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Abstract

Energy-efficient navigation is considered as a promising but complex and comprehensive approach based on knowledge of interactions between vessel and engine characteristics (e.g. vessel size, hydrodynamic characteristics, etc.), fairway parameters (e.g. frequently changing waterway depths, current), vessel speed and the resulting fuel consumption. The core approach is to reduce energy consumption by adaption of the speed (power) profile of the vessel to the waterway profile, considering the following measures:

- speed (power) adaption in dependence of water depth, fairway width and counter-current;
- choice of the optimum sailing track, i.e. the path with the highest water depth;
- provision of the needed information to the skipper in an efficient and user-friendly way.

The implementation of energy-efficient navigation is one of the core objectives of PROMINENT. In the PROMINENT Deliverable 2.3, the settings for the pilot tests of the energy-efficient navigation system were already defined. The respective specification is concluded by the ex-ante cost/benefit analysis presented in this report. More in detail, the following issues are considered:

- state of the art of energy-efficient navigation, providing input on potential savings in fuel consumption and system costs;
- description of principles of energy-efficient navigation;
- description of the methodology used for the ex-ante cost/benefit analysis;
- presentation of the results regarding the Net Present Value and Internal Rate of Return derived for different fuel consumptions per year of a vessel, as well as the PROMINENT fleet families and representative journeys, considering different scenarios with respect to investment, operational and fuel costs, as well as potential savings in fuel consumption to be achieved.

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1. Introduction

Energy-efficient navigation is considered as a promising but complex and comprehensive approach based on knowledge of interactions between vessel and engine characteristics (e.g. vessel size, hydrodynamic characteristics, etc.), fairway parameters (e.g. frequently changing waterway depths, current), vessel speed and the resulting fuel consumption. The core approach is to reduce energy consumption by adaption of the speed (power) profile to the waterway profile, considering the following measures:

- speed (power) adaption in dependence of water depth, fairway width and counter-current;
- choice of the optimum sailing track, i.e. the path with the highest water depth;
- provision of the needed information to the skipper in an efficient and user-friendly way.

The greatest impact on the reduction of fuel consumption can be achieved by combining all measures listed above. However, the measures can be considered also as stand-alone ones, resulting also in reduced fuel consumption or increased utilization of the vessel. E.g. provision of comprehensive information on the fairway conditions may allow the master of a vessel either to choose the track with greatest water depths, reducing the shallow-water resistance, or to maximize the amount of cargo to be taken on board.

Apart from engine and hydrodynamics characteristics, the fuel efficiency of an inland waterway vessel is also largely dependent on - continuously changing - fairway characteristics. The most important parameters are the fairway depth influencing the shallow-water resistance, the width resulting possibly in the so-called "canal effect" and the flow velocity of the river. The energy consumption of a vessel rises disproportionately in shallow and narrow waters (confined conditions) and in areas with higher counter-current flow if a constant speed over ground is to be maintained. Accordingly, a remarkable potential to save fuel exists on free flowing rivers with continuously changing underwater topography and corresponding varying waterway depths and flow velocities. The fuel savings can be achieved by adaption of the vessel speed to the changing navigation conditions e.g. by reducing the speed in unfavourable stretches, leading to significant reduction of power at relatively small increase of sailing time. Depending on the present navigation conditions, it can be even possible to achieve noticeable fuel savings without increasing the sailing time too much or at all, e.g. by going faster in deep river stretches and slowing down in shallow-water stretches. The potential gains in fuel savings depend on the respective waterway conditions. Referring to the state-of-the-art research results presented in the following chapter, an average value of 14 % may be assumed.

As already mentioned, the resistance and power requirement of a vessel for sailing on a certain stretch of a waterway at a given speed over ground are affected by the river cross section and the lateral distribution of its flow velocities. The fuel consumption of the vessel is directly related to its power requirement. In areas with reduced water depths, shallow-water effects may occur, increasing the power requirement and the fuel consumption disproportionately. These effects can be reduced by finding those parts in the cross section where the water depths are greatest, leading to minimum fuel consumption. Provided the flow velocities across the river are constant or very small, the track for minimum fuel consumption can be defined as the one where the water depths are greatest. However, the flow velocities can change across the river depending on the water level changes as well as the shape of the cross section. As the flow velocities have an impact on the fuel consumption of a vessel - e.g. when sailing upstream greater flow velocities will lead to an increase in fuel consumption - the correct determination of the track associated with the minimum fuel consumption has to be done considering the lateral distributions of both parameters: the water depth and the flow velocity. Then, the optimum track would comprise in the ideal case greatest water depths and lowest flow velocities – for the upstream voyage - which, however, is not necessarily to be found in a river cross section at the same location, leading to the demand of proper estimation and balancing the effects due to changing water depths as well as flow velocities.

The provision of full information on the navigation conditions of a waterway (water depth and flow velocities across the river, both, spatially (longitudinal and lateral direction), as well as temporally, enables the application of energy-efficient sailing via adaption of the vessel speed to the changing navigation conditions and choice of the optimum track for minimum fuel consumption as already described. Besides, the location with the lowest water depth on the whole transport route determines the possible draught and thus the maximum payload and the load-factor of a vessel (so-called load-limiting water depth). Hence, the knowledge of this depth is a precondition for the optimization of the payload (by reduced necessary safety margins). The information requested can be derived by comprehensive surveying of the entire waterway using dedicated surveying vessels and application of proper water-level and hydro-morphologic models accounting for water-level and riverbed changes in real time, whereby the impacts on water depths and flow velocities are to be determined. Further, the respective information can be derived in real time, using measurements performed on cargo and passenger vessels in operation e.g. via echo-sounder measurements and flow velocity measurements. However, the measurements performed by vessels in operation pose still many open questions regarding spatial density, frequency, accuracy and reliability of the measurements derived and the information on the navigation conditions provided.

The implementation of energy-efficient navigation is one of the core objectives of PROMINENT. In the PROMINENT Deliverable 2.3, *PROMINENT (2015 a),* the settings for the pilot tests of the energy-efficient navigation system were already defined. The respective specification is concluded by the ex-ante cost/benefit analysis presented in this report. More in detail, the following issues are considered:

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2. State of the art

In the last years, research has been carried out with respect to the development of several tools for monitoring of fuel consumption of inland waterway vessels. Some of them were developed even up to a commercial status. Also first developments took place with respect to the creation of tools for energy-efficient sailing. Nevertheless, none of them integrates real-time data such as fairway conditions, in particular water depth, flow velocities and engine load in a permanent vessel-infrastructure interaction. Consequently, the further development towards a real-time advising system for the boat master on the optimum choice of the fairway trajectory and the engine speed/load is an important next innovation step for efficient inland navigation. In the following, the most significant developments in the past and present are outlined.

a. Econaut

Econaut is a popular mobile Application. Econaut 0.0.5 APK was launched by Stichting Projecten Binnenvaart. It can be derived from Google Play and App Store (Apple), as well as it can be downloaded from http://bestapkcollection.com/apps/econaut.

The App is a CO_2 calculation tool, raising the awareness of ship operators with respect to fuel consumption and CO_2 emissions of their vessels on a certain route. It was developed for the following purposes:

- provision of insight into the sustainability of business;
- provision of access to CO_2 performance of the contractors of the ship owners;
- provision of a balanced CO_2 reporting.

The information gained can be used also for the evaluation of the efficiency of the ship operation, allowing for detection of operational measures reducing the fuel consumption.

The App calculates the amount of CO_2 emissions per tonne kilometre (tkm) on the basis of the following information to be provided manually:

- transported tonnage;
- distance travelled;
- fuel consumption.

Econaut includes the ability to automate the CO_2 emissions calculation. The distance travelled can be determined automatically on the basis of GPS. Based on manual input of tonnage and fuel consumed, the respective emissions per tkm can be calculated and reported.

b. VoortVarend Besparen

The programme is being managed by EICB, and it can be accessed via the EICB website: http://eicb.nl/diensten/expertise/projecten/185-voortvarend-besparen.

The idea of VoortVarend Besparen is to generate awareness of the possibilities for smart steaming (energy-efficient sailing). For this purpose the ship owners are provided with some tools. Initially, the programme was focussed on the following three pillars:

- Education: a training consisting of theory, exercises and simulator training on smart steaming, given by STC (Rotterdam) and the Nova College (Ijmuiden);
- Competition: a fuel saving competition between ship owners, where the yearly fuel consumptions related to one tkm of the participating vessels were recorded and compared with the ones obtained for several consecutive years.
- Platform: a group of relevant stakeholders (e.g. ship owners, sector organisations, port authorities and Rijkswaterstaat) which met each other several times a year in order to exchange ideas about fuel-saving options.

During the last four years, the EICB has been managing the programme, the following changes have been realised:

- Education: Besides the training at STC, also an e-learning course is offered. The training at STC is one of the options to get points for the Green Award certification[1]. Since October 2015, also for the e-learning course points are rewarded for the Green Award certification. Slides on the e-learning course can be found at: http://eicb.nl/documenten/nieuws/8520141202-ocbpresentatie-elearning-vvb/file
- Econaut: See above.

Comparing the results for energy consumption, being also a measure for the fuel consumption, per km of 2007 and 2010, a reduction by 6.7 % could be realised, *Gille and de Vries (2011)*. However, this value was also the result of other developments, e.g. water levels, new vessels, and lower sailing speeds due to the economic crisis, *Common Expert Group (2012)*. The evaluation report on the Smart Steaming project estimated that 3 up to 4 % overall fuel consumption reduction can be attributed to the programme.

Considering all participating cargo vessels, the CO_2 competition resulted in an average fuel reduction by 14 %, 12.4 % and 1.74 % for 2008, 2009 and 2010, *Gille and de Vries (2011)*. In addition, a CO_2 competition was organised using the full-mission bridge simulator of MARIN. On average the fuel consumption was reduced by 14.2 %. The maximum reduction achieved in the simulator competition was 25.4 %, *MARIN (2008)*.

[1] http://www.greenaward.org/greenaward/467-english.html

c. Topofahrt

The objective of the project Topofahrt, *Alumni (2014)*, carried out by DST and the University Duisburg-Essen and funded by the European Union within the Ziel2 Programme between March 2012 and January 2014, was to develop a simulator-based training for ship operators, aiming at waterway-topography adapted sailing of a vessel. Waterway-adapted operation of a vessel ("smart steaming"), taking into account locally changing water depths and stream velocities, may lead to significant reduction of fuel consumption and emissions while the transportation task can be fulfilled. According to Topofahrt, the potential for reduction of fuel consumption is given as 3 up to 7 %, depending on the vessel type.

The training, lasting two days, comprises a theoretical part as well as a practical one. In the theoretical part, knowledge of the relationship between waterway topography and fuel consumption of a vessel, as well as determination of fuel consumption based on engine characteristics is provided, complemented by a theoretical training on fuel efficient sailing and long-term route planning, including the consideration of a predetermined time of arrival. The practical training is performed using the full-mission bridge simulator SANDRA of DST, which was further developed for this purpose. It is able to deal with shallow-water effects, commonly appearing on inland waterways. The training is completed by a theoretical and practical examination, and also for this training points are rewarded for the Green Award certification.

d. CREATING and The Cleanest Ship

Focussed on emissions to the air, the environmental performance of inland navigation and means for its improvement were investigated in the EU project CREATING[2], carried out within the Sixth Framework Programme of the European Union. The application of advising Tempomaat, low sulphur fuel equal to road standard EN 590, selective catalytic reduction and particulate matter filter was found to be the most suitable solution to improve the environmental performance of inland navigation. These systems were utilised in the demonstration project The Cleanest Ship, *Schweighofer and Blaauw (2009)*, set up in CREATING and further carried out for one year after the finalisation of CREATING.

The advising Tempomaat (ATM), a system enabling an economically optimised operation of a vessel was intended to be applied for demonstration of the effects of energy-efficient sailing. The estimated savings in fuel consumption accounted for 7 %. The core of the ATM was to be formed by a computer programme advising the skipper on the most economical combination of route and speed, enabling the vessel to arrive on time with a most efficient use of fuel leading to a reduction of fuel consumption and emissions. The ATM, where the advised fuel settings were to be realised manually, was claimed to be the successor of the Tempomaat which did automatically adjust the speed of the vessel, without giving advice.

In the project The Cleanest Ship, the ATM was used mainly for monitoring purposes of fuel consumption, energy output in kWh and sailed distance in km, whereby the results with respect monitoring of fuel consumption were associated with great uncertainties of about 15 %. The ATM

[2] www.creating.nu

was not applied as an advising tool for optimum rate of revolutions as well as optimum speed of the vessel as the operational area was considered to be not suitable for this purpose.

The ATM was implemented also in the Veerhaven X, a pusher of ThyssenKrupp Veerhaven B.V. However, already a long time ago the shipping company switched to another system comprising cruise control, *Schweighofer (2015)*. The associated costs are only 10 up to 15 % of the ones of the ATM. The system gives the master of the vessel the possibility to choose a constant speed independent of the water level in the river or to set a constant fuel consumption, whereby the speed will automatically decrease on stretches with low water and increase on stretches with deep water.

e. NEWADA DUO

The overriding aim of the pilot action for depth data provision via echo sounders of the NEWADA DUO project, *Radl and Hartl (2014)*, was to evaluate the achievable accuracy and reliability of representative echo sounder equipment currently used on board of commercial passenger vessels (data gathering) and to look into a feasible solution for ship-shore communication (data exchange). The task also investigated the potential for a water depth information system which could be based on the data produced on board of commercial Danube vessels (feasibility check).

The basic principle of the evaluation of the vertical extension of the riverbed profiles is described in the following in a simplified way:

- The vertical position (Z-value) of a GPS reference point (GNSS) is known.
- The vertical distance of the GPS device on board the vessel from the reference point is known.
- The vertical distance of the echo sounder from the GPS device is known or can be calculated.
- The distance between the echo sounder and the river bottom is measured by the echo sounder.
- Summing up all distances up to the GPS reference point gives the vertical location of one point on the river bottom at a certain longitudinal and lateral location (X-, Y-coordinates) with respect to the GPS reference point, and the location of the point can be given as height referred to Adria.
- For each river kilometre the vertical location of the water level at Low Navigable Water Level (LNWL) is known as height referred to Adria. Subtracting the height referred to Adria of the point on the river bottom from the height referred to Adria of the water level at LNWL gives the water depth at LNWL at this point.

The operated test series on the Austrian stretch of the Danube showed that depth data received via basic echo sounding equipment can be automatically collected. For the next step it will be recommended to install the equipment (Sigma 120 and automatic data collector) on a passenger vessel or a cargo ship in order to perform additional test series in a different environment. Further topics which are of relevance for developing a Danube-wide water depth information system like quality control, data processing, visualisation and data provision can be discussed in the future. External assistance, specialised in geo data processing, will be advisable in this respect.

Before implementing a potential water depth information system in other countries involved in the activity local conditions will need to be checked, especially regarding the availability of current and future national positioning systems.

In general, it can be said, that the tested Sigma 120 echo sounder in combination with Real Time Kinematic positioning on the Austrian stretch of the Danube yielded an accuracy in the dimensions X, Y and Z (longitude, latitude and altitude/depth) which was considered sufficient for the general aim of the pilot action, i.e. receiving additional "real-time" depth information in between high-precision riverbed surveys conducted by waterway management authorities or administrations. Table 1 specifies the accuracy in the X, Y and Z dimensions which could be achieved during the three test series which were performed by viadonau's hydrography department on the Austrian stretch of the Danube.

Component	**Description**	**Accuracy-Z**
Echo sounder (ordinary)	Sigma 120	within 5 % of depth
Echo sounder (high accuracy)	Kongsberg EA400	+/- 1 cm
Positioning	APOS-RTK	+/-4 cm
	optional: AIS / VHF-DGPS	+/-1 m (average value)
Results of test series	Sigma 120 / APOS-RTK	+/-30 cm (average value)

Table 1: Accuracy of echo-sounder equipment and tests performed

Due to the high costs for vessel owners and the reduced quality in comparison to high-end surveying, it may be not worth following up the activity the way it was technically set up for the three test series performed on the Austrian stretch of the Danube in NEWADA DUO. If an improvement in AIS technology will take place in the future and positioning with AIS (RTK) will be available all along the Danube, a cost reduction for navigation companies will probably be the result.

Component	**Description**	**Costs**
Echo sounder (ordinary)	Sigma 120	1,700 EUR
Echo sounder (high accuracy)	*Kongsberg EA400 (excluding support and service)*	*27,000 EUR*
Positioning	APOS-RTK / Month	200 EUR
	GNSS-Device (Leica GPS 1200)	25,000 EUR
	GMS Module / Antenna	1,400 EUR
	Optional for the future: AIS / VHF-RTK	n/a
Automatic Data Collector	Portable Case	950 EUR
	Mini-PC	2,500 EUR
	Service Module for remote control and GSM Antenna	800 EUR

	QINSy Inshore for single-beam echo sounders	2,500 EUR
	Installation (3 days) excluding travel expenses	3,600 EUR
	Total costs (Sigma 120)	38,650 EUR

Table 2: Costs of echo-sounder equipment and installation

The steps towards a comprehensive water depth information system subsequent to data transfer and quality control of the generated data are data processing, visualisation and provision to specific user groups. The option installed during the test series of an automatic data collector in combination with a QINSy Inshore software package allows for data processing and data visualisation on board of a vessel, but this option is not advisable to be used for a general roll-out of a water depth information system on the Danube, as the costs per vessel are rather high. On this account, data processing, visualisation and data provision should be achieved by use of an onshore server infrastructure which enables the automatic processing, visualisation and provision of the depth data gathered on board of the involved vessels.

In the NEWADA DUO project, the data transfer onshore was realised manually using an USB keychain.

As one of the deliverables of the project the Danube FIS Portal (Fairway Information Service Portal) is providing comprehensive fairway information (water level, bottleneck information, ice information etc.) for the end-users on one single map basis for the whole Danube River (see Fig. 1).

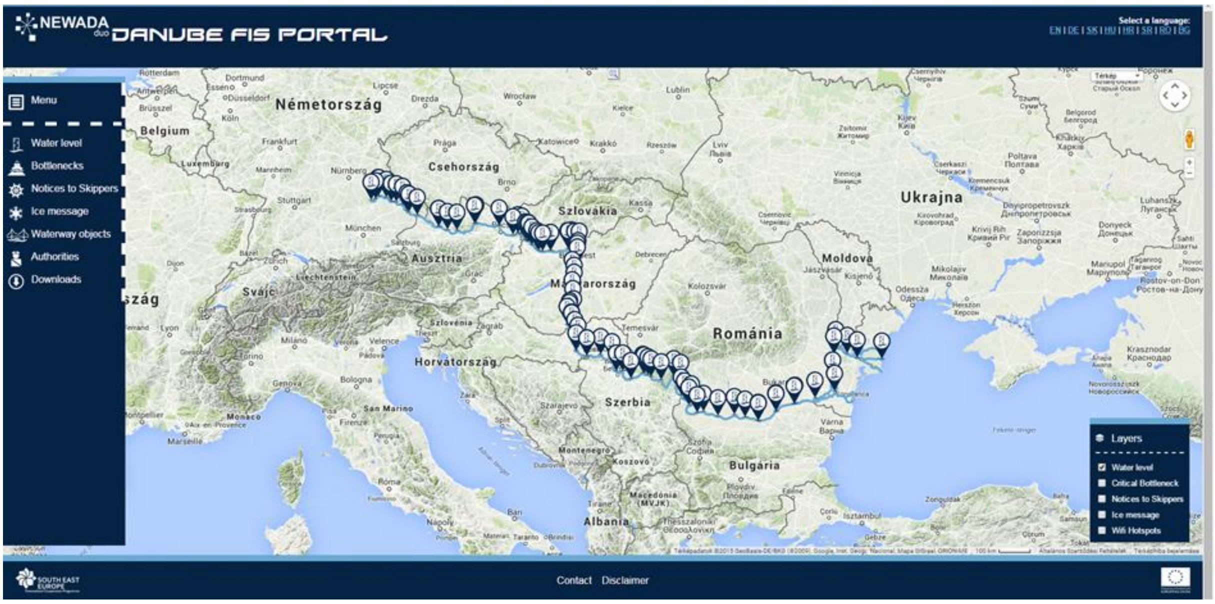

Figure 1: Screen shot of the Danube FIS Portal.

f. COVADEM and MoVe IT!

According to information on the project website, the Dutch project COVADEM[3] aims at sharing current navigable depth measurements with the help of which shipmasters will be able to navigate more efficiently in the future and make maximum use of the navigable area provided by the waterway. This is done as follows: Inland waterway vessels are provided with a basic on-board computer to read the data from existing sensors, such as the echo-sounder, loading gauge, (D)GPS and optionally, the fuel gauges, and then link the data and compile them into a message and send this to shore via mobile Internet (UMTS/HSDPA). Based on these measurements, the current measured keel clearance is converted into the current water depth of the route being navigated. For this, the draught of the vessel needs to be calculated, taking into account sinkage and trim (=squat). This is done on the basis of the flow rates of the water at that time (project partner Deltares) and the mathematical models of MARIN (Maritime Research Institute Netherlands), included in the so-called "virtual ship". These current navigable depth measurements are made available to shipmasters so that, in the future, these data can be used for predicting the water depths of the route to be navigated.

The purpose of the COVADEM project is to demonstrate that it is possible to create a reliable depth chart with the help of a standardised depth gauge on board and a limited number of vessels navigating in a certain area. Next steps are to extend the trial further with several vessels, to establish the reliability of measured data to a further extent and to make efforts to display the data on a chart. Meanwhile, 54 vessels are participating in the project, v*an Wirdum and van Laar (2015)*. It is planned to increase the number of vessels up to 250 within 4 years.

The MoVe IT! project[4], *Bons (2013 a, b, c), Bons, Wilcke, Molter, van der Meij and Schweighofer (2014), Schweighofer et al. (2014),* funded within the Seventh Framework Programme of the European Union, was carried out in close cooperation with COVADEM. The goals set with respect to energy efficient ship operation were very ambitious:

- develop and install an economy planner;
- integrate communication in a way that water depth information can be broadcasted from ships to other ships with the economy planner;
- determine the optimal track based on water depth and ship draught, calculate the Estimated Time of Arrival (ETA), and adapt the speed accordingly;
- develop an auto pilot being able to make the ship follow a selected track generating as little extra resistance as possible due to steering.

Due to the complexity of the task, as well as issues relating to the reliability and validation of some results to be obtained, the scope of the work was limited mainly to automatic creation of a water depth chart on the river Waal, which was displayed on a server as well as a mobile app. For the river Waal, the necessary local hydrological models were available through FEWS-Waterways, developed by Deltares for dealing with Dutch waterways. Instead of applying the economy planer in its entirety as a speed advice tool, the echo sounder measurement programme was extended to about 40 ships in cooperation with COVADEM.

[3] http://www.covadem.eu/en/
[4] http://www.moveit-fp7.eu/

The following results were derived and demonstrated for operation on the river Waal:

- conduction of echo sounder measurements and calculation of the real-time water depth at a defined location => cooperative water depths;
- calculation of sinkage and trim (= squat) as one basic input for the calculation of the water depth;
- detection of the optimum route, presented as line in the river where the water depths are greatest, taking into account the turning circle of the vessel;
- display of water depth information on the screen of the test server as well as a mobile app;
- provision of minimum water depth information (shallowest point) on a defined route of the test area.

It seems that the "virtual ship", of the economy planner has been developed also for the advice on the optimal rate of revolutions, *Bons et al. (2014)*. The "virtual ship" is a mathematical model of the ship representing it on a personal computer. It contains mathematical models for the evaluation of ship performance e.g. squat, as well as resistance and propulsion characteristics based on the QDESP software of MARIN, which is based on regression analysis of model test results and sea trials. Shallow-water effects are accounted for by the Schlichting and Landweber methods. However, no proper validation results regarding the provision of correct water depths, optimum route evaluated as well as optimum rate of revolutions has been carried out so far. Validations using reference measurements by a third party are under way, giving the following first result: the water depth measurements tend to be within a 20 cm margin, *van Wirdum and van Laar (2015)*.

g. IRIS EUROPE 3

Within the project IRIS EUROPE 3, funded through the TEN-T Programme of the European Union, the DoRIS App[5] was developed. Its working functionalities exceed by far the ones of the mobile app developed in MoVe IT!. The DoRIS App can be considered as a kind of best practice how to provide comprehensive information on navigation conditions of a waterway. It displays comprehensive information retrieved from the Austrian River Information Services system DoRIS (Donau River Information Services) on a mobile device. The app was developed specifically for Smartphones. It can be downloaded from Google play as well as the App Store.

The app provides the user with information on:

- Water levels:
  The app gives an overview of 9 published gauges on the Danube including latest water level, deviation to last measurement and 3 days forecast. The data is updated every 15 minutes. Additionally a hydrograph is available for each water gauge.
- Lock status:
  The status of both lock chambers is given for all 9 Austrian locks. Details comprise additional information such as reason and validity of a closure, contact details and a traffic overview showing the number of approaching and currently locked vessels.
- Fairway condition:
  The whole stretch of the Austrian Danube has been divided into several fairway sections which indicate limitations such as high water or ice.

[5] http://www.doris.bmvit.gv.at/en/services/doris-mobile/

- Overview of fairway information:
  An overview of fairway information is available combined in a PDF file. It includes information on water levels, lock status, shallow sections and most up-to-date Notices to Skippers. Roaming costs can be reduced by downloading once this information.
- Shallow sections:
  This service includes actual minimum depth information, actual and forecast data that support voyage planning and a depth profile for each shallow section.
- Notices to Skippers:
  An interface for Austria and Slovakia is available. It provides the following features:
  - fairway and traffic related messages (FTM) and ice messages (ICEM);
  - filtering of search results;
  - overview with most important information of each message;
  - detailed content display available for each message;
  - information on the location and period of limitation in a map.
- Position service:
  The user gets his/her own position as well as all information displayed on a map. Different information layers can be activated or deactivated using the filter option. Each point of interest (POI) shows the latest information and allows the user to directly switch to the related service with one click only.
- Push service:
  The app includes a push service which notifies the user when important changes in the availability of the fairway occur. For the services lock status and fairway condition, the user gets notified if a lock is completely closed or if at least one fairway section is closed.

Similarly to the DoRIS App, the SlovRIS mobile App[6] providing a wide range of fairway-related information for users of the Slovak inland waterways was also developed in IRIS EUROPE 3, as well as the Hungarian PannonRIS App[7] and the Romanian RoRIS Mobile provides supportive information for the end-users.

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[6] http://www.iris-europe.net/news-events/news/news-detail/after-doris-mobile-slovris-mobile-now-expands-danube-navigation-services-on-the-app-market-49/
[7] http://www.ris.eu/news/pannonris_application_launched

3. Principles of energy-efficient navigation

Energy-efficient navigation aims at provision of the same service at reduced energy consumption of the vessel under consideration. This may be achieved by lowering the speed of the vessel, called slow-steaming, provided the schedule to be kept allows for it. If the sailing time is to be kept more or less unchanged, then the so-called smart-steaming strategy may be applied, demanding the presence of changing waterway conditions as they occur on inland waterways. In favourable stretches, e.g. with deep water, the speed of a vessel may be increased at a minor increase of fuel consumption, and in unfavourable stretches, e.g. with shallow water, its speed may be reduced at a major decrease of fuel consumption, leading to a decrease of the overall fuel consumption at unaltered service of transportation. In addition, energy savings may be also realised by sailing a vessel along a route where the sum of the forces affected by the cross-section geometry and the magnitude of the flow velocities of the river, acting on the vessel becomes a minimum.

The fuel consumption of a vessel is determined by multiplying the specific fuel consumption of the engine with its brake power. The specific fuel consumption of a marine diesel engine is a function of the engine loading, which, for modern engines, changes only little as long as the engine is not operated at extreme part loads.

The brake power P_B of a marine diesel engine requested for a determined vessel speed V may be obtained from the following formula:

$$P_B = 0.5 \rho C_T V^3 S \frac{1}{\eta_D \eta_S \eta_G},$$

where ρ is the density of water, C_T is the total resistance coefficient of the vessel, and S is the wetted surface of the vessel. η_D, η_S, and η_G denote the propulsive, shafting and gearing efficiencies. The formula above shows a very strong dependence of the brake power on the vessel speed. A minor reduction of vessel speed will result in a significant reduction of the brake power requested, and, therefore, also the fuel consumption will be significantly reduced. For vessels operating in shallow water with Froude numbers based on the water depth in the vicinity of the critical Froude number ($Fn_h = 1$), the effects mentioned above will be by far stronger (see also Fig. 2, h = 3.2 m). Therefore, proper knowledge of ship performance in confined waters (mostly shallow-water hydrodynamics) is of great importance, in particular, as most inland waterway vessels are more or less affected by the geometrical limitations of the waterway they are sailing on.

Various engine emissions may be considered proportional to the fuel consumption, being a function of the power utilised. Obviously, it is of primary importance for both fuel efficiency and emission reduction to reduce the power needed for moving a ship. Unfortunately, this is not a straightforward task, as for doing so knowledge of the constantly changing navigation conditions as well as ship performance is necessary, including a procedure for the evaluation and optimisation of transportation parameters like estimated time of arrival or fuel consumption.

In Figure 2, the power-speed diagram of a Johann-Welker-type vessel is presented. The power-speed curves are given for different water depths h ranging from 3.2 m up to unlimited. It can be seen how the power-speed curves become steeper with reduced water depth, caused by the shallow-water effects occurring around the vessel (e.g. increased flow velocities, change of flow direction, change of floating condition of the vessel, etc.). This is most obvious if one looks at the curve for the water depth h = 3.2 m. If the vessel is sailing using 600 kW of the delivered power P_D, it would move at a speed V_S of approximately 13.3 km/h. If the delivered power would be lowered to 400 kW, the vessel would sail at a speed of approximately 12.8 km/h. For simplicity of the calculation, if we assume that the engine's specific fuel consumption is 0.2 kg/kWh, we can easily determine that with 600 kW of the delivered power the engine is consuming around 120 kg of fuel per hour, while with 400 kW it is consuming 80 kg of fuel per hour. That is a fuel saving of 33.3 % while only being slower by 0.5 km/h or 3.75 %. Most likely, this amount of savings may be not achieved for the entire length of a vessel's voyage due to changing navigation conditions (fairway depth is changing from meter to meter). However, this simple calculation shows as an example how easy it could be, under certain circumstances, to save fuel.

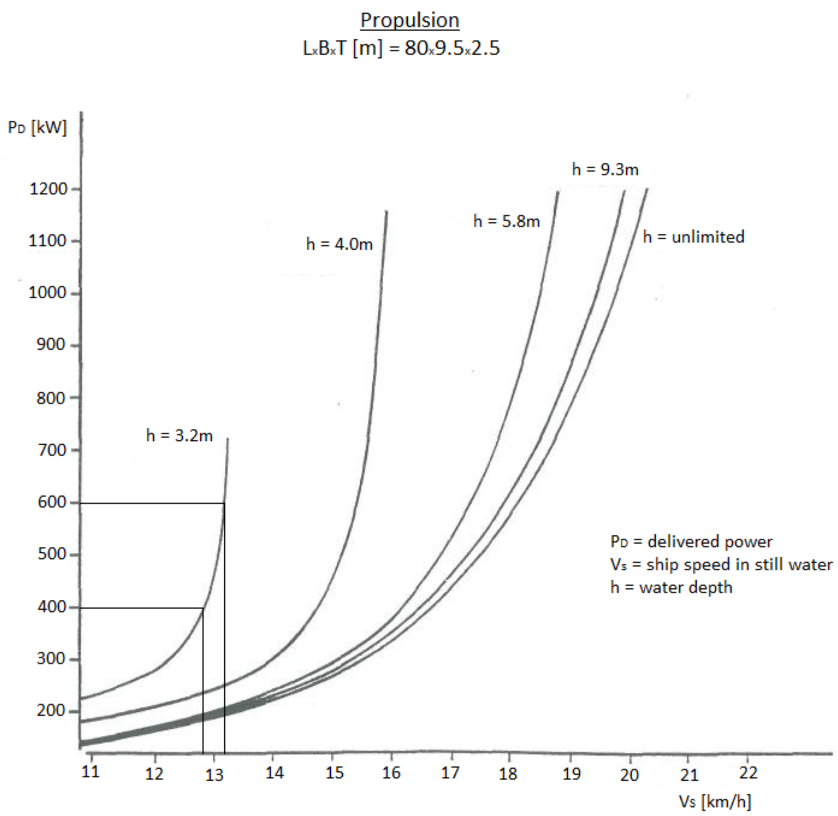

Figure 2: Power-speed curves of a Johann Welker type vessel (L = 80 m, B = 9.5 m, T = 2.5 m) for different water depths h, manipulated figure. Source of original figure: VBW (1992)

4. Methodology used in the ex-ante cost/benefit analysis

a. Introduction

The cost/benefit calculations are based on the results of PROMINENT SWP 1.1 as presented in the Deliverable 1.1, *PROMINENT (2015)*. For the distinguished fleet families and their representative vessels the cost structure has been defined in detail for the current situation. First the cost structure was defined for the range of representative vessels. This concerns the following cost elements:

- capital costs: the depreciation and interest costs;
- repair and maintenance costs;
- labour costs;
- port dues;
- fuel costs (averages, e.g. based on CDNI data from Deliverable 1.1 on fuel consumption);
- other costs (clustered miscellaneous smaller cost items).

The cost structure for Western European vessels is derived on a recent publication by the Dutch Rijkswaterstaat organisation which was approved as well by the professional organisations BLN and CBRB[8]. Since the Dutch fleet has a quite large share in the western European fleet and in particular in the segment of larger vessels (with high share in total fuel consumption) these cost structures are seen as quite representative for the Western European IWT market.

As regards the situation on the Danube, the general cost structure for the defined push convoys was derived from the European research project "ECCONET" (2010-2012)[9]. The figures for the Danube were subsequently validated by the project partners Navrom, ProDanube and viadonau. The average fuel consumption figures could however not be derived from CDNI since CDNI is limited to the Rhine. Therefore, the fuel consumption estimates have been derived from the average values for the representative journeys and have been validated with DST, viadonau and Navrom.

As a next step the specific costs of transport were estimated for various representative journeys. These estimates for each journey take into account the defined operational profile and characteristics for the journeys with these vessels, elements such as: the transported volume of cargo, the distance of the trip, the speed, the trip duration, the required propulsion and – last but not least - the fuel consumption per trip[10].

Based on the cost estimations for the present situation, the so called 'base line' situation of the business-economic impacts of energy-efficient navigation was estimated. The base line situation presents the economic performance without the implementation of the energy-efficient-navigation technologies developed by PROMINENT. Using this basis, subsequently the relevant cost parameters for the vessels and the journeys were adapted. These adaptations in the cost structure concern

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[8] The general costs structures have been based on Rijkswaterstaat May 2015 Excel file which describes in detail the cost structure for Western European vessels, see the following link: http://www.rws.nl/zakelijk/werken-aan-infrastructuur/steunpunt-economische-expertise/kengetallen/overige-documenten/index.aspx

[9] More information about ECCONET: http://www.transport-research.info/web/projects/project_details.cfm?id=41592

[10] Note: the representative journeys have been taken into account for which the operational profile was made available by DST. For some journeys specified in SWP 1.1, the profile could not be made available due to missing information on the waterway characteristics

mainly the additional costs for the hardware and installation, some fixed annual costs (training and communication), while there is a saving on fuel consumption. The results taking into account the adapted cost structure present the economic performance in case of application of the PROMINENT technologies for energy-efficient navigation. By means of comparing these outcomes with the outcomes for the baseline, the impact is derived and the differences are made clear. The overview of the impact on costs per year allows assessments such as the Net Present Value and the Internal Rate of Return.

Net Present Value (NPV) is a formula used to determine the present value of an investment by the discounted sum of all cash flows as result of the investment.

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_T}{(1+r)^T}$$

$- C_0 = Initial\ Investment$
$C = Cash\ Flow$
$r = Discount\ Rate$
$T = Time$

The formula for the discounted sum of all cash flows can be rewritten as

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}$$

When a company or investor takes a project or makes an investment, it is important to calculate an estimate of how profitable the project or investment will be. In the formula, the ***$-C_0$*** is the initial investment, which is a negative cash flow showing that money is going out as opposed to coming in. Considering that the money going out is subtracted from the discounted sum of cash flows coming in, the net present value would need to be positive in order to be considered a valuable investment.

In our case it is about the decision whether it makes sense to make the investment to equip the vessel with the tools for energy-efficient navigation. The elements affecting the cash flow are mainly the savings on fuel consumption and the annual costs to operate the energy-efficiency tools (e.g. communication, licences and training of (new) personnel). Obviously the savings on fuel consumption shall be sufficient enough to offset not only the annual cost to operate the energy tools but also to earn back the initial investment.

The fact that money loses value in future, or the opportunity costs of the cash invested in the vessel, is also taken into account by means of the so called 'discount rate'. As a result the benefits of future are corrected by means of a fixed percentage. A value of 4 % is taken into account as discount rate.

The **Internal rate of return (IRR)** is the interest rate at which the Net Present Value of all the cash flows (both positive and negative) from a project or investment equal zero. The IRR value therefore illustrates the attractiveness of the investment. If the IRR of a new project exceeds a company's required rate of return, it can be concluded that the project is desirable. For example the investment can be compared to other investment opportunities or other revenues on money (e.g.

interest rates on bank savings or bonds). If IRR falls below a certain required rate of return, the project should be rejected. The formula is as follows:

$0 = C_0 + C_1/(1+IRR) + C_2/(1+IRR)_2 + C_3/(1+IRR)_3 + . . . +C_n/(1+IRR)_n$
where C_0, C_1, . . . C_n equals the discounted cash flows in periods 1, 2, . . . n, respectively; and IRR equals the internal rate of return of the investment.

In order to derive the NPV and the IRR values for energy-efficient navigation, a spreadsheet calculation model was developed and applied. A time horizon of 15 years was assumed. For the calculation, it is assumed that the initial investment will be done by end of 2015 and the impacts on the cash flow are taken into account until the year 2030.

Other relevant indicators are the share of the investment in relation to the capital value of the vessel. In case the share of the investment is high, there can be a barrier because of lack of collateral in case of loans (borrowed capital) for the investment.

Another relevant indicator is the impact on the total transport costs. The transport costs determine into large extent the competitiveness within the sector (between different vessel owner/operators) and with other modes of transport. In particular if there are large impacts and if (on long term) the costs are reflected in transport prices, there can be a shift to other modes as well. Therefore, a strong saving could result in additional cargo for the inland waterway transport sector. However, it shall be noted that this response from the market (shippers and freight forwarders) on prices for IWT is highly dependent on the specific commodity and the available alternatives. In many cases transport by barges is the only efficient option available to transport high volumes of cargo. This was also demonstrated in the ECCONET project, when the impact on climate change (low/high water levels and currents) was studied in detail.

The range of different typical vessel types (representative for the fleet family) and the representative journeys present an overview of the various situations and the bandwidth that can be seen as regards the economic performance. Obviously, the best economic performance for application of Energy Efficient Navigation is expected for vessels and journeys that show relatively high fuel consumption. Examples are the larger vessels that are operating on long distance journeys on rivers such as the Rhine. On the other side, for small vessels with a limited capital value, the investment for on board equipment is relatively high while the amount of money saved due to less fuel consumption is relatively low.

Besides illustrating the different outcomes for the range of representative vessels types and journeys also sensitivity analyses have been made for key parameters. These concern the following:

- the fuel price;
- the investment costs;
- the percentage of fuel saving as result of energy-efficient navigation.

The results of the cost-benefit analyses are therefore quite different for the different operating conditions and vessels and also depend into large extent on the assumptions for the key parameters. Through the execution of the pilots much more certainty and accuracy is expected about the investment levels in relation to the percentage of fuel savings that can be reached as result of investing in energy-efficient-navigation tools.

b. Specification

Vessel types taken into account, average in Europe according to fleet families

Fleet family	Vessel type	Length (m)	Width (m)	Draught (m)	Max payload (t)	Installed power (kW)	Fuel cons. per year (m^3)
Passenger vessels (hotel/cruise)	PAX 135m	135	11.5	2.0		1492	438
Push boats <500 kW	PB <500 kW B04	85	8.2	2.7	1250	400	82
Push boats 500-2000 kW	PushB2L 500-2000kW	190	11.4	3.0	5000 (352 TEU)	1249	141
Push boats 500-2000 kW	PushBII-1, 500-2000kW	130	11.4	6.0	2800	1249	178
Push boats >=2000 kW	Push B4 > 2000 kW	190	22.8	4.0	11200	4080	1107
	Push B6 > 2000 kW	270	22.8	4.0	16800	4080	2351
Motorvessel dry cargo >=110m length	MVS 110m	110	11.4	3.5	3043	1527	311
	MVS 135m	135	11.4	3.3	3300 (268 TEU)	1492	477
Motorvessel liquid cargo >=110m length	MTS 110m	110	11.4	3.5	2908	1550	360
	MTS 135m (M11)	135	11.4	4.0	4290 (5320 m3)	2347	357
	MTS 135M (M12)	135	17.0	3.8	6228	2370	357
Motorvessel dry cargo 80-109m length	MVS 80m	80	8.2	2.7	1250	700	111
	MVS 86m	86	9.5	2.9	1522	756	155
	MVS 105m	105	9.5	3.0	2050	1286	311
Motorvessel liquid cargo 80-109m length	MTS 86m	86	9.5	3.2	1680 (1918 m3)	1210	272
Motorvessels <80 m. length	MVS 67m	67	8.2	2.7	985	445	81
	MVS 55m	55	7.2	2.6	653	319	48
	MVS 50m	50	6.6	2.6	650	300	34
	MVS 38,5m	39	5.1	2.5	400	220	23
Coupled convoys (mainly class Va + Europe II lighter)	C3L/B	110 + 80	11.4	3.4	5500	2351	558
Danube barges	Push Barge, 4 units, Danube	178	22.8	2.7	6400	2000	1533
	Push Barge, 8/9 units, Danube	267	33.0	2.9	17400	2000	1252

Table 3: Vessel types, average in Europe according to fleet families

Representative journeys taken into account

Rhine						
Trip No.	Port A	Port B	Type	Vessel type	Payload per trip (t)	Fuel consumption per year (m^3)
1	Rotterdam	Duisburg	Dry bulk	Push B4	11200	3939
2	Rotterdam	Antwerp	Container	C3L/B	4420	531
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	2917	1176
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	3795	1190
5	Rotterdam	Basel	Container	C3L/B	4607	879
7	Amsterdam	Antwerp	Container	C3L/B	4420	645
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	4750	1443
10	Antwerp	Mainz	Container	MVS 135m	3179	733
12	Antwerp	Duisburg	Container	C3L/B	6375	980
13	Rotterdam	Duisburg	Container	MVS 110m	2465	311
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	1210	240
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	2039	432
18	Duisburg	Antwerp	General cargo	MVS 110m	2039	643
22	Rotterdam	Herne	Dry Bulk	MVS 86m	1096	184
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	2039	565
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	1237	265

Table 4: Representative journeys for the Rhine

Danube						
Trip No.	Port A	Port B	Type	Vessel type	Payload (t)	Fuel consumption per year (m^3)
1	Bor district	Constanza	Dry bulk	Push 8/9	9000	1555
2	Bor district	Constanza	Liquid Bulk	Push 8/9	9000	1555
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	9000	1391
4	Giurgiu	Constanza	Dry bulk	Push 8/9	9000	954
5	Calafat	Constanza	Dry bulk	Push 8/9	9000	1557
6	Bratislava	Linz	Dry bulk	Push 4	4400	1533
7	Calafat	Constanza	Dry bulk	Push 8/9	9000	1557
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	9000	1391
9	Giurgiu	Constanza	Dry bulk	Push 8/9	9000	954
10	Giurgiu	Constanza	Dry bulk	Push 8/9	9000	954

Table 5: Representative journeys for the Danube

Other waterways						
Trip No.	Port A	Port B	Type	Vessel type	Payload (t)	Fuel consumption per year (m^3)
7	Rotterdam	Hannover	Dry Bulk	MVS 86m	1096	200
8	Duisburg	Wolfsburg	General goods	MVS 86m	1096	125
16	Rotterdam	Oldenburg	Dry Bulk	MVS 80m	910	102
17	Rotterdam	Lingen	Liquid Bulk	MTS 86m	1039	176

Table 6: Representative journeys for the Other Waterways

Passenger cruise vessels					
Trip No.	Waterway	Port A	Port B	Vessel type	Fuel consumption per year (m^3)
1	ARA/Rhine	Amsterdam	Basel	PAX 135m	243
3	Danube	Passau	Budapest	PAX 135m	189

Table 7: Representative journeys for the passenger vessels

Sensitivity analyses, key parameters

As regards the sensitivity analyses, the following figure presents the development of the **fuel price** (red line = average for the period). It can be seen that the fuel price is rather volatile.

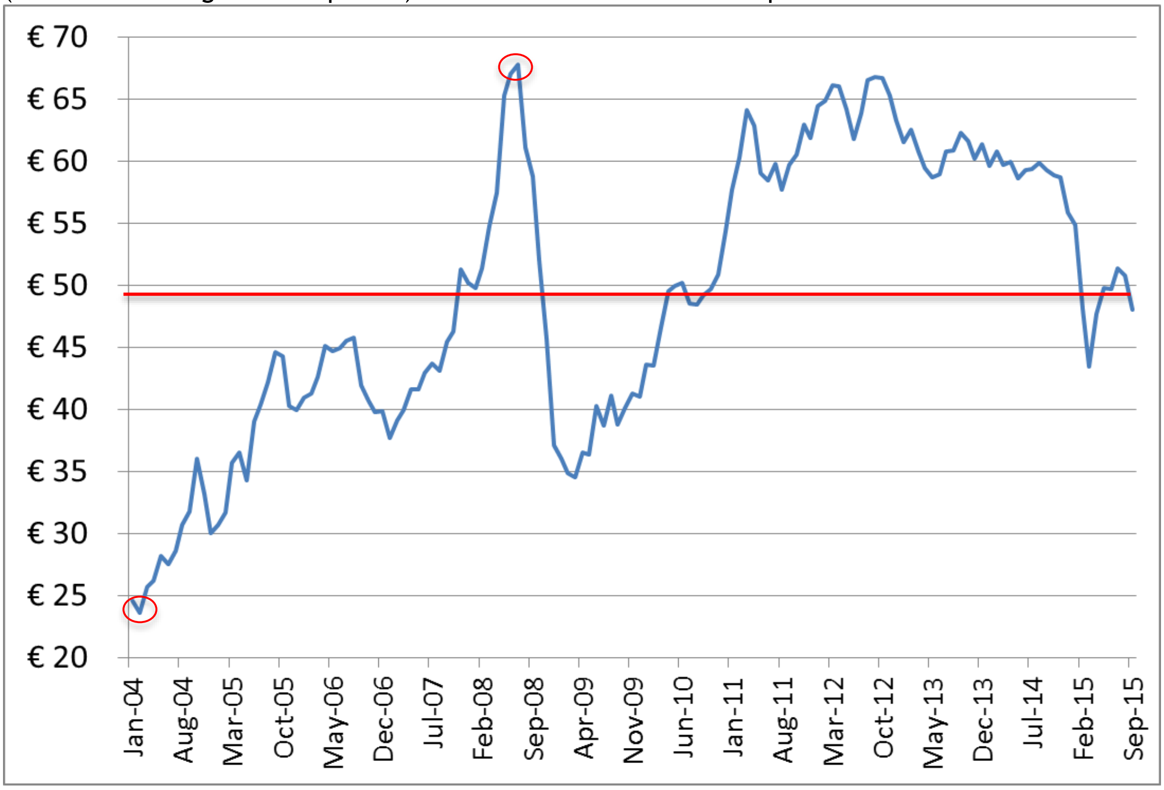

Figure 3: Diesel fuel price development for inland waterway transport, EUR per 100 litre for the period January 2004-September 2015.

To get a view on the bandwidth of the impact of the fuel prices, the following values were used:

- L: the lowest monthly average value seen since 2004: **23.65** EUR per 100 litre (Feb. 2004);
- M: the average fuel price between January 2004-September 2015: **49.25** EUR per 100 litre;
- H: the highest monthly average value seen since 2004: **67.81** EUR per 100 litre (July 2008).

As regards the **savings on fuel** as result of energy-efficient navigation, there were also three values taken into account to illustrate the impact. This is based on the ranges of savings found in the literature (see also Chapter 2 of this document):

- L: **3 %;**
- M: **14 %;**
- H: **25 %.**

As regards the **hardware costs**, the following assumptions were taken into account[11]:

- L: If an ordinary echo-sounder without sophisticated GNSS device and velocity meter is used then the costs may be in the range of **10,000** EUR.
- M: Based on the cost estimations for the pilots with NAVROM and their available budget in PROMINENT: costs of the system (echo-sounder and velocity meter) are estimated as **40,000** EUR.
- H: If a highly sophisticated ADCP (or GNSS GPS device) is to be used then the costs might be in the order of **80,000** EUR (EUR 35 000 for echo-sounder and 55 000 for ADCP).

The following table presents the values of the vessels, as well as the ratios between the different investment levels (10,000 – 80,000 EUR) and the values of the respective vessels in per cent. It can be seen that for small vessels the investment is relatively high in comparison with the overall value of the vessel, this might be a barrier for funding.

[11] See also Chapter 2 for more details on the cost estimates for the hardware

Fleet family	Vessel type	Capital value of vessel	Ratio at 10 K EUR	Ratio at 40 K EUR	Ratio at 80 K EUR
Passenger vessels (hotel/cruise)	PAX 135m	€ 7,000,000	0.14%	0.57%	1.14%
Push boat <500 kW	PB <500 kW B04	€ 300,000	3.33%	13.33%	26.67%
Push boat 500-2000 kW	PushB2L 500-2000kW	€ 4,400,000	0.23%	0.91%	1.82%
Push boat 500-2000 kW	PushBII-1, 500-2000kW	€ 1,400,000	0.71%	2.86%	5.71%
Push boat >=2000 kW	Push B4 > 2000 kW	€ 9,300,000	0.11%	0.43%	0.86%
	Push B6 > 2000 kW	€ 12,700,000	0.08%	0.31%	0.63%
Motor vessel dry cargo >=110m length	MVS 110m	€ 2,457,200	0.41%	1.63%	3.26%
	MVS 135m	€ 3,576,667	0.28%	1.12%	2.24%
Motor vessel liquid cargo >=110m length	MTS 110m	€ 5,027,240	0.20%	0.80%	1.59%
	MTS 135m (M11)	€ 9,065,668	0.11%	0.44%	0.88%
	MTS 135M (M12)	€ 11,100,817	0.09%	0.36%	0.72%
Motor vessel dry cargo 80-109m length	MVS 80m	€ 488,400	2.05%	8.19%	16.38%
	MVS 86m	€ 937,500	1.07%	4.27%	8.53%
	MVS 105m	€ 1,482,727	0.67%	2.70%	5.40%
Motor vessel liquid cargo 80-109m length	MTS 86m	€ 2,178,750	0.46%	1.84%	3.67%
Motor vessel <80 m length	MVS 67m	€ 359,304	2.78%	11.13%	22.27%
	MVS 55m	€ 338,200	2.96%	11.83%	23.65%
	MVS 50m	€ 237,534	4.21%	16.84%	33.68%
	MVS 38,5m	€ 124,000	8.06%	32.26%	64.52%
Coupled convoy (mainly class Va + Europe II lighter)	C3L/B	€ 3,635,758	0.28%	1.10%	2.20%
Danube barge	Push Barge, 4 units, Danube	€ 4,000,000	0.25%	1.00%	2.00%
	Push Barge, 8/9 units, Danube	€ 6,000,000	0.17%	0.67%	1.33%

Table 8: Ratio of investment (10,000 / 40,000 / 80,000 EUR) compared to the ship value

5. Results

a. Business economics depending on fuel consumption per year

From the analyses it became clear that the most important parameter is the annual volume of fuel consumption. Therefore, the relations between the business-economic performance of the investment and the fuel consumption of the vessels are presented in the next sections. The results presented in the following graphs are based on the fuel consumptions listed in the previous Chapter 4 for the different vessels and journeys. There is a bandwidth between 23 m^3 per year for the Peniche (400 tons) and 2,350 m^3 per year for the 6-barge pushed convoys on the Rhine (16,800 tons). With respect to the representative journeys, the values range from 102 m^3 per year (Rotterdam-Oldenburg, MVS 80 m, 910 tons) up to 3,939 m^3 per year (Rotterdam-Duisburg, pushed convoy, 11,200 tons).

Base-case scenario
The base-case scenario is defined using the ‘medium’ or ‘average’ values for the key parameters: hardware and the fuel savings. Since the fuel prices are external and cannot be influenced by PROMINENT, the calculations are performed using different fuel price assumptions (low, average, high). The base case assumes:

- 40,000 EUR for the initial investment for the equipment;
- 14 % saving in fuel consumption per year;
- time for installation of the equipment on board of the vessel: 1 day => 2000 EUR;
- 3000 EUR per year to cover additional variable costs for communication, maintenance, training etc. to enable energy-efficient navigation.

The following figures present the Net Present Value and the Internal Rate of Return. The figures present on the vertical axis the outcome of the NPV and the IRR for the time period 2016-2030 as function of the volume of fuel consumption per year in m^3 (horizontal axis). The three lines present the outcomes at different fuel-price levels (low, average or high, see Chapter 4).

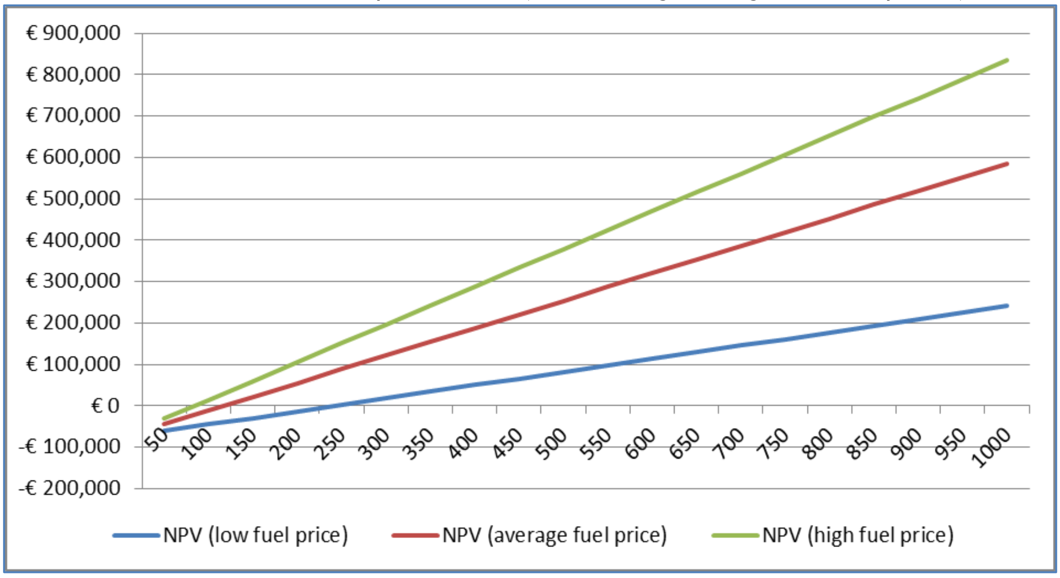

Figure 4: Development of Net Present Value (NPV) depending on fuel consumption (m^3/year) at different fuel-price levels calculated for the base-case scenario.

It can be seen that the NPV for the business case is positive from around 70 m^3 per year in case of high fuel prices, around 100 m^3 per year for average fuel prices and 250 m^3 per year for low fuel prices. In case of very high fuel-consumption figures such as 1000 m^3 per year, the total sum of the discounted saving for a vessel can be 250,000 EUR at low fuel prices and up to 850,000 EUR at high fuel prices. Compared to an investment of 40,000 EUR these benefits are quite remarkable. This means that each euro initial investment (40,000 EUR) will yield 21 times more money (850,000 EUR / 40,000 EUR) in case of high fuel prices over a 15 year time period and about 6 times more in case of low fuel prices (250,000 / 40,000 EUR).

The following figure presents the development of the Internal Rate of Return. It can be seen that quite high Internal Rates of Return are possible. The Internal Rate of Return presents the annual profit that is made on each euro invested in the project for the period 2016-2030, while taking into account already the discount rate of 4 %.

In-line with the results of the NPV, it can be seen that the IRR becomes positive for fuel-consumption values starting from around 70 m^3, 100 m^3 and 250 m^3 per year in the case of high fuel prices, average fuel prices and low fuel prices, respectively.

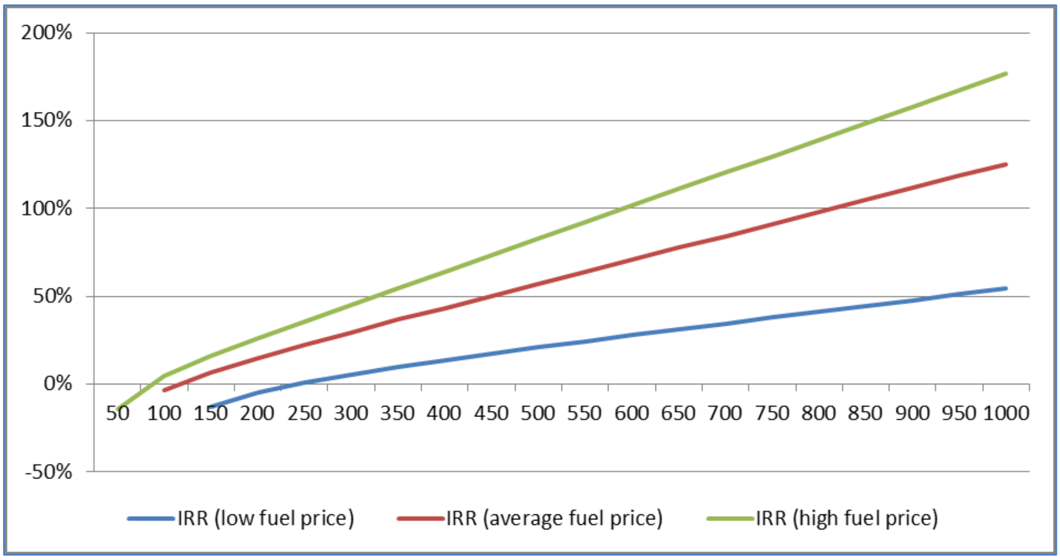

Figure 5: Development of Internal Rate of Return (IRR) depending on fuel consumption (m^3/year) at different fuel price levels calculated for the base-case scenario

Pessimistic scenario:
The following figures present the Net Present Value and the Internal Rate of Return of the investment for the period 2016-2030, depending on the fuel consumption per year (m^3) and the fuel price level (low, average or high) for the pessimistic scenario. The pessimistic scenario assumes:

- 80,000 EUR for the initial investment in the equipment;
- 3 % saving in fuel consumption per year.

The time for installation of equipment and the variable costs are kept similar to the base-case scenario.

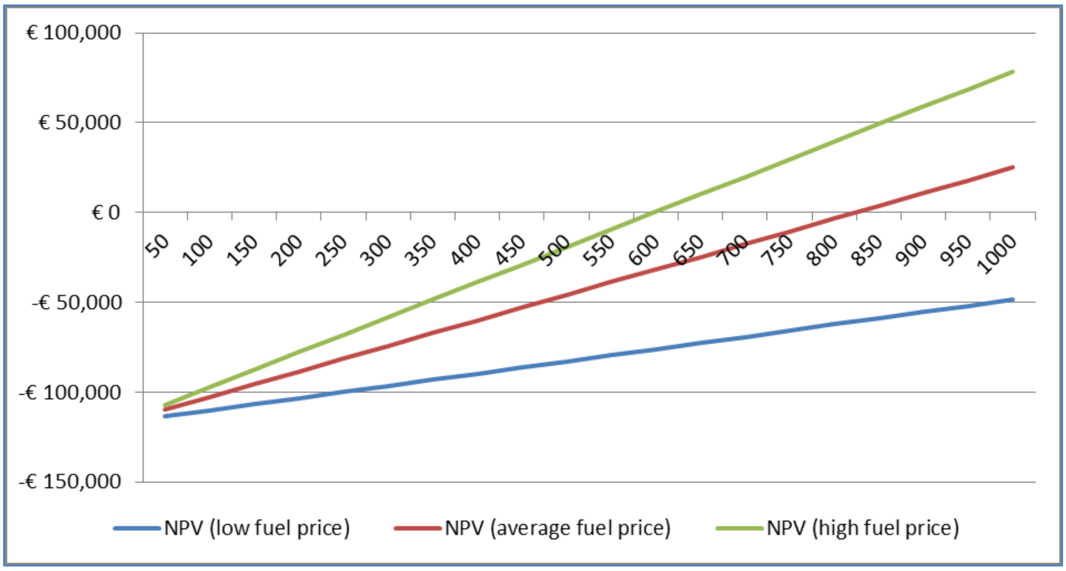

Figure 6: Development of Net Present Value (NPV) depending on fuel consumption (m^3/year) at different fuel-price levels calculated for the pessimistic scenario

It is clear that with these high investment costs and only limited savings on fuel costs of 3 % per year only the large vessels have some benefit in case of average or high fuel prices due to their high fuel consumption values. Assuming the average fuel price (red line), a break-even situation is given for vessels with a yearly fuel consumption of 800 m^3. However, it shall be reminded that the calculation takes into account the savings over a period of 15 years while the fuel price development is quite uncertain. Therefore, the risk to be taken as regards the fuel price development shall be incorporated in these investment decisions.

Although a discount rate of 4 % is taken into account already, the ship owner/operator will expect a higher Return on Investment (ROI). In general, the Internal Rate of Return shall be at least 4 %.

The following graph shows the development of the Internal Rate of Return. For the pessimistic scenario, it can be seen that at the average fuel price a 4 % return rate is reached in case of 1000 m^3 fuel consumed per year. However, in case of high fuel prices, a gain of 4 % would be reached already at 750 m^3 fuel consumed per year.

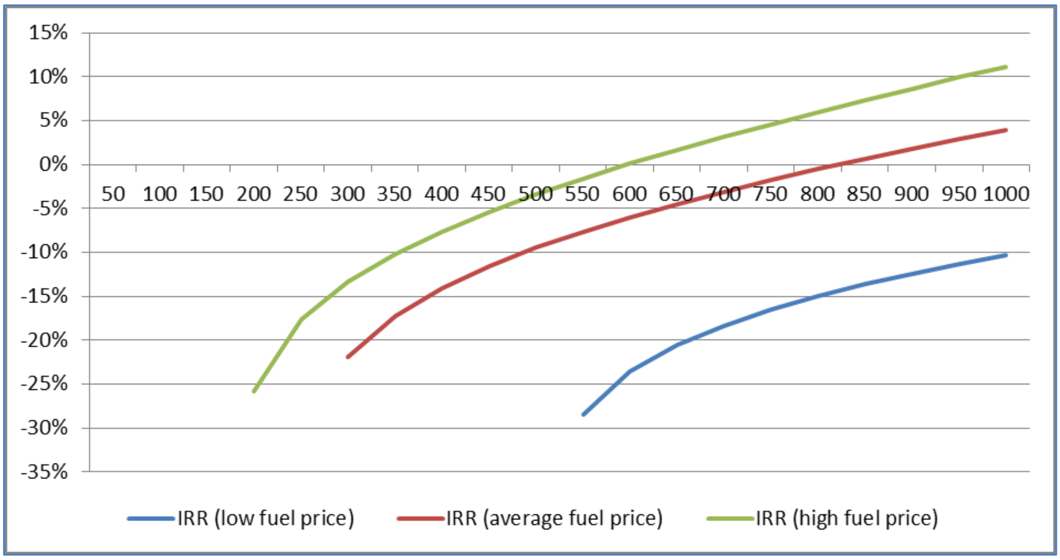

Figure 7: Development of Internal Rate of Return (IRR) depending on fuel consumption (m^3/year) at different fuel price levels calculated for the pessimistic scenario

Optimistic scenario:
The following figures present the Net Present Value and the Internal Rate of Return of the investment for the period 2016-2030, depending on the fuel consumption per year (m^3) and the fuel-price level (low, average or high). The optimistic scenario is defined as follows:

- 10,000 EUR for the initial investment in the equipment;
- 25 % saving in fuel consumption per year.

The time for installation of the equipment and variable costs are again kept similar to the base-case scenario.

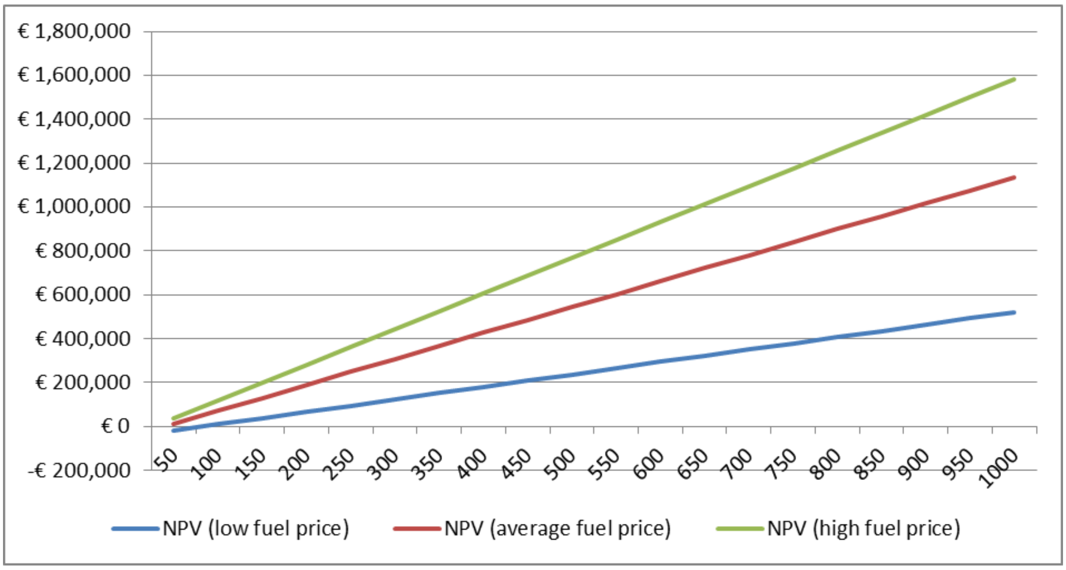

Figure 8: Development of Net Present Value (NPV) depending on fuel consumption (m^3/year) at different fuel-price levels calculated for the optimistic scenario

For the optimistic scenario, the Net Present Value is positive for almost all yearly fuel-consumption values presented, and significant savings can be achieved for the entire bandwidth of fuel prices considered (Fig. 8).

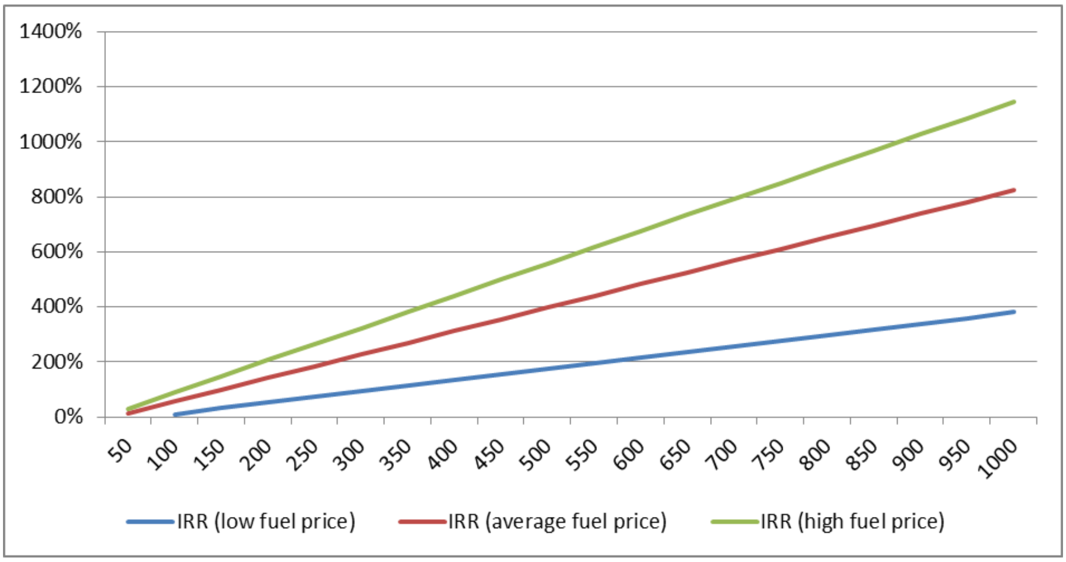

Figure 9: Development of Internal Rate of Return (IRR) depending on fuel consumption (m^3/year) at different fuel price levels calculated for the optimistic scenario

The development of the Internal Rate of Return yields the same positive result. The calculations show that already at a very low fuel consumption of 50 m^3 per year the Internal Rate of Return accepts values of 12 % and 29 % at average and high fuel prices, respectively.

b. Fleet families

In this section, the Net-Present-Value results derived for the fleet families are presented. They are based on the average-fuel-consumption figures reported in Deliverable 1.1, *PROMINENT (2015)*. For the Danube vessels, additional calculations were performed. For each single journey, the average fuel consumption was estimated using the sailing profiles provided by the project partner DST and assuming a specific fuel consumption of 220 g/kWh. Subsequently, the total amount of fuel consumed per journey was known. The total fuel consumption per year was derived by multiplication of the fuel consumption per journey with the number of journeys within one year. The number of journeys was derived from the time for one journey and the operational hours per year, including waiting times e.g. in ports.

For each scenario (base case, pessimistic, optimistic), three figures are presented for three different vessels showing the development of the Net Present Value until 2030. By means of these figures, it can also be seen whether or how soon there is a break-even situation. At the year when the lines cross the value 0 €, the investment is earned back, and after that point in time, the investment in energy-efficient navigation starts making money for the ship owner/operator.

Base-case scenario:
As already mentioned, the base-case scenario is defined by the medium or average values of the most uncertain key parameters:

- hardware investment costs: 40,000 EUR;
- fuel saving: 14 %.

For the calculations, the average fuel price of 49.25 EUR per 100 litre was taken into account. The following figure presents the development of the Net Present Value for the so called “working horse” in inland waterway transport in Europe, comprising a 110 metre motor vessel for transportation of dry cargo. The result presented is based on an estimated annual fuel consumption of 311 m^3 per year on average which was derived from the CDNI data. It can be seen that after an initial investment taken in the first year, the benefits are providing a break-even situation already after 2.5 years. Note: in Fig. 10, e.g. 2016 means end of the year 2016, and negative values are denoted by red colours (e.g. € 50.000 in brackets below € 0). The investment was made end of 2015. The Net Present Value for this time span till 2030 is 172,000 EUR and the Internal Rate of Return is 41 %. This is quite significant and positive.

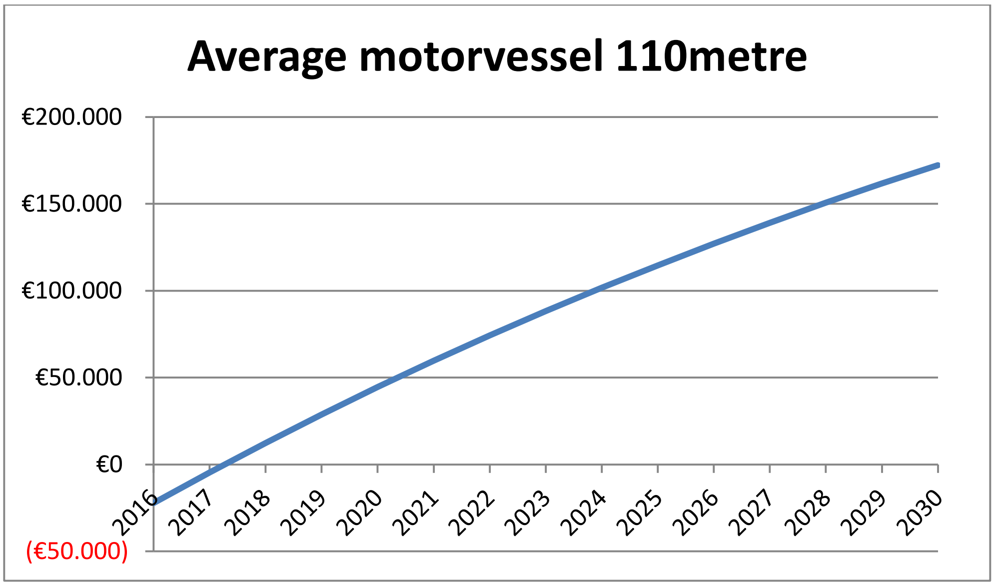

Figure 10: Development of Net Present Value (NPV) over time presented for the base-case scenario and the average fuel price considered for a 110 metre vessel

To illustrate the bandwidth, the same figures are presented for a 4-barge pushed convoy (fuel consumption on average 1107 m^3 per year) and an average 86 metre vessel (fuel consumption 155 m^3 per year).

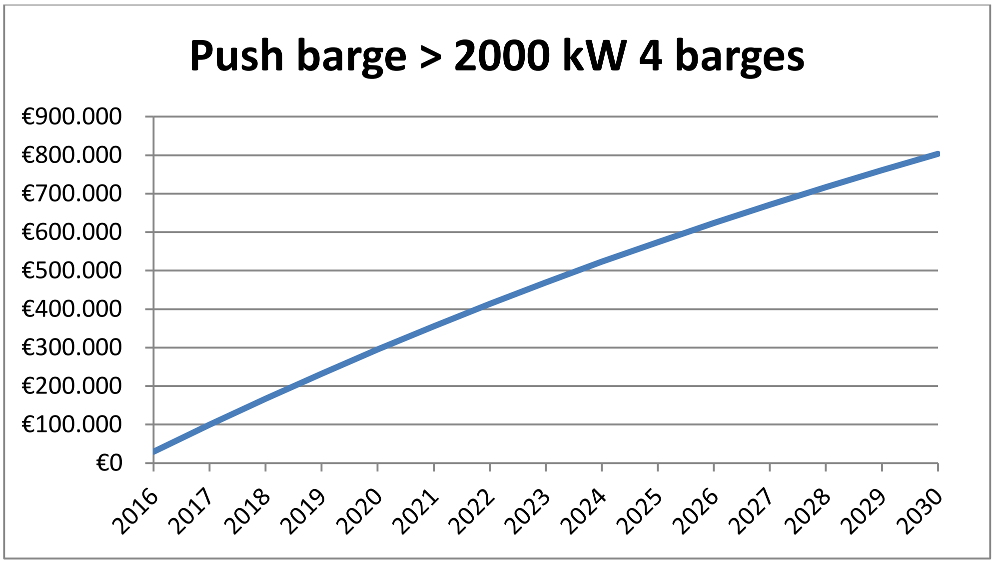

Figure 11: Development of Net Present Value (NPV) over time presented for the base-case scenario and the average fuel price considered for a 4-barge pushed convoy operated with a pusher of more than 2000 kW

For the 4-barge pushed convoy, the results are even better because of the higher fuel consumption per year. The break-even situation is achieved already within the first year.

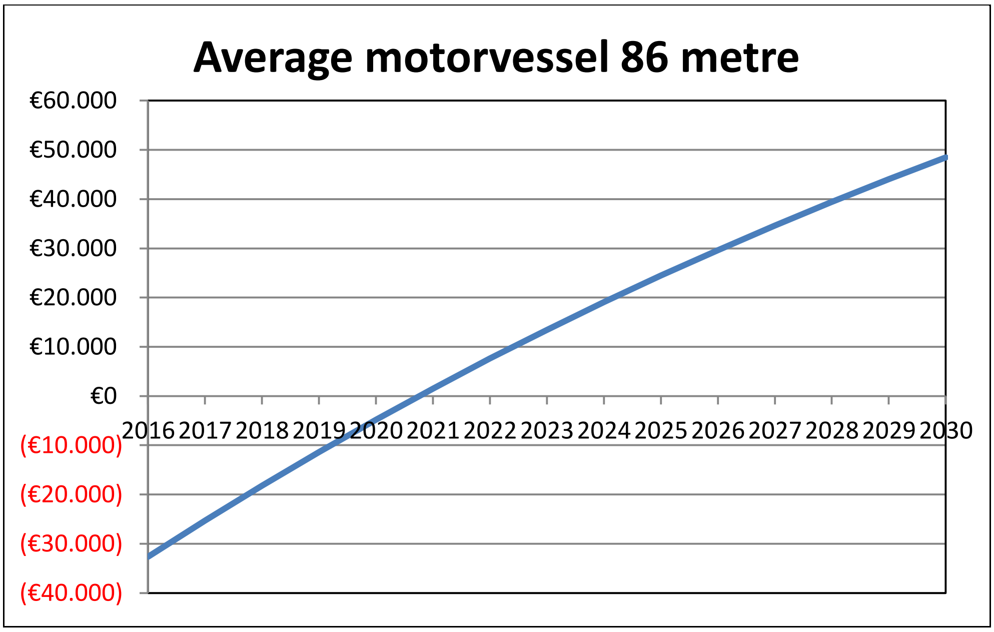

Figure 12: Development of Net Present Value (NPV) over time presented for the base-case scenario and the average fuel price considered for an 86 metre motor vessel

The figure showing the results for the 86 metre vessel gives a break-even situation after a period of 5 years (at 155 m^3 fuel consumed per year). After 15 years the Net Present Value of the investment made (40,000 EUR) is close to 50,000 EUR.

In the table on the next page, the full details of the assumptions made, as well as the complete results derived for the Net Present Values and Internal Rates of Return are listed for all vessel types, considering the base-case scenario, as well as the three fuel-price scenarios: Low, Medium (average) and High. Consulting the table, it can be concluded that the small vessels (length below 80 metres) have no positive business case (see red colours). However, all vessels with a length of above 86 metres show positive values for the Net Present Value and also the Internal Rate of Return. As concluded in the PROMINENT Deliverable 1.1, this group of vessels over a length of 86 meters represents a large share of the fuel consumption and emissions to air of the European fleet. Therefore, the impact and the roll-out potential can be considered relatively high under the assumed conditions.

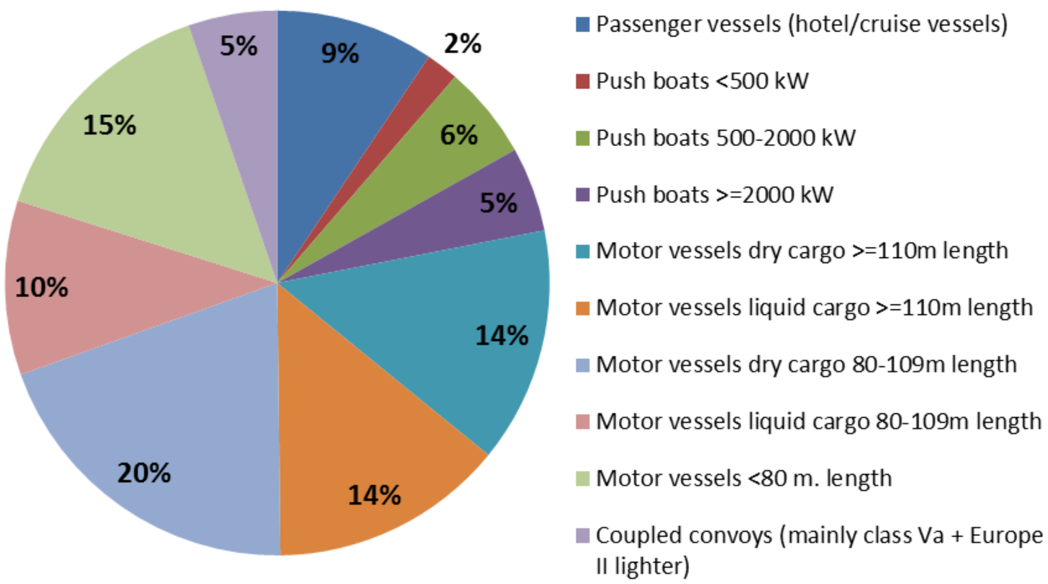

Figure 13: Share of main fleet families in Europe based on estimated fuel consumption

Investment On Board Unit and equipment	**€ 40,000**
Residual value	€ 0
Fixed annual costs (communication, membership, maintenance, training,..)	€ 3,000
Lifetime (years) (=depreciation time)	15
Installation time (days)	1
Fuel savings as result of energy efficient navigation	**14%**

		Fuel: Low	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Fleet family	Vessel type	**NPV**	**NPV**	**NPV**	**IRR**	**IRR**	**IRR**
Passenger vessels (hotel/cruise)	PAX 135m	€ 89,073	€ 270,793	€ 402,540	21%	58%	84%
Push boats <500 kW	PB <500 kW B04	€ -43,366	€ 35,951	€ 78,426		-3%	5%
Push boats 500-2000 kW	PushB2L 500-2000kW	€ -22,637	€ 35,951	€ 78,426	-9%	10%	20%
Push boats 500-2000 kW	PushBII-1, 500-2000kW	€ -7,158	€ 66,733	€ 120,304	-3%	18%	30%
Push boats >=2000 kW	Push B4 > 2000 kW	€ 344,802	€ 803,712	€ 1,136,423	72%	161%	226%
	Push B6 > 2000 kW	€ 819,355	€ 1,793,508	€ 2,499,768	159%	343%	476%
Motor vessel dry cargo >=110m length	MVS 110m	€ 43,534	€ 172,355	€ 265,751	12%	41%	61%
	MVS 135m	€ 106,848	€ 304,647	€ 448,051	27%	69%	99%
Motor vessel liquid cargo >=110m length	MTS 110m	€ 61,494	€ 210,527	€ 318,576	16%	49%	71%
	MTS 135m (M11)	€ 59,228	€ 207,006	€ 314,146	16%	47%	69%
	MTS 135M (M12)	€ 58,744	€ 206,522	€ 313,662	15%	46%	68%
Motor vessel dry cargo 80-109m length	MVS 80m	€ -32,320	€ 13,775	€ 47,195	-17%	4%	13%
	MVS 86m	€ -15,729	€ 48,472	€ 95,018	-6%	14%	25%
	MVS 105m	€ 43,748	€ 172,504	€ 265,853	12%	41%	62%
Motor vessel liquid cargo 80-109m length	MTS 86m	€ 28,823	€ 141,579	€ 223,328	9%	35%	52%
Motor vessel <80 m. length	MVS 67m	€ -43,966	€ -10,525	€ 13,720		-4%	4%
	MVS 55m	€ -56,612	€ -36,868	€ -22,553		-23%	-10%
	MVS 50m	€ -61,874	€ -47,847	€ -37,677			-25%
	MVS 38,5m	€ -66,081	€ -56,684	€ -49,871			
Coupled convoys (Va + Europe II lighter)	C3L/B	€ 137,387	€ 368,634	€ 536,289	33%	82%	116%
Danube barges	Push Barge, 4 units	€ 510,210	€ 1,145,495	€ 1,606,076	110%	241%	336%
	Push Barge, 8/9 units	€ 401,567	€ 920,391	€ 1,296,538	85%	190%	265%

Table 9: Net Present Values and Internal Rates of Return presented for the various representative vessels from the fleet families and the base-case scenario

Pessimistic scenario:
The most pessimistic scenario takes into account an investment of 80,000 EUR in hardware and 3 % savings in fuel consumption. The following figure presents the development of the Net Present Value for an 110 metre motor vessel for transportation of dry cargo. For the calculations, the average fuel price of 49.25 EUR per 100 litre was taken into account.

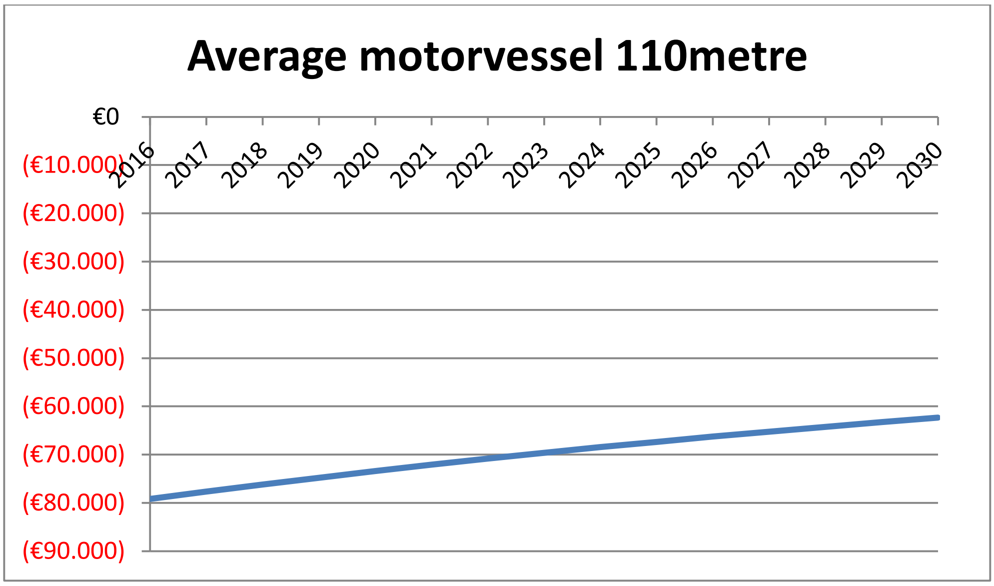

Figure 14: Development of Net Present Value (NPV) over time presented for the pessimistic scenario and the average fuel price considered for a 110 metre vessel

It can be seen that once the investment has been taken, a small net saving on the cash position is reached on an annual basis. However the saving is not sufficient to offset the initial (cash out) investment.

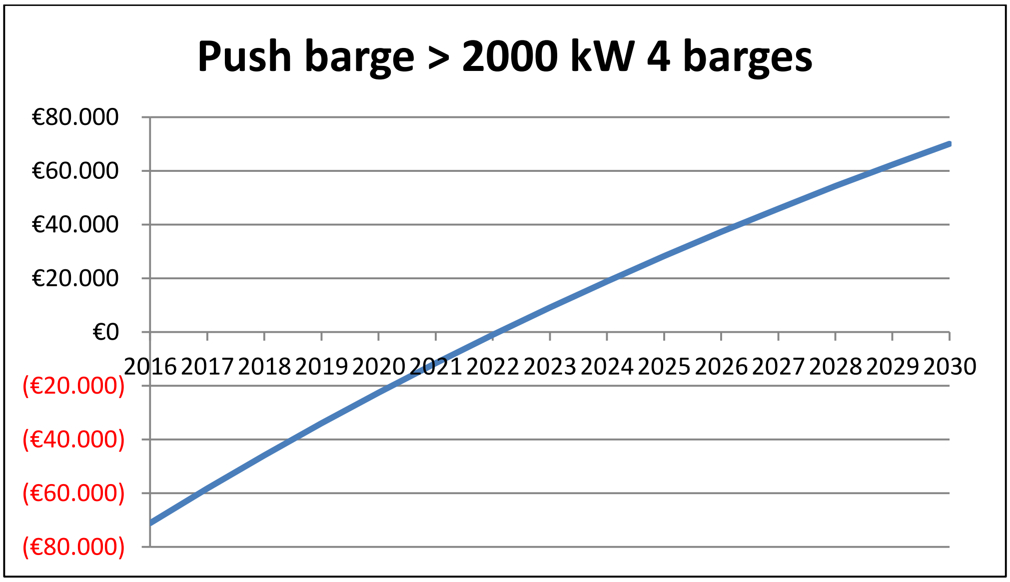

Figure 15: Development of Net Present Value (NPV) over time presented for the pessimistic scenario and the average fuel price considered for a 4-barge pushed convoy operated with a pusher of more than 2000 kW

For the pushed convoy, the situation is different. Assuming a fuel consumption of 1107 m^3 per year for the pusher, a break-even situation is reached after 7 years (2022, average fuel price, pessimistic scenario).

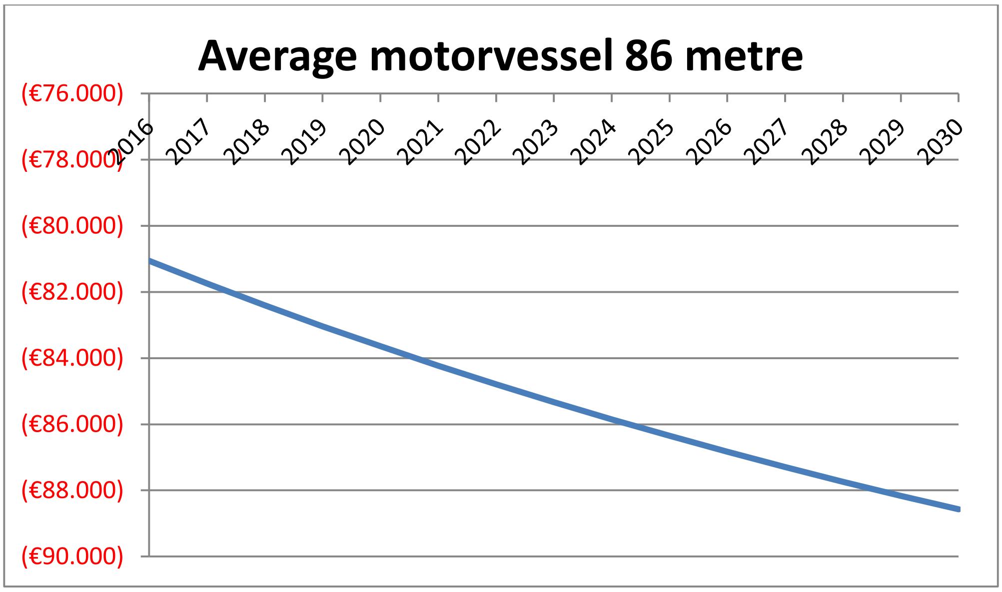

Figure 16: Development of Net Present Value (NPV) over time presented for the pessimistic scenario and the average fuel price considered for an 86 metre motor vessel

The graph for the motor vessel with a length of 86 m shows that the 3 % saving in fuel consumption is not higher than the annual variable costs to run the energy-efficient navigation tool. As a result the losses increase after the investment has been made. This is obviously not an attractive situation for the ship owner/operator as the investment would only cost money after installation and operation of the tools.

In the table on the next page, the full details of the assumptions made, as well as the complete results derived for the Net Present Values and Internal Rates of Return are listed for all vessel types, considering the pessimistic scenario, as well as the three fuel-price scenarios: Low, Medium (average) and High.

Consulting the table, it can be concluded that the vast majority of the vessels has a negative business case (see red colours) and making a respective investment would make no sense from an business-economic point of view. Consequently, the roll-out potential is very low. Only for the 6-barge pushed convoy operated on the Rhine a positive business case is obtained also for low fuel prices. For this vessel configuration, the 3 % savings in the extremely high fuel consumption of 3939 m^3 per year results in sufficient savings in fuel costs in order to end up with a positive business case.

Investment On Board Unit and equipment	**€ 80,000**
Residual value	€ 0
Fixed annual costs (communication, membership, maintenance, training,..)	€ 3,000
Lifetime (years) (=depreciation time)	15
Installation time (days)	1
Fuel savings as result of energy efficient navigation	**3%**

Fleet family	Vessel type	**Fuel: Low NPV**	**Fuel: Med. NPV**	**Fuel: High NPV**	**Fuel: Low IRR**	**Fuel: Med. IRR**	**Fuel: High IRR**
Passenger vessels (hotel/cruise)	PAX 135m	€ -82,831	€ -43,891	€ -15,659		-9%	-3%
Push boats <500 kW	PB <500 kW B04	€ -108,132	€ -92,609	€ -83,507			
Push boats 500-2000 kW	PushB2L 500-2000kW	€ -105,163	€ -92,609	€ -83,507			
Push boats 500-2000 kW	PushBII-1, 500-2000kW	€ -100,793	€ -84,959	€ -73,480			-22%
Push boats >=2000 kW	Push B4 > 2000 kW	€ -28,306	€ 70,032	€ 141,327	-5%	10%	18%
	Push B6 > 2000 kW	€ 72,252	€ 280,999	€ 432,340	10%	33%	48%
Motor vessel dry cargo >=110m length	MVS 110m	€ -89,973	€ -62,369	€ -42,355		-15%	-9%
	MVS 135m	€ -76,727	€ -34,342	€ -3,612	-26%	-7%	-1%
Motor vessel liquid cargo >=110m length	MTS 110m	€ -86,684	€ -54,748	€ -31,595		-12%	-6%
	MTS 135m (M11)	€ -88,039	€ -56,372	€ -33,414		-13%	-6%
	MTS 135M (M12)	€ -88,523	€ -56,856	€ -33,898		-13%	-6%
Motor vessel dry cargo 80-109m length	MVS 80m	€ -105,780	€ -95,902	€ -88,741			
	MVS 86m	€ -102,331	€ -88,574	€ -78,599			
	MVS 105m	€ -89,711	€ -62,120	€ -42,117		-15%	-9%
Motor vessel liquid cargo 80-109m length	MTS 86m	€ -93,024	€ -68,862	€ -51,344		-19%	-11%
Motor vessels <80 m. length	MVS 67m	€ -108,240	€ -101,074	€ -95,879			
	MVS 55m	€ -110,944	€ -106,713	€ -103,645			
	MVS 50m	€ -112,056	€ -109,051	€ -106,871			
	MVS 38,5m	€ -112,903	€ -110,889	€ -109,429			
Coupled convoys (Va + Europe II lighter)	C3L/B	€ -70,468	€ -20,915	€ 15,011	-19%	-4%	2%
Danube barges	Push Barge, 4 units	€ 9,079	€ 145,212	€ 243,908	1%	19%	30%
	Push Barge, 8/9 units	€ -15,029	€ 96,147	€ 176,750	-3%	13%	22%

Table 10: Net Present Values and Internal Rates of Return presented for the various representative vessels from the fleet families and the pessimistic scenario

Optimistic scenario:
The most optimistic situation takes into account a rather limited investment of 10,000 euro in hardware while a 25 % saving in fuel consumption is assumed, which would be quite substantial. Similarly to the presentation of the results for the base-case scenario and the pessimistic scenario, the following figures present the developments of the Net Present Values for an 110 metre motor vessel for transportation of dry cargo, a 4-barge pushed convoy and an 86 metre vessel. For the calculations, the average fuel price of 49.25 EUR per 100 litre was taken into account.

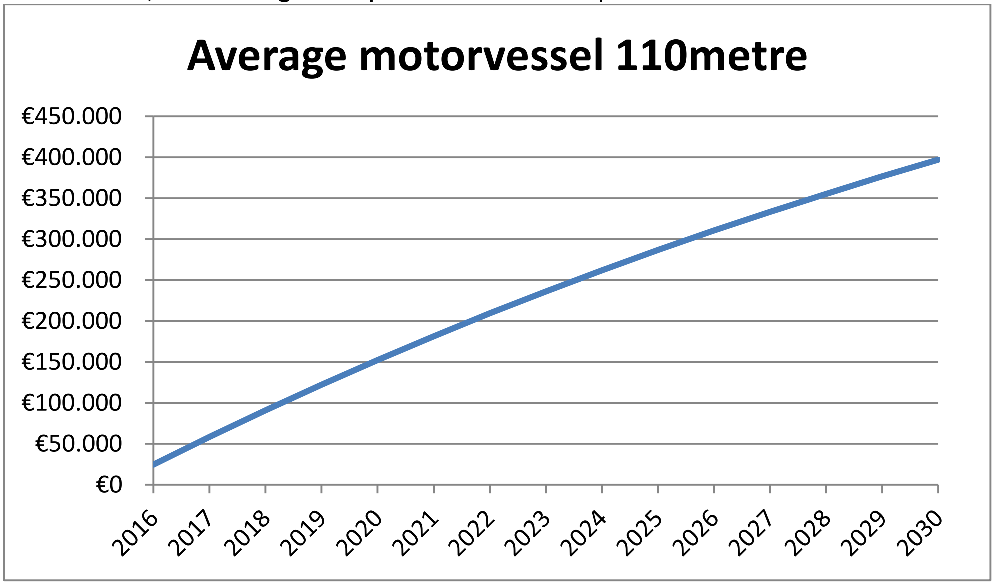

Figure 17: Development of Net Present Value (NPV) over time presented for the optimistic scenario and the average fuel price considered for a 110 metre vessel

The business case for the 110 metre vessel is rather positive for the optimistic scenario. Already in the first year (2016) the savings are higher than the initial investment costs. The figure below shows that the situation becomes even more positive for large push boats.

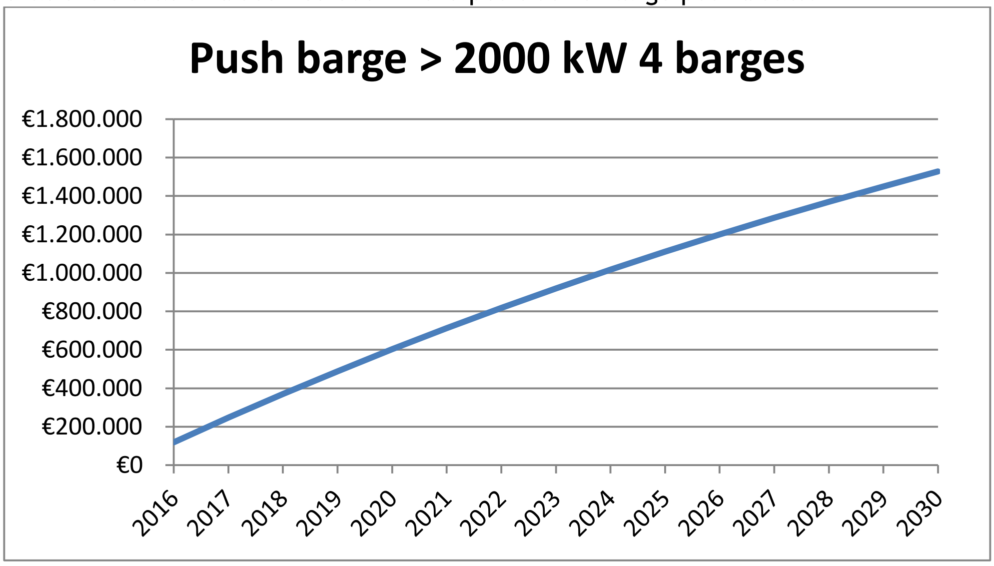

Figure 18: Development of Net Present Value (NPV) over time presented for the optimistic scenario and the average fuel price considered for a 4-barge pushed convoy operated with a pusher of more than 2000 kW

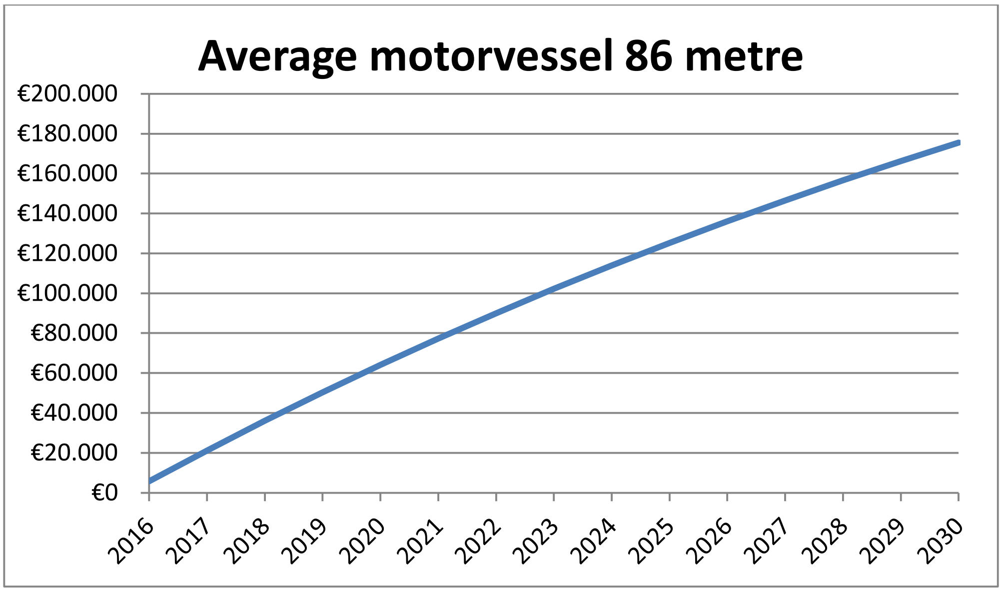

Figure 19: Development of Net Present Value (NPV) over time presented for the optimistic scenario and the average fuel price considered for an 86 metre motor vessel

Also for most smaller vessels, the situation is positive. The figure presenting the results for the 86 metre vessel (Fig. 19) indicates that the investment is earned back within one year.

In the table on the next page, the full details of the assumptions made, as well as the complete results derived for the Net Present Values and Internal Rates of Return are listed for all vessel types, considering the optimistic scenario, as well as the three fuel-price scenarios: Low, Medium (average) and High.

Quite in contrast to the outcome derived for the pessimistic scenario, it can be seen that the vast majority of the vessels has a positive business case. There are hardly any red colours (negative values) seen. Therefore, making a respective investment would make sense for a lot of vessels from a business-economic point of view. Consequently, the impact on reduction of operational costs and the roll-out potential are extremely high under the assumptions made for the optimistic scenario.

Nevertheless, for the 38.5 metre vessel (Peniche), the average fuel consumption is only 23 m^3. Even a limited investment of 10,000 EUR and 25 % saving in fuel consumption does not result in sufficient savings to end up with a positive business case for this vessel.

Investment On Board Unit and equipment	**€ 80,000**
Residual value	€ 0
Fixed annual costs (communication, membership, maintenance, training,..)	€ 3,000
Lifetime (years) (=depreciation time)	15
Installation time (days)	1
Fuel savings as result of energy efficient navigation	**3%**

		Fuel: Low	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Fleet family	Vessel type	**NPV**	**NPV**	**NPV**	**IRR**	**IRR**	**IRR**
Passenger vessels (hotel/cruise)	PAX 135m	€ 250,978	€ 575,478	€ 810,740	159%	357%	502%
Push boats <500 kW	PB <500 kW B04	€ 11,399	€ 154,510	€ 230,360	13%	66%	104%
Push boats 500-2000 kW	PushB2L 500-2000kW	€ 49,890	€ 154,510	€ 230,360	40%	115%	170%
Push boats 500-2000 kW	PushBII-1, 500-2000kW	€ 76,477	€ 208,425	€ 304,088	66%	173%	250%
Push boats >=2000 kW	Push B4 > 2000 kW	€ 707,909	€ 1,527,392	€ 2,121,518	428%	918%	1273%
	Push B6 > 2000 kW	€ 1,556,458	€ 3,296,016	€ 4,557,196	851%	1797%	2483%
Motor vessel dry cargo >=110m length	MVS 110m	€ 167,041	€ 397,079	€ 563,857	139%	323%	457%
	MVS 135m	€ 280,423	€ 633,635	€ 889,714	221%	494%	692%
Motor vessel liquid cargo >=110m length	MTS 110m	€ 199,672	€ 465,803	€ 658,747	155%	355%	500%
	MTS 135m (M11)	€ 196,495	€ 460,385	€ 651,705	140%	321%	452%
	MTS 135M (M12)	€ 196,011	€ 459,901	€ 651,221	134%	309%	435%
Motor vessel dry cargo 80-109m length	MVS 80m	€ 31,139	€ 113,452	€ 173,130	31%	101%	151%
	MVS 86m	€ 60,872	€ 175,518	€ 258,636	56%	151%	221%
	MVS 105m	€ 167,208	€ 397,129	€ 563,822	142%	332%	469%
Motor vessel liquid cargo 80-109m length	MTS 86m	€ 140,669	€ 342,020	€ 488,000	119%	282%	401%
Motor vessel <80 m. length	MVS 67m	€ 10,307	€ 70,024	€ 113,319	12%	64%	101%
	MVS 55m	€ -12,280	€ 22,977	€ 48,538		24%	46%
	MVS 50m	€ -21,693	€ 3,356	€ 21,517		4%	22%
	MVS 38,5m	€ -29,260	€ -12,479	€ -313			0%
Coupled convoys (Va + Europe II lighter)	C3L/B	€ 335,241	€ 748,183	€ 1,047,566	256%	565%	789%
Danube barges	Push Barge, 4 units	€ 1,001,341	€ 2,135,778	€ 2,958,245	727%	1545%	2138%
	Push Barge, 8/9 units	€ 808,163	€ 1,734,634	€ 2,406,325	540%	1155%	1600%

Table 11: Net Present Values and Internal Rates of Return presented for the various representative vessels from the fleet families and the optimistic scenario

c. Representative journeys

Base-case scenario:
The following tables present the Net Present Values (NPV) and Internal Rates of Return (IRR) derived for the various sailing areas (Rhine, Danube, Other Waterways, passenger vessels-PAX) and the three different fuel-price scenarios considered.

Rhine journeys						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
1	Rotterdam	Duisburg	Dry bulk	Push B4	11,200	€ 1,429,087	€ 3,061,684	€ 4,245,318	283%	600%	831%
2	Rotterdam	Antwerp	Container	C3L/B	4,420	€ 126,997	€ 346,998	€ 506,499	31%	77%	110%
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	2,917	€ 374,461	€ 861,938	€ 1,215,359	83%	186%	260%
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	3,795	€ 379,164	€ 872,125	€ 1,229,521	84%	186%	261%
5	Rotterdam	Basel	Container	C3L/B	4,607	€ 260,158	€ 624,299	€ 888,302	59%	135%	190%
7	Amsterdam	Antwerp	Container	C3L/B	4,420	€ 170,854	€ 438,330	€ 632,249	40%	96%	136%
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	4,750	€ 476,688	€ 1,074,821	€ 1,508,467	105%	230%	321%
10	Antwerp	Mainz	Container	MVS 135m	3,179	€ 204,671	€ 508,359	€ 728,532	48%	112%	158%
12	Antwerp	Duisburg	Container	C3L/B	6,375	€ 299,016	€ 705,220	€ 999,718	67%	152%	213%
13	Rotterdam	Duisburg	Container	MVS 110m	2,465	€ 43,430	€ 172,139	€ 265,452	12%	41%	61%
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	1,210	€ 16,607	€ 116,141	€ 188,303	5%	29%	45%
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	2,039	€ 89,946	€ 269,006	€ 398,825	23%	62%	89%
18	Duisburg	Antwerp	General cargo	MVS 110m	2,039	€ 170,850	€ 437,485	€ 630,796	41%	98%	139%
22	Rotterdam	Herne	Dry Bulk	MVS 86m	1,096	€ -4,700	€ 71,441	€ 126,643	-2%	19%	32%
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	2,039	€ 140,766	€ 374,837	€ 544,538	34%	84%	120%
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	1,237	€ 26,049	€ 135,805	€ 215,377	8%	33%	51%

Table 12: Net Present Values and Internal Rates of Return presented for the representative journeys on the Rhine and the base-case scenario

For the base-case scenario, almost all representative journeys on the Rhine show convincing business cases. The only journey for which the business case could be subject to discussion is the journey 22: Rotterdam- Herne realised with the 86 metre motor vessel (low fuel price).

For the Danube journeys and the base-case scenario considered, all business cases are positive and convincing (Table 13).

Danube journeys						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
1	Bor district	Constanza	Dry bulk	Push 8/9	9,000	€ 517,728	€ 1,162,290	€ 1,629,598	109%	238%	332%
2	Bor district	Constanza	Liquid Bulk	Push 8/9	12,000	€ 517,728	€ 1,162,290	€ 1,629,598	109%	238%	332%
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	9,000	€ 454,897	€ 1,031,448	€ 1,449,447	96%	212%	296%
4	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ 287,657	€ 683,180	€ 969,933	63%	142%	200%
5	Calafat	Constanza	Dry bulk	Push 8/9	9,000	€ 518,222	€ 1,163,320	€ 1,631,016	109%	239%	332%
6	Bratislava	Linz	Dry bulk	Push 4	4,400	€ 510,210	€ 1,145,495	€ 1,606,076	110%	241%	336%
7	Calafat	Constanza	Dry bulk	Push 8/9	9,000	€ 518,222	€ 1,163,320	€ 1,631,016	109%	239%	332%
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	9,000	€ 454,897	€ 1,031,448	€ 1,449,447	96%	212%	296%
9	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ 287,657	€ 683,180	€ 969,933	63%	142%	200%
10	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ 287,657	€ 683,180	€ 969,933	63%	142%	200%

Table 13: Net Present Values and Internal Rates of Return presented for the representative journeys on the Danube and the base-case scenario

The next tables present the results for the Other Waterways and passenger vessels.

Journeys on Other Waterways						Fuel: Low	Fuel: Med.	Fuel: High	Fuel: Low	Fuel: Med.	Fuel: High
Journey #:	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
7	Rotterdam	Hannover	Dry Bulk	MVS 86m	1,096	€ 1,434	€ 84,214	€ 144,230	0%	22%	35%
8	Duisburg	Wolfsburg	General goods	MVS 86m	1,096	€ -27,335	€ 24,304	€ 61,743	-12%	7%	17%
16	Rotterdam	Oldenburg	Dry Bulk	MVS 80m	910	€ -36,028	€ 6,054	€ 36,563	-21%	2%	11%
7	Rotterdam	Lingen	Liquid Bulk	MTS 86m	1,039	€ -8,094	€ 64,702	€ 117,479	-3%	17%	29%

Table 14: Net Present Values and Internal Rates of Return presented for the representative journeys on the Other Waterways and the base-case scenario

PAX Journeys					Fuel: Low	Fuel: Med.	Fuel: High	Fuel: Low	Fuel: Med.	Fuel: High
Journey #	Waterway	Port A	Port B	Vessel type	NPV	NPV	NPV	IRR	IRR	IRR
1	ARA/Rhine	Amsterdam	Basel	PAX 135m	€ 14,089	€ 114,643	€ 187,544	4.1%	26.8%	41.4%
3	Danube	Passau	Budapest	PAX 135m	€ -6,633	€ 71,489	€ 128,128	-2.2%	17.7%	29.5%

Table 15: Net Present Values and Internal Rates of Return presented for the representative journeys with passenger vessels and the base case scenario

Table 14 shows that on the Other Waterways, the business cases for the 80 metre vessels and 86 metre vessels are not always positive, and, therefore, fully convincing. This circumstance is caused by the rather small amounts of fuel consumed per year and the low fuel-price level considered, resulting in rather low fuel-cost savings.

The business cases for the selected journeys realised by the passenger vessels (135 metre hotel/cruise vessel) are neither fully convincing. For the journey Passau-Budapest, a negative business case is obtained, considering a low fuel-price level.

For the journeys on the rivers Rhine and Danube, the impact on the overall costs was also calculated. This illustrates to what extent there is a reduction of transport costs per ton which could have an impact on the competitive position of inland waterway transport compared to other modes. The following tables present the results derived for the different fuel-price scenarios (low, average, high).

Journey #	Port A	Port B	Type	Vessel type	Commodity	% net reduction @ low fuel price	% net reduction @ average fuel price	% net reduction @ high fuel price
1	Rotterdam	Duisburg	Dry bulk	Push B4	Ore	3.9%	6.4%	7.5%
2	Rotterdam	Antwerp	Container	C3L/B	Containers	0.9%	2.3%	3.1%
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	Crude oil	1.9%	3.8%	4.8%
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	Coal	2.5%	4.6%	5.7%
5	Rotterdam	Basel	Container	C3L/B	Containers	1.8%	3.6%	4.7%
7	Amsterdam	Antwerp	Container	C3L/B	Containers	1.2%	2.8%	3.7%
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	Oil	2.3%	4.4%	5.4%
10	Antwerp	Mainz	Container	MVS 135m	Containers	1.7%	3.5%	4.6%
12	Antwerp	Duisburg	Container	C3L/B	Containers	2.0%	3.9%	5.0%
13	Rotterdam	Duisburg	Container	MVS 110m	Containers	0.7%	2.4%	3.4%
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	Chemicals	0.3%	2.0%	3.0%
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	Agribulk	1.4%	3.4%	4.5%
18	Duisburg	Antwerp	General cargo	MVS 110m	Metal products	2.4%	4.8%	6.1%
22	Rotterdam	Herne	Dry Bulk	MVS 86m	Metal (scrap)	-0.1%	1.3%	2.1%
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	Agribulk	2.0%	4.4%	5.6%
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	Agribulk	0.5%	2.3%	3.3%

Table 16: Impact on total transport costs presented for the representative journeys on the Rhine and the base-case scenario

The savings in total costs can accept values of up to 7.5 %, e.g. in the case of the large-scale pushed barge transport between Rotterdam and Duisburg, realised at high fuel-price levels.

Journey #	Port A	Port B	Type	Vessel type	Commodity	% net reduction @ low fuel price	% net reduction @ average fuel price	% net reduction @ high fuel price
1	Bor district	Constanza	Dry bulk	Push 8/9	Agribulk	2.7%	4.8%	5.9%
2	Bor district	Constanza	Liquid Bulk	Push 8/9	Petroleum products	2.7%	4.8%	5.9%
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	Coal	2.4%	4.5%	5.5%
4	Giurgiu	Constanza	Dry bulk	Push 8/9	Building mat. / minerals	1.6%	3.3%	4.3%
5	Calafat	Constanza	Dry bulk	Push 8/9	Building mat. / minerals	2.7%	4.8%	5.9%
6	Bratislava	Linz	Dry bulk	Push 4	Ores	3.4%	5.9%	7.0%
7	Calafat	Constanza	Dry bulk	Push 8/9	Agribulk	2.7%	4.8%	5.9%
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	Agribulk	2.4%	4.5%	5.5%
9	Giurgiu	Constanza	Dry bulk	Push 8/9	Agribulk	1.6%	3.3%	4.3%
10	Giurgiu	Constanza	Dry bulk	Push 8/9	Ores	1.6%	3.3%	4.3%

Table 17: Impact on total transport costs presented for the representative journeys on the Danube and the base-case scenario

For the Danube, the savings in total costs may accept values of up to 7 %, e.g. in the case of transporting ore between Bratislava and Linz, realised at high fuel-price levels. The large savings are caused by the large fuel-costs share of the total costs, resulting from the high fuel consumption per year.

Pessimistic scenario:

The following tables present the Net Present Values (NPV) and Internal Rates of Return (IRR) derived for the various sailing areas (Rhine, Danube, Other Waterways, passenger vessels-PAX) and the three different fuel-price scenarios considered.

Rhine journeys						Fuel: Low	Fuel: Med.	Fuel: High	Fuel: Low	Fuel: Med.	Fuel: High
Journey #	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
1	Rotterdam	Duisburg	Dry bulk	Push B4	11,200	€ 204,041	€ 553,884	€ 807,519	25%	61%	87%
2	Rotterdam	Antwerp	Container	C3L/B	4,420	€ -72,694	€ -25,551	€ 8,627	-21%	-5%	1%
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	2,917	€ -19,382	€ 85,078	€ 160,811	-4%	12%	21%
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	3,795	€ -18,658	€ 86,976	€ 163,561	-3%	12%	21%
5	Rotterdam	Basel	Container	C3L/B	4,607	€ -44,160	€ 33,870	€ 90,442	-9%	5%	13%
7	Amsterdam	Antwerp	Container	C3L/B	4,420	€ -63,296	€ -5,980	€ 35,574	-16%	-1%	5%
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	4,750	€ 2,524	€ 130,696	€ 223,620	0%	18%	28%
10	Antwerp	Mainz	Container	MVS 135m	3,179	€ -55,765	€ 9,311	€ 56,491	-13%	2%	8%
12	Antwerp	Duisburg	Container	C3L/B	6,375	€ -35,833	€ 51,211	€ 114,317	-7%	8%	16%
13	Rotterdam	Duisburg	Container	MVS 110m	2,465	€ -89,996	€ -62,415	€ -42,419		-15%	-9%
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	1,210	€ -95,641	€ -74,313	€ -58,849		-23%	-14%
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	2,039	€ -80,028	€ -41,658	€ -13,839		-9%	-2%
18	Duisburg	Antwerp	General cargo	MVS 110m	2,039	€ -62,691	€ -5,555	€ 35,869	-16%	-1%	6%
22	Rotterdam	Herne	Dry Bulk	MVS 86m	1,096	€ -99,968	€ -83,652	€ -71,823			-21%
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	2,039	€ -69,138	€ -18,980	€ 17,385	-19%	-3%	3%
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	1,237	€ -93,618	€ -70,099	€ -53,048		-20%	-12%

Table 18: Net Present Values and Internal Rates of Return presented for the representative journeys on the Rhine and the pessimistic scenario

For pessimistic scenario, many of the representative journeys on the Rhine show negative business cases. The only exemption is the journey 1: Rotterdam-Duisburg with large-scale pushed convoys.

The following table presents the results for the Danube journeys for the pessimistic scenario. As this concerns mainly journeys with pushed convoys with relatively high fuel consumption, the results are more positive compared to the Rhine. However, at low fuel-price levels the results are not satisfactory.

Danube journeys						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
1	Bor district	Constanza	Dry bulk	Push 8/9	9,000	€ 9,862	€ 147,983	€ 248,120	2%	19%	30%
2	Bor district	Constanza	Liquid Bulk	Push 8/9	12,000	€ 9,862	€ 147,983	€ 248,120	2%	19%	30%
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	9,000	€ -3,601	€ 119,945	€ 209,517	-1%	16%	26%
4	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ -39,438	€ 45,316	€ 106,764	-8%	7%	14%
5	Calafat	Constanza	Dry bulk	Push 8/9	9,000	€ 9,968	€ 148,204	€ 248,424	2%	19%	30%
6	Bratislava	Linz	Dry bulk	Push 4	4,400	€ 9,079	€ 145,212	€ 243,908	1%	19%	30%
7	Calafat	Constanza	Dry bulk	Push 8/9	9,000	€ 9,968	€ 148,204	€ 248,424	2%	19%	30%
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	9,000	€ -3,601	€ 119,945	€ 209,517	-1%	16%	26%
9	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ -39,438	€ 45,316	€ 106,764	-8%	7%	14%
10	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ -39,438	€ 45,316	€ 106,764	-8%	7%	14%

Table 19: Net Present Values and Internal Rates of Return presented for the representative journeys on the Danube and the pessimistic scenario

The next tables present the results for the other waterways and passenger vessels. All cases are clearly negative and investing under the assumtpions considered (80,000 EUR investment at 3% fuel savings) would make no sense.

Journeys on Other Waterways						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #:	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
7	Rotterdam	Hannover	Dry Bulk	MVS 86m	1,096	€ -98,653	€ -80,915	€ -68,054			-19%
8	Duisburg	Wolfsburg	General goods	MVS 86m	1,096	€ -104,818	€ -93,752	€ -85,730			
16	Rotterdam	Oldenburg	Dry Bulk	MVS 80m	910	€ -106,574	€ -97,557	€ -91,019			
7	Rotterdam	Lingen	Liquid Bulk	MTS 86m	1,039	€ -100,934	€ -85,335	€ -74,026			-23%

Table 20: Net Present Values and Internal Rates of Return presented for the representative journeys on the Other Waterways and the pessimistic scenario

PAX Journeys					**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Waterway	Port A	Port B	Vessel type	NPV	NPV	NPV	IRR	IRR	IRR
1	ARA/Rhine	Amsterdam	Basel	PAX 135m	€ -98,899	€ -77,352	€ -61,730		-23.1%	-14.2%
3	Danube	Passau	Budapest	PAX 135m	€ -103,339	€ -86,599	€ -74,462			-20.7%

Table 21: Net Present Values and Internal Rates of Return presented for the representative journeys with passenger vessels and the pessimistic scenario

For the journeys on the rivers Rhine and Danube, the impact on the overall costs was also calculated. This illustrates to what extent there is a reduction of transport costs per ton which could have an impact on the competitive position of inland waterway transport compared to other modes. The following tables present the results derived for the different fuel-price scenarios (low, average, high) and the pessimistic scenario.

Journey #	Port A	Port B	Type	Vessel type	Commodity	% net reduction @ low fuel price	% net reduction @ average fuel price	% net reduction @ high fuel price
1	Rotterdam	Duisburg	Dry bulk	Push B4	Ore	0.6%	1.1%	1.4%
2	Rotterdam	Antwerp	Container	C3L/B	Containers	-0.5%	-0.2%	0.0%
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	Crude oil	-0.1%	0.4%	0.6%
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	Coal	-0.1%	0.5%	0.8%
5	Rotterdam	Basel	Container	C3L/B	Containers	-0.3%	0.2%	0.5%
7	Amsterdam	Antwerp	Container	C3L/B	Containers	-0.5%	0.0%	0.2%
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	Oil	0.0%	0.5%	0.8%
10	Antwerp	Mainz	Container	MVS 135m	Containers	-0.5%	0.1%	0.3%
12	Antwerp	Duisburg	Container	C3L/B	Containers	-0.3%	0.3%	0.6%
13	Rotterdam	Duisburg	Container	MVS 110m	Containers	-1.5%	-0.9%	-0.6%
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	Chemicals	-1.9%	-1.3%	-1.0%
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	Agribulk	-1.2%	-0.6%	-0.2%
18	Duisburg	Antwerp	General cargo	MVS 110m	Metal products	-0.9%	-0.1%	0.3%
22	Rotterdam	Herne	Dry Bulk	MVS 86m	Metal (scrap)	-2.1%	-1.6%	-1.3%
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	Agribulk	-1.0%	-0.2%	0.2%
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	Agribulk	-1.9%	-1.2%	-0.8%

Table 22: Impact on total transport cost for representative journeys on the Rhine and the pessimistic scenario

In-line with the results for the NPV and IRR, the situation is only positive for the Journey 1 (Rotterdam-Duisburg push convoy). The savings on the costs per ton could run up to 1.4 % at the pessimistic scenario at high fuel price levels.

Journey #	Port A	Port B	Type	Vessel type	Commodity	% net reduction @ low fuel price	% net reduction @ average fuel price	% net reduction @ high fuel price
1	Bor district	Constanza	Dry bulk	Push 8/9	Agribulk	0.1%	0.6%	0.9%
2	Bor district	Constanza	Liquid Bulk	Push 8/9	Petroleum products	0.1%	0.6%	0.9%
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	Coal	0.0%	0.5%	0.8%
4	Giurgiu	Constanza	Dry bulk	Push 8/9	Building mat. / minerals	-0.2%	0.2%	0.5%
5	Calafat	Constanza	Dry bulk	Push 8/9	Building mat. / minerals	0.1%	0.6%	0.9%
6	Bratislava	Linz	Dry bulk	Push 4	Ores	0.1%	0.7%	1.1%
7	Calafat	Constanza	Dry bulk	Push 8/9	Agribulk	0.1%	0.6%	0.9%
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	Agribulk	0.0%	0.5%	0.8%
9	Giurgiu	Constanza	Dry bulk	Push 8/9	Agribulk	-0.2%	0.2%	0.5%
10	Giurgiu	Constanza	Dry bulk	Push 8/9	Ores	-0.2%	0.2%	0.5%

Table 23: Impact on total transport cost for representative journeys on the Danube and the pessimistic scenario

For the Danube the maximum saving is obtained for the journey 6 between Bratislava and Linz (1.1% at high fuel price) while also several other journeys (1, 2, 3, 5, 6, 7) show some cost reductions at all fuel price levels.

Optimistic Scenario:
The following tables present the Net Present Value (NPV) and Internal Rate of Return (IRR) for the various sailing areas (Rhine, Danube, Other Waterways, PAX) at the different fuel price scenarios considered. It can be seen that for almost all journeys convincing business cases, positive results, are obtained.

Rhine journeys						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
1	Rotterdam	Duisburg	Dry bulk	Push B4	11,200	€ 2,644,132	€ 5,559,485	€ 7,673,116	1586%	3329%	4593%
2	Rotterdam	Antwerp	Container	C3L/B	4,420	€ 316,688	€ 709,547	€ 994,370	242%	536%	749%
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	2,917	€ 758,303	€ 1,628,798	€ 2,259,906	591%	1263%	1751%
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	3,795	€ 766,987	€ 1,647,274	€ 2,285,482	579%	1237%	1715%
5	Rotterdam	Basel	Container	C3L/B	4,607	€ 554,475	€ 1,204,728	€ 1,676,162	420%	906%	1259%
7	Amsterdam	Antwerp	Container	C3L/B	4,420	€ 395,005	€ 872,639	€ 1,218,924	300%	658%	917%
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	4,750	€ 940,852	€ 2,008,946	€ 2,783,314	732%	1557%	2155%
10	Antwerp	Mainz	Container	MVS 135m	3,179	€ 455,107	€ 997,407	€ 1,390,574	356%	775%	1079%
12	Antwerp	Duisburg	Container	C3L/B	6,375	€ 623,865	€ 1,349,230	€ 1,875,119	472%	1014%	1408%
13	Rotterdam	Duisburg	Container	MVS 110m	2,465	€ 166,855	€ 396,692	€ 563,324	139%	323%	456%
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	1,210	€ 118,855	€ 296,595	€ 425,456	101%	246%	350%
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	2,039	€ 249,920	€ 569,670	€ 801,490	205%	462%	647%
18	Duisburg	Antwerp	General cargo	MVS 110m	2,039	€ 394,391	€ 870,526	€ 1,215,723	321%	703%	980%
22	Rotterdam	Herne	Dry Bulk	MVS 86m	1,096	€ 80,568	€ 216,533	€ 315,108	72%	186%	268%
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	2,039	€ 340,670	€ 758,654	€ 1,061,692	278%	613%	856%
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	1,237	€ 135,717	€ 331,708	€ 473,802	115%	274%	389%

Table 24: Net Present Values and Internal Rates of Return presented for the representative journeys on the Rhine and the optimistic scenario

The following table presents the results for the Danube journeys for the optmistic scenario. Also for the Danube, all business cases are convincing and positive.

Danube journeys						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
1	Bor district	Constanza	Dry bulk	Push 8/9	9,000	€ 1,015,593	€ 2,166,598	€ 3,001,076	678%	1441%	1994%
2	Bor district	Constanza	Liquid Bulk	Push 8/9	12,000	€ 1,015,593	€ 2,166,598	€ 3,001,076	678%	1441%	1994%
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	9,000	€ 903,395	€ 1,932,950	€ 2,679,378	604%	1286%	1781%
4	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ 604,753	€ 1,311,043	€ 1,823,103	406%	874%	1213%
5	Calafat	Constanza	Dry bulk	Push 8/9	9,000	€ 1,016,476	€ 2,168,436	€ 3,003,607	679%	1442%	1996%
6	Bratislava	Linz	Dry bulk	Push 4	4,400	€ 1,001,341	€ 2,135,778	€ 2,958,245	727%	1545%	2138%
7	Calafat	Constanza	Dry bulk	Push 8/9	9,000	€ 1,016,476	€ 2,168,436	€ 3,003,607	679%	1442%	1996%
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	9,000	€ 903,395	€ 1,932,950	€ 2,679,378	604%	1286%	1781%
9	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ 604,753	€ 1,311,043	€ 1,823,103	406%	874%	1213%
10	Giurgiu	Constanza	Dry bulk	Push 8/9	9,000	€ 604,753	€ 1,311,043	€ 1,823,103	406%	874%	1213%

Table 25: Net Present Values and Internal Rates of Return presented for the representative journeys on the Danube and the optimistic scenario

The next tables present the results for the Other Waterways and passenger vessels.

Journeys on Other Waterways						**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #:	Port A	Port B	Type	Vessel type	Payload (t)	NPV	NPV	NPV	IRR	IRR	IRR
7	Rotterdam	Hannover	Dry Bulk	MVS 86m	1,096	€ 91,521	€ 239,343	€ 346,514	81%	205%	294%
8	Duisburg	Wolfsburg	General goods	MVS 86m	1,096	€ 40,148	€ 132,361	€ 199,215	38%	115%	171%
16	Rotterdam	Oldenburg	Dry Bulk	MVS 80m	910	€ 24,518	€ 99,664	€ 154,145	25%	89%	135%
7	Rotterdam	Lingen	Liquid Bulk	MTS 86m	1,039	€ 74,746	€ 204,739	€ 298,983	65%	171%	247%

Table 26: Net Present Values and Internal Rates of Return presented for the representative journeys on the Other Waterways and the optimistic scenario

PAX Journeys					**Fuel: Low**	**Fuel: Med.**	**Fuel: High**	**Fuel: Low**	**Fuel: Med.**	**Fuel: High**
Journey #	Waterway	Port A	Port B	Vessel type	NPV	NPV	NPV	IRR	IRR	IRR
1	ARA/Rhine	Amsterdam	Basel	PAX 135m	€ 117,077	€ 296,637	€ 426,818	76.5%	186.5%	266.3%
3	Danube	Passau	Budapest	PAX 135m	€ 80,073	€ 219,578	€ 320,718	53.8%	139.3%	201.3%

Table 27: Net Present Values and Internal Rates of Return presented for the representative journeys with passenger vessels and the pessimistic scenario

For the journeys on the rivers Rhine and Danube, the impact on the overall costs was also calculated. This illustrates into what extent there is a reduction of transport costs per ton which could have an impact on the competitive position of inland waterway transport compared to other modes. The following table presents the results derived for the different fuel price scenarios (low, average, high).

Journey #	Port A	Port B	Type	Vessel type	Commodity	% net reduction @ low fuel price	% net reduction @ average fuel price	% net reduction @ high fuel price
1	Rotterdam	Duisburg	Dry bulk	Push B4	Ore	7.3%	11.6%	13.6%
2	Rotterdam	Antwerp	Container	C3L/B	Containers	2.3%	4.7%	6.1%
3	Rotterdam	Karlsruhe	Liquid Bulk	MTS 135m	Crude oil	3.9%	7.1%	8.9%
4	Amsterdam	Karlsruhe	Dry bulk	C3L/B	Coal	5.0%	8.7%	10.7%
5	Rotterdam	Basel	Container	C3L/B	Containers	3.8%	7.0%	8.8%
7	Amsterdam	Antwerp	Container	C3L/B	Containers	2.8%	5.5%	7.1%
9	Amsterdam	Rotterdam	Liquid Bulk	MTS 135m	Oil	4.6%	8.2%	10.0%
10	Antwerp	Mainz	Container	MVS 135m	Containers	3.7%	6.9%	8.7%
12	Antwerp	Duisburg	Container	C3L/B	Containers	4.2%	7.6%	9.4%
13	Rotterdam	Duisburg	Container	MVS 110m	Containers	2.7%	5.6%	7.2%
14	Rotterdam	Ludwigshafen	Liquid Bulk	MTS 86m	Chemicals	2.3%	5.1%	6.7%
16	Rotterdam	Strassbourg	Dry Bulk	MVS110m	Agribulk	3.8%	7.3%	9.1%
18	Duisburg	Antwerp	General cargo	MVS 110m	Metal products	5.5%	9.7%	11.7%
22	Rotterdam	Herne	Dry Bulk	MVS 86m	Metal (scrap)	1.6%	4.0%	5.4%
23	Dusseldorf	Antwerp	Dry Bulk	MVS 110m	Agribulk	4.9%	8.8%	10.8%
25	Rotterdam	Duisburg	Dry bulk	MVS 86m	Agribulk	2.6%	5.6%	7.3%

Table 28: Impact on total transport cost for representative journeys on the Rhine and the optimistic scenario

The savings on total cost can run up to 13.6 % in case of the large-scale pushed barge transport between Rotterdam and Duisburg at high fuel price levels.

Journey #	Port A	Port B	Type	Vessel type	Commodity	% net reduction @ low fuel price	% net reduction @ average fuel price	% net reduction @ high fuel price
1	Bor district	Constanza	Dry bulk	Push 8/9	Agribulk	5.2%	9.0%	10.9%
2	Bor district	Constanza	Liquid Bulk	Push 8/9	Petroleum products	5.2%	9.0%	10.9%
3	Constanza	Dunaújváros	Dry bulk	Push 8/9	Coal	4.8%	8.4%	10.3%
4	Giurgiu	Constanza	Dry bulk	Push 8/9	Building mat. / minerals	3.4%	6.3%	8.0%
5	Calafat	Constanza	Dry bulk	Push 8/9	Building mat. / minerals	5.2%	9.0%	10.9%
6	Bratislava	Linz	Dry bulk	Push 4	Ores	6.7%	10.9%	13.0%
7	Calafat	Constanza	Dry bulk	Push 8/9	Agribulk	5.2%	9.0%	10.9%
8	Constanza	Dunaújváros	Dry bulk	Push 8/9	Agribulk	4.8%	8.4%	10.3%
9	Giurgiu	Constanza	Dry bulk	Push 8/9	Agribulk	3.4%	6.3%	8.0%
10	Giurgiu	Constanza	Dry bulk	Push 8/9	Ores	3.4%	6.3%	8.0%

Table 29: Impact on total transport cost for representative journeys on the Danube and the optimistic scenario

For the Danube, the maximum saving is derived for the journey between Bratislava and Linz (13.0 % at high fuel price). This is a result of the high fuel consumption per year. It is assumed that the pushed convoy sails efficiently up- and downstream during the whole year.

6. Summary

This PROMINENT report, Deliverable 2.4, presents the ex-ante cost/benefit analyses for energy-efficient navigation. The major goal of energy-efficient navigation is to reduce the fuel consumption of a vessel while preserving or even improving the service quality of transportation. This shall result in cost savings for the ship owner/operator, as well as a reduction of climate emissions (CO2) and air-pollutant emissions such as NOx and PM. Fuel savings are expected to result from sailing at the optimal location in the fairway (causing the least resistance), as well as by means of optimising the sailing speed based on the actual conditions of the waterway.

This report presents the costs and benefits from the viewpoint of the shipowner/operator. The economic advantage for the ship owner/operator is a decisive element for the roll-out potential of energy-efficient navigation.

The work started with desk research on various costs estimations and impacts of energy-efficient navigation (notably fuel savings), based on a great number of programmes and research projects. The main sources consulted were COVADEM, MoVe IT!, IRIS EUROPE 3, NEWADA Duo, Voortvarend besparen, Econaut, Topofahrt, CREATING and The Cleanest Ship, describing different systems and tools, as well as test results derived with relevance to energy-efficient navigation.

This desk research provided however an unclear and scattered view on the costs and the estimated fuel savings. There is a large bandwidth in the cost, as well as the fuel-saving estimations. This wide uncertainty shows the need for the pilot activity to be carried out in PROMINENT, as a clear view is needed on the economic value of energy efficient navigation, taking into account differentiated costs and benefits for different types of waterways and vessels. In order to be able to calculate the costs and benefits, a scenario approach was used. The following tables present the bandwidth of values for the costs of the on-board unit and equipment, as well as the fuel consumption assumed. It is noted that the results presented are supposed to be of the correct order of magnitude. Deviations are expected, becoming clearer once the results of the pilots are known.

Costs of on-board unit and equipment	Low	Medium	High
	Ordinary echo-sounder: 10,000 EUR (COVADEM approach)	Advanced echo-sounder: 40,000 EUR (NAVROM pilot)	Sophisticated ADCP (or GNSS GPS) and advanced echo-sounder: 80,000 EURO (BAW – NEWADA DUO)

Table 30: Bandwidth in costs relating to the on-board unit and equipment

Fuel consumption savings	Low	Medium	High
	3 %	14 %	25 %

Table 31: Bandwidth in fuel-consumption savings

Three scenarios have been defined:

	Pessimistic scenario	Base-case scenario	Optimistic scenario
Investment in on-board unit and equipment	80,000 EUR	40,000 EUR	10,000 EUR
Fuel saving	3 %	14 %	25 %

Table 32: Scenario characteristics

Moreover, the time for installation of the hardware and equipment was assumed at 1 day with an average value of 2000 Euro. In addition, an annual cost of 3000 EUR was taken into account to cover variable costs for communication, maintenance, training etc.

Since the effect to be expected is a reduction of fuel consumption, the economic saving is very much dependent on the fuel price. Since the fuel price is volatile, a sensitivity analyses was carried out also for the fuel price with the following values:

Fuel price per 100 litre	Low	Medium	High
	23.65 EUR (February 2004)	49.25 EUR per 100 litre (monthly average in period January 2004 - September 2015)	67.81 EUR (July 2008)

Table 33: Fuel price settings for sensitivity analyses

The results of the calculations of the costs and benefits show that the business case is very much depending on the total fuel consumption of the vessel. The costs and benefits were calculated for the fleet families and for the representative journeys (defined in PROMINENT WP1.1), taking into account the estimations on their annual fuel consumptions.

Results base case

For the base case, the business case is positive from a fuel consumption of around 70 m^3 per year in case of high fuel prices, around 100 m^3 per year for average fuel prices and 250 m^3 per year for low fuel prices. In case of very high fuel-consumption figures such as 1000 m^3 per year, the total sum of the discounted saving (NPV) over a 15 year period can be 250,000 EUR at low fuel prices and up to 850,000 EUR at high fuel prices. Compared to an investment of 40,000 EUR, these benefits are quite remarkable. This means that each euro initial investment (40,000 EUR) will yield 21 times more money (850,000 EUR / 40,000 EUR) in case of high fuel prices over a 15 year time period and about 6 times more in case of low fuel prices (250,000 / 40,000 EUR).

Since the 110 meter dry-cargo motor vessel is considered as the “working horse” for European inland waterway transport, the following graph shows the development of the cash flow after the 40,000 EUR investment at the average fuel price of 49.25 EUR per 100 litre. The result presented is based on an estimated annual fuel consumption of 311 m^3 per year.

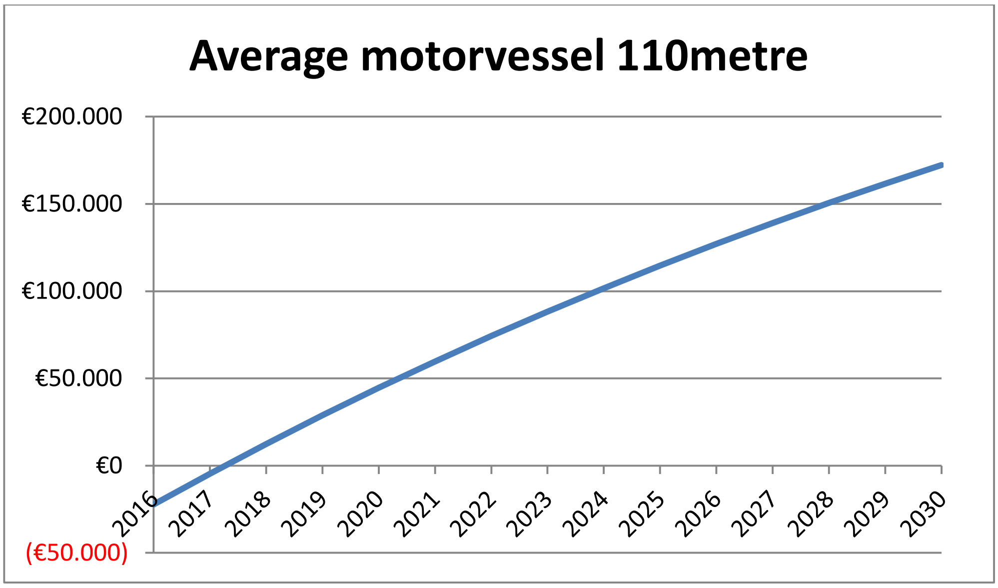

Figure 20: Development of Net Present Value (NPV) over time presented for the base-case scenario and the average fuel price considered for a 110 metre vessel. Note: e.g. 2016 means end of the year 2016

It can be seen that after an initial investment taken in the first year (end of 2015), the benefits are providing a break-even situation already after 2.5 years. The Net Present Value for this time span is 172,000 EUR and the Internal Rate of Return is 41 %. This is quite significant and positive.

Results pessimistic scenario

The CBA calculations for the pessimistic scenario illustrate that only really large vessels such as 6-barge pushed convoys have some benefit in case of average or high fuel prices due to their high fuel consumption values. Assuming the average fuel price, a break-even situation is given for vessels with a yearly fuel consumption of 800 m^3. However, it shall be reminded that the calculation takes into account the savings over a period of 15 years while the fuel price development is quite uncertain. Therefore, the risk to be taken as regards the fuel price development shall be incorporated in these investment decisions. The ship owner/operator will expect a higher Return on Investment (ROI). In general, the Internal Rate of Return shall be at least 4 %. For the pessimistic scenario, at the average fuel price a 4 % return rate is reached in case of 1000 m^3 fuel consumed per year. However, in case of high fuel prices, a gain of 4 % would be reached already at 750 m^3 fuel consumed per year.

Results optimistic scenario

For the optimistic scenario, the Net Present Value (period 2016 – 2030) is positive already starting from an annual fuel consumption of around 50 m^3. Already at this relatively low fuel consumption of 50 m^3 per year the Internal Rate of Return accepts values of 12 % and 29 % at average and high fuel prices, respectively. This means that also for smaller vessels below 86 metres that operate on daily basis the business case can be positive.

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