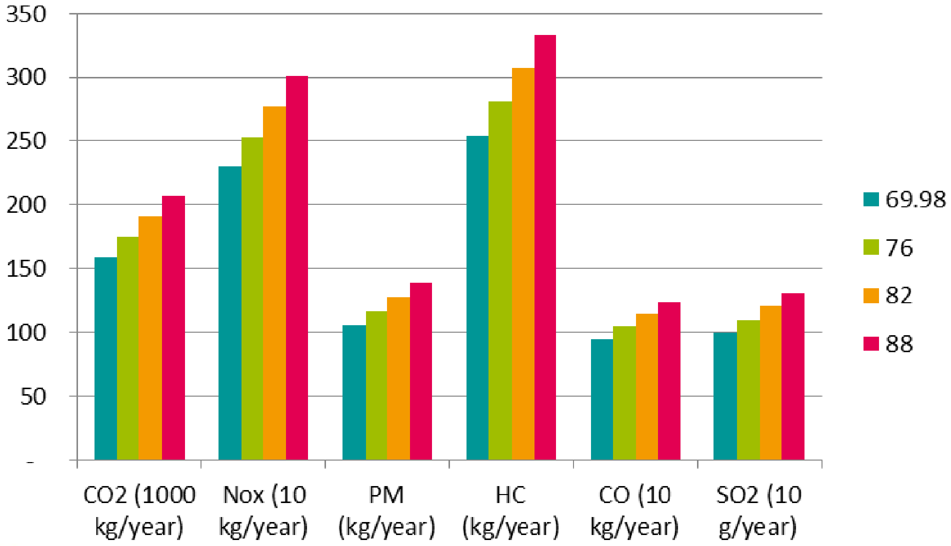
	Ship's length (m)	CO_2 (g/tkm)	NOx (mg/tkm)	PM (mg/tkm)	HC (mg/tkm)	CO (mg/tkm)	SO_2 (mg/tkm)
Propeller: naked	69.98	7.4	107.925	4.965	11.966	44.578	0.0469
	76	7.3	106.272	4.888	11.782	43.895	0.0462
	82	7.2	104.798	4.821	11.619	43.286	0.0456
	88	7.2	104.141	4.790	11.546	43.015	0.0453
Propeller: nozzle	69.98	6.1	88.102	4.053	9.768	36.390	0.0383
	76	5.9	86.006	3.956	9.535	35.524	0.0374
	82	5.8	84.053	3.866	9.319	34.178	0.0365
	88	5.7	82.496	3.795	9.146	34.074	0.0359

Although the emission levels are increasing in absolute numbers, lengthening has a positive environmental impact as the emissions per tonne kilometre are all decreasing once more cargo is transported. The installation of a propeller in nozzle is beneficial as the emissions will decrease considerably and can be further decreased once more cargo is transported. Therefore it would be wise to install a propeller in nozzle at all times as the environmental performance will increase, even when no additional cargo is transported.

7.3 Sensitivity analysis

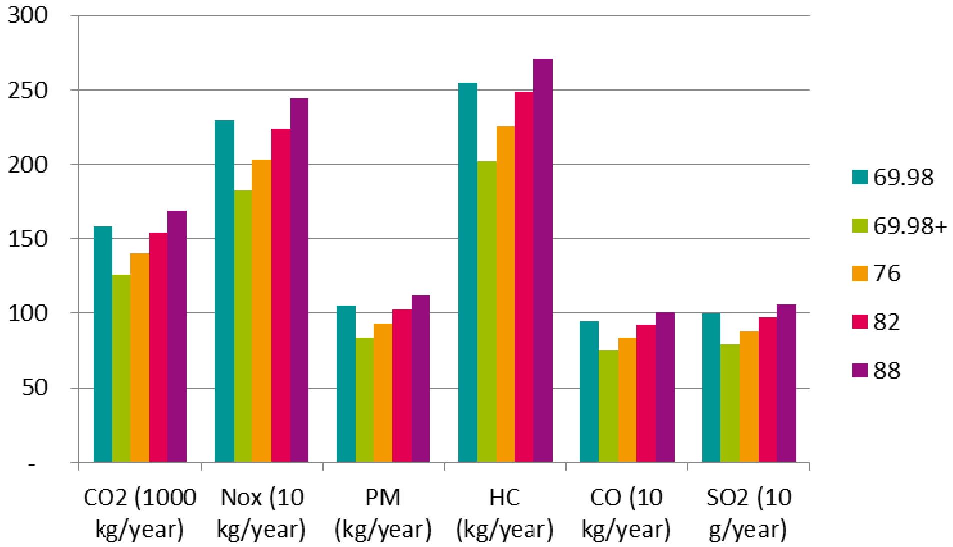
In the sensitivity analysis the relative speed is increased from 10.0 km/h to 14.4 km/h. In the first step only the lengthening of the vessel is considered. The results are presented in the figure below.

Figure 7.3 Annual emissions of the Hendrik for an average speed of 14,4 km (naked propeller)



The environmental performance of the vessel has decreased and the absolute emission levels increase once the vessel is lengthened. In the second step the installation of a propeller in nozzle is considered. As the figure below shows, the environmental performance of the vessel improves once the new propeller is installed. For the current length and the first lengthening steps the absolute emission levels are below the current emission levels. If the vessel is lengthened by 18 metres the absolute emission levels will increase, however the levels are below the levels of the lengthening only options.

Figure 7.4 Annual emissions of the Hendrik for an average speed of 14,4 km (propeller in nozzle)



The third step in the sensitivity analysis is to calculate the emission per ton kilometre. The results are presented in the table below.

Table 7.3 Emissions in g/tkm and mg/tkm for relative speed of 14.4 km/h

	Ship's length (m)	CO_2 (g/tkm)	NOx (mg/tkm)	PM (mg/tkm)	HC (mg/tkm)	CO (mg/tkm)	SO_2 (mg/tkm)
Propeller: naked	69.98	14.8	214.512	9.868	23.783	88.603	0.0933
	76	14.7	212.459	9.773	23.555	87.755	0.0924
	82	14.5	210.173	9.668	23.302	86.810	0.0914
	88	14.4	208.424	9.587	23.108	86.088	0.0906
Propeller: nozzle	69.98	11.8	170.827	7.858	18.939	70.559	0.0743
	76	11.7	170.318	7.835	18.883	70.349	0.0741
	82	11.7	169.938	7.817	18.841	70.192	0.0739
	88	11.7	169.254	7.786	18.765	69.909	0.0736

When the relative speed increases, the level of emission increases as well. Compared to the emission levels when sailing with a relative speed of 10.0 km/h emission levels of CO_2 are almost two times as high. The environmental performance is increasing once the vessel transports more cargo. The installation of a propeller in nozzle has a positive effect on the environmental performance of the vessel and the emission levels per tonne kilometre will be reduced even more. Also when sailing with a higher relative speed the installation of a propeller in nozzle is beneficial from an environmental point of view.

Part B: Rheinland

8 Description of the ship

The Rheinland (currently named Napoleon) was built in 1959 at the German yard Lankewerft, located in Berlin-Splandau. The length of the vessel was 57.50 metres and the vessel has one cargo hold, which is covered with a hatch cover.

It seems that the vessel is already lengthened once; however it is unknown to the Consortium when this lengthening took place. Current length of the vessel is 63.44 metres. For research purposes the lengthening is not considered in the analyses and the starting point of the lengthening assignment is the original length of the vessel, hence 57.50 metres. The vessel can be qualified as a CEMT II ship. Following table provides the original measurements of the vessel.

Table 8.1 Main characteristics of the Rheinland (1959)

Length	57.50 m
Beam	6.35 m
Draught	2.43 m
Displacement	537 ton
Main engine	Deutz 375 hp TAMD 163 C

Source: www.binnenvaart.eu.

Figure 8.1 Impression of the Rheinland

Source: www.binnenvaart.eu.

8.1 Operational profile

As the actual operating profile of the vessel is unknown to the Consortium, several assumptions have been made which are used in the economic and environmental assessment. It is assumed that the vessel operates between Budapest, Hungary and Constanta, Romania. A one way trip has a length of approximately 1,000 km and so a round trip has a length of 2,000 km.

It is assumed that the trip downstream takes 10 days on average, while the journey upstream, will take 14 days. The days in port and waiting for cargo are taken into account in these figures as well. Therefore it is assumed that a round trip will take approximately 24 days and on average 15 round trips per year are performed. As the vessel is sailing on long distances it is assumed that the vessel will wait for cargo instead of sailing empty. Therefore it is assumed that the vessel will carry cargo on all its 30 single trips. However the vessel will not be fully loaded.

9 Considered ship modifications

This chapter presents the outcomes of tasks 6.1 to 6.3 for the Rheinland. In task 6.1 several lengthening steps were considered and for each of the steps considered tasks 6.2 assessed the manoeuvrability of the vessel under different circumstances by carrying out several manoeuvrability tests. Task 6.3 assessed the power requirements once the vessel is lengthened taking into account different water depths and currents.

9.1 Ship structure

In task 6.1 the lengthening option of the Rheinland was analysed. Starting point of the analysis is the original length of the vessel (57.50 metres) instead of the current length (63.44 metres). The lengthening steps proposed comply with current BV rules. Each lengthening steps is 6.0 metres and in total 2 lengthening steps were considered.

The following table shows the maximum draft and the total cargo capacity per option. For each new option also the additional cargo capacity is presented.

Table 9.1 Max. draught and additional cargo for different lengthening steps

		Loa 57.50m	Loa 63.50 m	Loa 69.50 m
Max draught	(m)	2.429	2.429	2.420
Total cargo in holds	(t)	537,8	615.6	694
Additional cargo in holds	(t)	-	77.8	156.2
Relative change cargo holds	(%)	-	14.5	29.0

Source: Move-it WP 6, task 6.1 final report.

For each of the options a detailed cost estimate is made. The following table shows the overall costs per lengthening step and the costs per metre.

Table 9.2 Summary of costs per lengthening meter for MV 'Rheinland'

		Loa 63.50 m	Loa 69.50 m
Lengthening step ΔL	(m)	6.0	12.0
Costs per meter of the new section (steel)	(€/m)	5.000	5.000
Costs per meter of the new section (dry dock per week)	(€/m)	800	400
Total cost per m	**(€/m)**	**5.800**	**5.400**

Source: Move-it WP 6, task 6.1 final report.

9.2 Manoeuvrability

Manoeuvrability and the impact of lengthening of the vessel on the manoeuvrability is the main focus of task 6.2. To establish the effect of lengthening on a vessel's manoeuvrability four different tests are conducted:

1. Combined turning circle / pull-out manoeuvres;
2. Standard zigzag manoeuvres;
3. Evasive manoeuvres; and
4. Crash stop manoeuvres.

The analysis was carried out for three different lengths of the vessel. The first length is the original length of 57.50 metres. The tests were also done for a ship's length of 63.50 metres and 69.50 metres. All tests are carried out for different water levels, to establish the effects in deep water as well as shallow water. The depths considered were 3.5 m, 5 m, and 20 m. Also different speed levels were considered and each test was carried out for a speed of 10 km/h and 13 km/h.

The lengthening of the vessel has no significant impact on the turning ability and directional stability of the vessel (the combined turning circle and pull-out manoeuvres). In shallow water the turning ability of the vessel is impaired, but to improve the turning ability the vessel could decrease it approach speed. No further improvements are needed. The same conclusions are drawn for the yaw checking ability and the initial turning ability (zigzag manoeuvres).

Also the lengthening of Rheinland has no influence on the evasive manoeuvring ability (evasive manoeuvres) and the stopping ability (crash stop manoeuvres) of the vessel and no action is needed.

9.3 Powering

In task 6.3 the influence of lengthening the vessel on the powering arrangement is analysed. The Rheinland is a single-propelled vessel, with a Deutz 375 hp TAMD 163 C engine. The vessel also has one propeller with a propeller diameter of 1.0 metres. The propeller has no nozzle.

It is estimated that the maximum speed of the vessel is 17.8 km/h, however the vessel hardly ever sails at maximum speed. In the analysis not only the effect of the lengthening on the required power is analysed, but also the water depth is considered.

The lengthening itself does not significantly influence the power needed to achieve a certain speed. Therefore the same power train (engine, gearbox and propeller) was considered for all lengthening steps. It should be noted that the power train is renewed in the analysis, but the technical specifications remain more or less the same.

Speed reductions of 1 to 2 km/h as result of the lengthening might occur in case the water depth changes. In shallow water (from deep to h= 5 m and then from 5 m to 3.5 m) the speed reduction of Rheinland is around 2 km/h. In very shallow water the maximum speed is even further reduced. The maximum allowed speed 10 km/h for h=3.5 m.

The installation of a propeller with nozzle will improve the propulsive efficiency compared to the usage of a naked propeller. The expected improvement is 10% which increases the max. speed up to 1 km/h.

10 Economic feasibility

10.1 Commercial / economic impacts

Lengthening of the vessel will have some impacts on the business case of the shipping company. First and foremost the fuel consumption of the vessel will change. Due to the lengthening it is expected that the vessel will consume more fuel if it wants to maintain the same operational level. According to the findings in task 6.3 it is likely that the absolute fuel consumption will increase, even in case a propeller in nozzle is installed. The following table provides an overview of the fuel consumption of the Rheinland under different relative speeds and retrofit options.

Table 10.1 Total fuel consumption of Rheinland in litre per year on Danube (litres per year)

	Relative speed 10.8 km/h		Relative speed 14.8 km/h	
Ship's length (m)	Naked propeller	Propeller in nozzle	Naked propeller	Propeller in nozzle
57	41,943	36,397	95,128	81,709
63	44,651	39,481	108,119	92,184
69	48,125	41,937	120,691	101,403

Besides an increase in fuel consumption the vessel is able to carry more cargo due to the lengthening. In case the vessel is lengthened by 6 metres the cargo carrying capacity increases with 77.8 tons and in case the vessel is lengthened by 12 metres the cargo carrying capacity increases with 156.2 tons.

These options might influence the logistical operation of the company. Main aim is to increase the cargo capacity of the vessel. On the one hand this option enables the company to transport the same amount of cargo with a lower draught. The vessel operates on the Danube, a river with fluctuating water levels, and if the vessel is able to sail with a lower draught, the company is able to operate longer than it is nowadays. On the other hand the company can transport more cargo than before and increase its revenue.

10.2 Input data and assumptions

For Rheinland two lengthening steps are considered. The investment costs of lengthening only are about € 34,800 for Loa 63.5 m, and € 64,800 for Loa 69.5 m. In task 6.3 it was advised that for each lengthening step the main engine needs to be changed as well, to ensure enough powering to operate the vessel in the same way. Total costs for the new engine add up to € 232.800. The investments costs for the new engine consist of both the selling price of an engine as well as the installation costs. In tasks 6.3 it was also advised to change the propeller from a naked propeller to a propeller in nozzle. It is assumed that the additional investments for the new propeller are € 57,500.[6]

[6] The costs for a new propeller are only considered in the option where the propeller is replaced and the costs are additional to the investment costs mentioned in table 10.2.

For both options it is considered that the time at yard is four weeks. The time at yard will not change due to lengthening as the lengthened part is pre-produced at the yard and once the vessel is in dry dock the total length of the new part is irrelevant for the time the vessel needs to be at the yard.

It is assumed that the additional insurance costs are the same for all lengthening steps and will increase the initial insurance costs by 10%.

Table 10.2 Overview of input data

	Loa 63.5 m	**Loa 69.5 m**
Investment costs	€ 267,600	€ 297,600
Time at yard	4 weeks	4 weeks
Maintenance costs	€ 0	€ 0
Additional ship capacity (ton)	78	156
Δ insurance costs	+ 10%	+10%

10.2.1 *Specific assumptions*

1. It is assumed that the vessel transports bulk, e.g. agricultural products. For each of these commodities a transport price per ton of € 17 is considered[7].

2. In case of lengthening the fuel consumption will rise. As no information is available for the fuel consumption of the main and auxiliary engine it is assumed that the fuel consumption used only compromises the main engine. The consumption of the auxiliary engines will not change as a result of the lengthening. Therefore, to calculate the fuel increase only the fuel consumption of the main engine is considered.

3. To lengthen the vessel, the vessel needs to go in dry-dock for 4 weeks. It is assumed that the vessel sails between Budapest and Constanta. If the vessel needs to go in dry dock the vessel will miss one round.

4. Inland vessels are often not fully loaded. The Rheinland is compared other vessels sailing on the Danube and it is assumed that the load factor of the vessel is 75%. This is more or less equal to the load factors of similar vessels. It is assumed, that also when the vessel is lengthened, the vessel will not be fully loaded. According the task 6.1 the additional cargo capacity for Loa 63.5 m is 78 tons and for Loa 69.5 m is 156 tons. For the additional capacity it is assumed that 75% will be used, equalling 59 respectively 118 tons (assuming there is sufficient demand).

10.3 Results of economic assessment

The economic assessment is carried out for two different relative speeds. The first table presents the results when a relative speed of 10.8 km/h is used. The upstream speed equals 6.8 km/h and the downstream speed 14.8 km/h. A distinction is made between

[7] Based on expert judgement.

the option of only lengthening the vessel with 6 or 12 metres and the option of also changing the propeller from a naked propeller to a propeller in nozzle.

Table 10.3 Outcome of economic assessment for relative speed of 10.8 km/h

	Loa 63.5 m		**Loa 69.5 m**	
	Naked propeller	**Propeller in nozzle**	**Naked propeller**	**Propeller in nozzle**
NPV (x 1000)	€ 70	€ 71	€ 298	€ 385
IRR	9%	8%	20%	18%
Payback time	15 years	16 years	6 years	7 years

As the table shows especially the lengthening of the vessel with 12 metres is a feasible option. It should be noted that according to ship owners interviewed even a payback period of 6 or 7 years is too long, however if the economic situation improves it might become an attractive option. To lengthen the vessel by only six metres is not economically feasible as the payback period is 15 respectively 16 years. The calculations show that the options with a naked propeller are earned back earlier then the options with a propeller in nozzle. These options have higher investment costs, as the nozzle needs to be installed, and the maintenance and insurance costs are higher as well. The amount of additional cargo does not compensate for this increase in costs and therefore it takes longer to earn back the initial investment.

The same analysis was also carried for a relative speed of 14.8 km/h. The upstream speed considered is 10.8 km/h and the downstream speed is 18.8 km/h. Also for this analysis both the lengthening only option and the option lengthening + propeller in nozzle are considered.

Table 10.4 Outcome of economic assessment for relative speed of 14.8 km/h

	Loa 63.5 m		**Loa 69.5 m**	
	Naked propeller	**Propeller in nozzle**	**Naked propeller**	**Propeller in nozzle**
NPV (x 1000)	€ -27	€ 75	€ 190	€ 325
IRR	4%	9%	13%	16%
Payback time	> 26 years	16 years	10 years	8 years

When the vessel sails with a relative speed of 14.8 km/h some options are feasible. Lengthening the vessel with 12 metres and installation of a propeller in nozzle is the most feasible option. The options where the vessel is lengthened with only 6 metres the payback period is not feasible. This is due to the increased fuel consumption. Sailing at a higher speed increases the fuel consumption of the vessel considerably and the additional cargo capacity does not compensate for the fuel increase. However the installation of a propeller in nozzle is beneficial as the payback period has decreased to 16 years.

10.4 Sensitivity analysis

The following tables show the outcome of the sensitivity analyses carried out for the lengthening options. All analyses are carried out for a relative speed of 10.8 km/h which is probably the speed most often used. The first analysis carried out focuses on lengthened the vessel with 6 metres and the current propeller arrangement. This option is chosen as it is the option with a longer payback period than desired by the ship owner, however with the potential to become an attractive option. Changes in fuel price, investment costs or transport prices might make this option a less desirable one. Each of these effects is considered separately and a worst case and best case scenario are presented.

Table 10.5 Outcome of sensitivity analysis Loa 63.5 m and naked propeller (relative speed 10.8 km/h)

		Investment costs		Fuel price		Transport price	
	Base case	**-20%**	**+20%**	**-10%**	**+10%**	**-25%**	**+25%**
NPV (x 1000)	€ 70	€ 116	€ 25	€ 73	€ 69	€ -17	€ 158
IRR	9%	12%	6%	9%	9%	5%	12%
Payback time	15 years	11 years	21 years	15 years	15 years	>26 years	11 years

As the analysis shows this lengthening option is most sensitive to changes in the investment costs and in changes in transport prices. In case the investment costs decrease or the transport prices increases the payback period is shortened from 15 to 11 years. However if the investment costs increase or the transport prices decrease the payback period becomes longer. In case the transport prices drop the ship owner is no longer able to earn back his initial investment.

In the second sensitivity analysis the lengthening option of 6 metres and installation of a propeller on nozzle is considered. Also in this analysis a change in investment costs, fuel prices and transport prices were taken into account.

Table 10.6 Outcome of sensitivity analysis Loa 63.5 m and propeller in nozzle (relative speed 10.8 km/h)

		Investment costs		Fuel price		Transport price	
	Base case	**-20%**	**+20%**	**-10%**	**+10%**	**-25%**	**+25%**
NPV (x 1000)	€ 71	€ 126	€ 15	€ 68	€ 73	€ -16	€ 158
IRR	8%	11%	6%	8%	8%	5%	11%
Payback time	16 years	12 years	22 years	16 years	16 years	>26 years	12 years

In this sensitivity analysis the conclusions are the same as for the previous analysis. It can be concluded that the effect of installation of a propeller in nozzle is not much influenced by changes in fuel prices at the shortest lengthening step.

11 Environmental feasibility

11.1 Input data and assumptions

The assessment of the environmental performance is carried out following the approach described in chapter 2. In the analysis a distinction is made between an average speed of 10.8 km/h per journey and an average speed of 14.8 km/h per journey. For each average speed a different speed upstream and downstream is used, resulting in a different fuel consumption. Following table shows the fuel consumption upstream and downstream per average speed and per lengthening step with and without the usage of a nozzle. It should be noted that the table presents the absolute increase in fuel consumption.

Table 11.1 Total fuel consumption of Rheinland in kg for operation of 1000 km on Danube

		Relative speed 10.8 km			Relative speed 14.8 km		
	Ship's length (m)	**Upstream 6.8 km/h**	**Downstream 14.8 km/h**	**Total**	**Upstream 10.8 km/h**	**Downstream 18.8 km/h**	**Total**
Propeller: naked	57	2,000	919	2,919	4,204	2,415	6,619
	63	2,147	960	3,107	4,778	2,745	7,523
	69	2,294	1,055	3,349	5,333	3,064	8,397
Propeller: nozzle	57	1,735	797	2,532	3,611	2,074	5,685
	63	1,882	865	2,747	4,074	2,340	6,414
	69	2,000	919	2,919	4,481	2,574	7,055

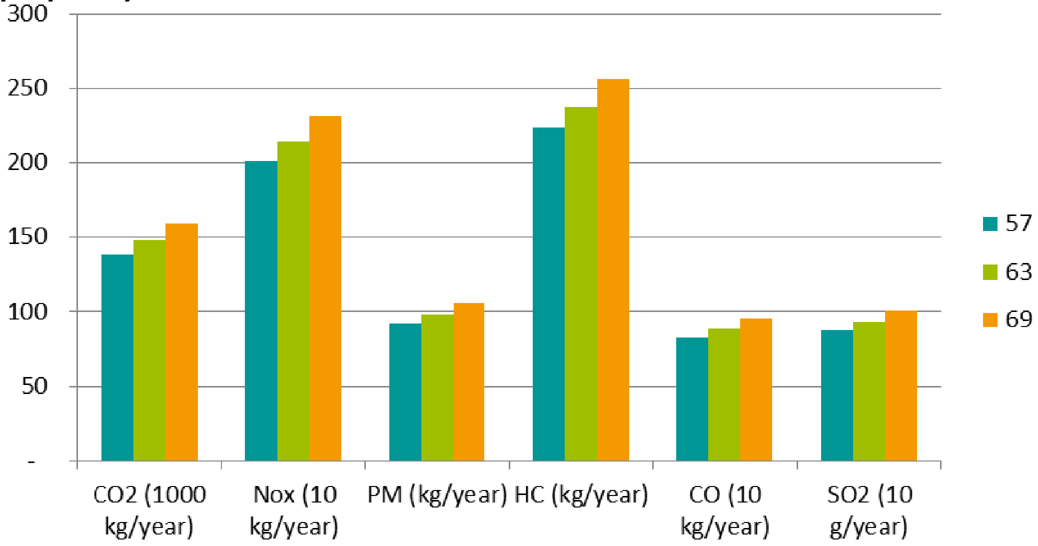
In the analysis the tonne kilometres per lengthening steps are considered. The following data are used:

- 57 m: 16,134,000 tkm;
- 63 m: 18,468,000 tkm;
- 69 m: 20,820,000 tkm.

11.2 Results

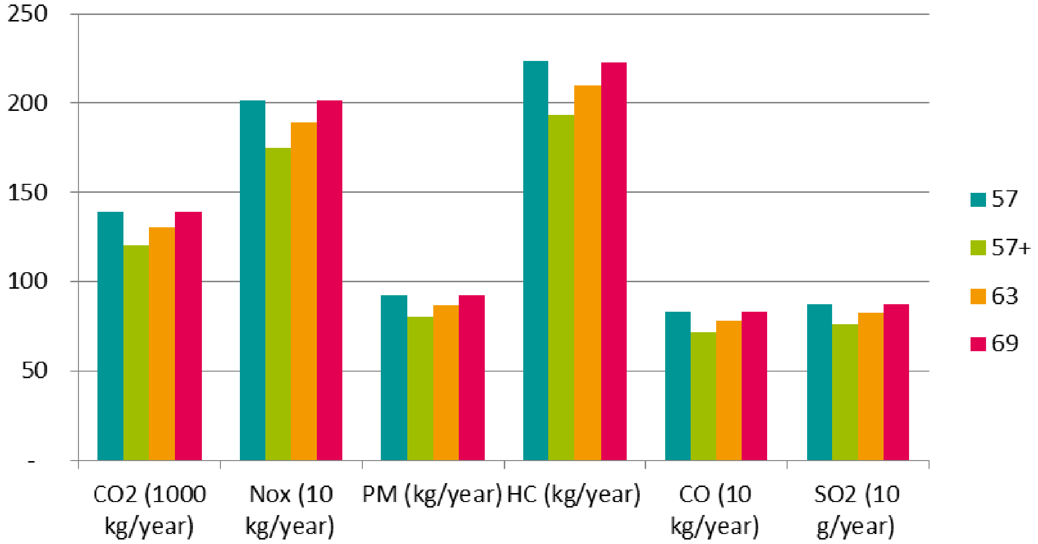
In the environmental assessment a distinction is made between lengthening only and lengthening + replacement of the propeller. The figure below shows the results of the environmental assessment for only the lengthening options in case the vessel operates on the relative speed of 10.8 km/h and in this case the vessel still uses its current 'naked' propeller. As the figure shows all emissions will increase.

Figure 11.1 Annual emissions of the Rheinland for an average speed of 10,8 km (naked propeller)



In **Figure 11.2** the lengthening options including a new propeller arrangement are considered. Also the current situation is added to the figure, this for comparison between sailing with and without a propeller in nozzle. The figure shows that adding a nozzle to the propeller without lengthening the vessel will decrease all emissions. Also in case the vessel is lengthened to 63 m and a nozzle is added the emissions will be below current level. If the vessel is lengthened to 69 m the emissions level will be similar to the current levels, however they will be lower than the emissions levels in case the vessel is lengthened but no rearrangement in the propeller system is made.

Figure 11.2 Annual emissions of the Rheinland for an average speed of 10,8 km (propeller in nozzle)



It should be noted that the figures only show the total emissions per year and therefore the absolute increase in emissions. However the cargo carrying capacity of the vessel also increases and the relative values (kg emission/tkm) can be lower than without the retrofitting. Following table show the change in emissions per tkm. Also in this table a distinction is made between the lengthening options with and without a propeller rearrangement.

Table 11.2 Emissions in g/tkm and mg/tkm for relative speed of 10.8 km/h

	Ship's length (m)	CO_2 (g/tkm)	NOx (mg/tkm)	PM (mg/tkm)	HC (mg/tkm)	CO (mg/tkm)	SO_2 (mg/tkm)
Propeller: naked	57	8.6	124.818	5.742	13.838	51.555	0.0543
	63	8.0	116.083	5.340	12.870	47.947	0.0505
	69	7.7	110.979	5.105	12.304	45.839	0.0483
Propeller: nozzle	57	7.5	108.311	4.982	12.008	44.737	0.0471
	63	7.1	102.641	4.721	11.380	42.395	0.0446
	69	6.7	96.710	4.449	10.722	39.945	0.0420

In all cases the emissions levels in g/tkm or mg/tkm reduce as the vessel is lengthened. The emissions are even further reduced once a propeller in nozzle is installed.

11.3 Sensitivity analysis

In the sensitivity analysis the higher relative speed is considered. The same analysis is carried out as was for the environmental assessment for a relative speed of 14.4 km/h. The first figure shows the outcome for the situation in which the vessel is only lengthened and the same propeller arrangement is used. As the figure shows the emission levels will increase once the vessel is lengthened.

Figure 11.3 Annual emissions of the Rheinland for an average speed of 14,4 km (naked propeller)

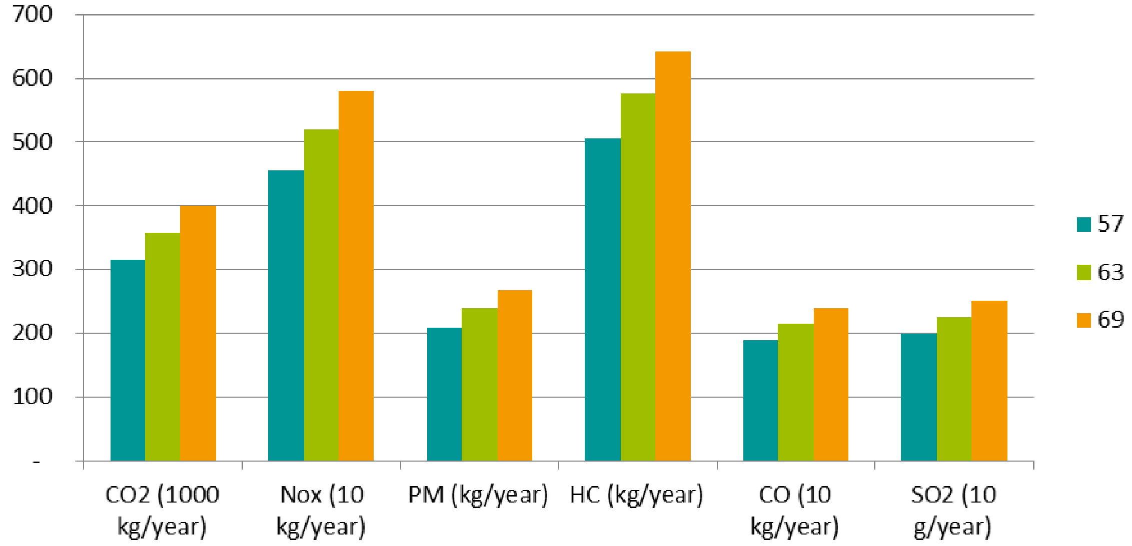
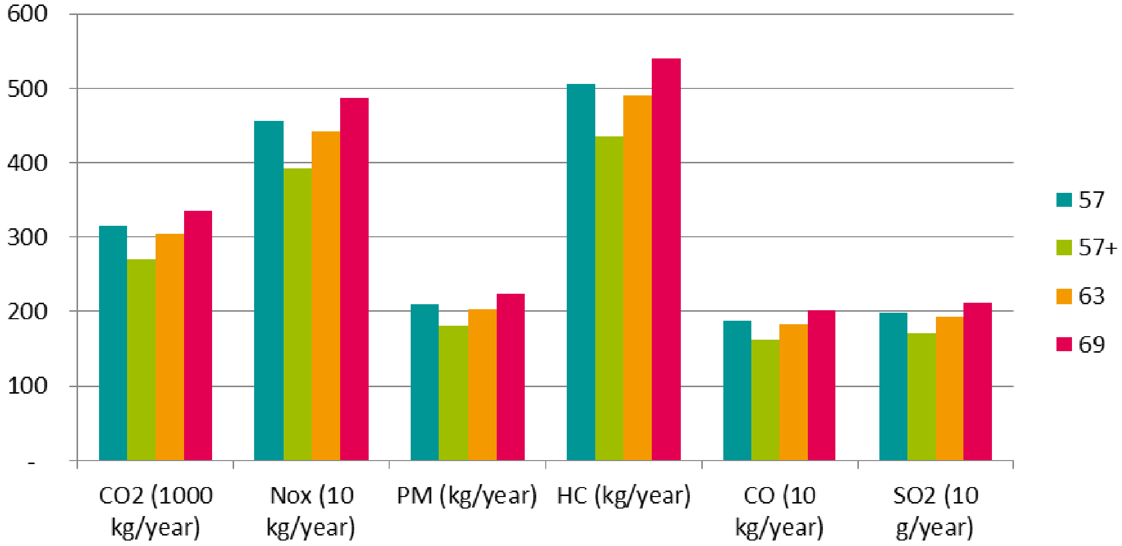


Figure 11.4 shows the lengthened options including the new propeller arrangement. Also in this figure the current situation (length of 57m and naked propeller) is shown for a good comparison. As the figure shows the environmental performance of the vessel increases once the propeller in nozzle is installed and the vessel is lengthened to maximum 63 m. In case the vessel is lengthened to 69 m the environmental impact will increase, however the increase is smaller than lengthening without a propeller in nozzle.

Figure 11.4 Annual emissions of the Rheinland for an average speed of 14,8 km (propeller in nozzle)



Also for sailing on this higher relative speed the performance per ton kilometre is calculated. Following table shows the outcomes of this analysis.

Table 11.3 Emissions in g/tkm and mg/tkm for relative speed of 14.8 km/h

	Ship's length (m)	CO_2 (g/tkm)	NOx (mg/tkm)	PM (mg/tkm)	HC (mg/tkm)	CO (mg/tkm)	SO_2 (mg/tkm)
Propeller: naked	57	19.5	283.087	13.022	31.386	116.927	0.1231
	63	19.4	281.084	12.930	31.164	116.100	0.1222
	69	19.2	278.323	12.803	30.857	114.959	0.1210
Propeller: nozzle	57	16.8	243.154	11.185	26.958	100.433	0.1057
	63	16.5	239.658	11.024	26.571	98.989	0.1042
	69	16.1	233.843	10.757	25.926	96.587	0.1017

At this higher speed the emissions tend to reduce less than sailing on a lower speed. In all cases the emissions per g/tkm or mg/tkm decrease once the vessel lengthened. If a propeller in nozzle is installed the performance of the vessel further increases and so the installation of a nozzle is beneficial for the environment. Overall it can be concluded that sailing on a higher speed increases the environmental impact of shipping.

12 Conclusions

12.1 The main conclusions for Hendrik:

- Lengthening of the vessel is technically possible, although not all considered or evaluated lengths within the boundaries of the CEMT class are suitable as a retrofit option, because at larger lengthening options the hull structure adjustments become technically very complicated, hence expensive too;
- Lengthening will not have a considerable effect on the manoeuvrability of the vessel. Speed reductions will solve manoeuvrability issues;
- Although the current power train is suitable for all lengthening steps considered, it is advised to change the engine and propeller to ensure better efficiency;
- Lengthening of this vessel is economically feasible, both with and without a propeller in nozzle, and under different relative speeds;
- Lengthening becomes more economically feasible for larger lengthening steps, as the additional cargo carrying capacity (revenue generating capacity) is the main benefit for the ship owner;
- The lengthening of the vessel will increase the fuel consumption of the vessel as well as its cargo carrying capacity and together this will affect the environmental performance of the vessel in a positive way. In case a nozzle is installed, the performance can be improved further.

12.2 Main conclusions for Rheinland:

- Lengthening of the vessel is technically feasible;
- Lengthening of the vessel will have no influence on the manoeuvrability of the vessel. In some cases the manoeuvrability can be improved by reducing the approach speed;
- Although the current power train is sufficient to perform in the same way, it is advised to change the current engine for a newer one and the install a propeller in nozzle;
- Lengthening of the vessel is often economically feasible, however lengthening the vessel with only 6 metres will have long payback period and under certain conditions the investment will not be earned back at all.
- It should also be noted that freight rates paid on the Danube do not generate enough income to earn back the investment. Even when the freight rates paid on the Rhine are considered for the Rheinland, the investments will be difficult to earn back.

12.3 Overall conclusions

Lengthening of smaller inland vessels is economically feasible mainly for mid-sized vessels in the fleet. It appears that vessels that fall within the CEMT III class can benefit of this retrofit option, while smaller ships do not. Based on the analysis done and also in line with the results of the lengthening options analysed in WP 7.2, inland vessels already need to have a critical mass to ensure that the lengthening will be economically feasible. If a vessel is too small, as is the case for the Rheinland, lengthening will often not be an option to make the vessel more competitive. The investment costs of lengthening cannot be compensated. It can also be concluded that a small vessel like Rhineland is wrongly utilized on large/long river as is the Danube.

From an environmental perspective it is desirable to install a propeller in nozzle instead of a naked propeller. The propeller in nozzle is able to reduce the fuel consumption and therefore the amount of all emissions. To have more benefit from the propeller in nozzle the vessel should also reduce its speed. In these cases the implementation of the nozzle works best.

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14 Indexes

14.1 Index of figures

14.2 Index of tables

14.3 List of abbreviations

BV	Bureau Veritas;
CBRB	Centraal Bureau voor de Rijn- en Binnenvaart
CCR	Central Commission for Navigation on the Rhine;
CO	Carbon monoxide;
CO_2	Carbon dioxide;
GL	Germanischer Lloyd;
HC	Hydrocarbon;
H&M	Hull and machinery;
IRR	Internal rate of return;
IW	Inland waterway;
IWT	Inland waterway transport;
kW	Kilo watt;
NOx	Nitrogen oxide;
NPV	Net present value;
P&I	Protection and indemnity;
PM	Particular matter;
SO_2	Sulphur dioxide;
TEU	Twenty feet equivalent unit;
WP	Work Package.