Sustainable, safe and economically feasible energy concepts and technologies for European Inland Shipping

D 1.2 List of best available greening technologies and concepts

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Abstract

This report was prepared within the framework of the **EU-co funded research and deployment project PROMINENT.** PROMINENT is ultimately aimed at providing **technologies and concepts** which make **inland navigation as competitive as road transport in terms of air pollutant emissions by 2020 and beyond, while keeping IWT´s advantage regarding energy consumption and carbon footprint**. PROMINENT shall produce **visible results already during project lifetime** and foster attractive business cases for the ship owner to **support technological implementation on larger scale no later than 2020.**

SWP 1.2 objectives

This report presents the findings of sub work package 1.2 and **identifies the best available technologies and concepts to raise energy efficiency and lower emissions in European inland navigation.** The assessment is based on the analysis of existing research and innovation projects, integrating the expert knowledge and networks of the PROMINENT consortium and the input of key stakeholders. The report also takes up the results of SWP 1.1, which identified the main European fleet families, and evaluates the technologies regarding their effects on those fleet families by means of "Technology Fact Sheets".

Based on the following criteria, the best available technologies have been selected and assessed:

- **Effects on energy consumption and emissions**: proven emission reduction of CO2 and CH4 (climate change emissions) and/or NOx and PM (air pollutant emissions)

  As regards targets to be achieved with respect to the emission reduction of NOx and PM, 3 different options are distinguished based on expert views and discussions. They are aiming at:

  - NOx levels of maximum 1.8 gram per kWh and no increase of PM
  - NOx levels of maximum 1.8 gram per kWh and PM maximum 0.045 gram per kWh
  - NOx levels of maximum 1.8 gram per kWh and PM maximum 0.015 gram per kWh. Additionally, a Particle Number (PN) below $1x10^{12}$ per kWh

- **Economic feasibility**: attractiveness for the ship owner has been investigated (business cases)
- **Technical feasibility**: impact from the technical side for the main European fleet families and operational profiles identified in SWP 1.1.
- **Technological maturity**: at least Technology Readiness Level 5 should be available in order to integrate the technology or concept in the envisaged roll-out plan towards 2020 (WP6)
- **Non-technological maturity**: financial and regulatory barriers to implementation of the PROMINENT results until 2020 have been assessed. The basis for developing measures to overcome barriers was outlined for further use in SWP 1.3 and WP6.

These criteria will be used as a yardstick in the further PROMINENT project to validate the technologies via on board measurements. Subsequently, this allows making statements on their applicability, the involved costs and investments, as well as the required financial and legal support in the roll-out plan for the European fleet (WP6 of PROMINENT).

SWP 1.2 results

Due to the topical focus of PROMINENT on **fuels, propulsion systems** (standardised solutions), **auxiliary systems** and **ship-operational measures** and after the criteria above were applied, the following measures have been selected from a long list of promising technologies to a **short list to be further analysed within PROMINENT**. Some of the measures identified focus primarily on reduction of energy consumption and CO2 while others are focussed specifically on the reduction of pollutant emissions:

Focussed on pollutant reduction:

- **LNG** as fuel in single or dual-fuel engines
- Installation of an **SCR diesel after-treatment system** and/or **diesel particulates filter**
- **GTL** (synthetic diesel made from natural gas) as fuel
- **Installation of new engines** complying with CCNR II or the future Stage V

Focussed on CO2 reduction:

- **Support tool for energy efficient navigation** with speed and/or track advice
- **Diesel hybrid propulsion**
- **Right engine size** (install a smaller engine)

The results of SWP 1.2 provide the **basis for the elaboration of the pilot tests** in the following PROMINENT work packages as well as the **roll-out plan** in WP6. The most promising technologies shall be tested for situations that are most common and representative for the inland waterway transport market.

In general, it can be concluded that:

- LNG as fuel is mainly an opportunity for large vessels that have a lot of fuel consumption per year. In that case the high investment costs of the LNG tank and fuel system can be earned back in savings in fuel costs. Although these vessels have a relatively big share in the emissions of IWT in Europe, the number of vessels suitable for LNG is relatively limited. Moreover, investing in a 100% LNG engine is risky because of the current uncertainty on the price gap between LNG and Diesel. The dual fuel engine is more likely to be selected by ship-owners. Therefore, the efforts to reduce costs by means of standardisation shall be combined with the dual fuel engine and needs to be validated in the pilot.

- SCR/DPF is mainly a cost-effective solution to reduce NOx and/or PM emissions for all vessels, and is attractive for environmentally conscious clients and/or in sensitive environments (e.g. urban areas). However, cost for periodic maintenance (once a year or more) are high, in particular for the DPF. Additional incentives are needed to increase the acceptance among ship-owners. In the meantime, also efforts shall aim at cost reductions by means of standardisations and development of modular systems.

- Energy efficient navigation is considered as a promising technology, in particular if the vessel makes a lot of sailing hours such as push boats and large motor vessels, and it is manoeuvring on free flowing sections with dynamic waterway conditions (strongly influencing fuel consumption). The payback time of investing in equipment will strongly depend on the fuel consumption savings.

- The economic value of hybrid drivetrains and right sizing are very much depending on the specific journey and the related operating profile. These technologies are more seen as niche solutions rather than large scale applications. Furthermore, they are found to have little effect on air pollutant emissions.

- Other technologies such as GTL and replacement with new CCNR II engines can have an additional benefit to reduce emissions, but are not stand-alone solutions to bring down the emission levels to one of the three target options defined in PROMINENT. However, it may still be a cost effective solution in terms of costs per kg of pollutant reduction. It can also be used in combination with other technologies and by this achieve one of the three target levels. This should be further investigated.

The **LNG, SCR, DPF and energy efficiency navigation technologies** will get the main attention in the further process. This is consistent with their identification already in the pre-project phase as being key technologies.

The remaining technologies assessed as particularly promising in this activity – **installation of new engines**, r**ight sizing** and **hybrid concepts -** will be assessed by measurements on existing conventional and hybrid ships (and consequent simulations). For **GTL**, monitoring results of vessels that are already sailing with this fuel, will be taken into account in order to validate the achievement of emission levels.

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1. Background

This report was prepared within the framework of the EU-co funded research and deployment project PROMINENT. PROMINENT is ultimately aimed at providing solutions which make inland navigation as competitive as road transport in terms of air pollutant emissions by 2020 and beyond. In parallel, PROMINENT aims to further decrease the energy consumption and carbon footprint of inland waterway transport (IWT), an area where IWT has already a strong advantage compared to road transport. PROMINENT aims at producing visible and physical results already during its project lifetime as well as on larger scale no later than 2020.

Beyond state-of-the-art
The requirements of the planned development work are defined by the following challenging design and engineering targets which go beyond the state-of-the-art:

- Develop solutions that are **applicable to at least 70% of the European inland fleet** (measures in share of fuel consumption) **and their operating areas**, including retrofit solutions
- Reduce **implementation costs of innovative greening solutions by 30%,** compared with the ones of 2015.
- Produce **results on the ground during the project lifetime (2017)** and provide a roll-out plan for implementation of project results by 2020.

2. Objective and method of this activity

This report will **identify** greening technologies and concepts that are most promising:

- ➔ regarding their impact on greening (higher energy efficiency and lower emissions)
- ➔ regarding their applicability on the European inland fleet (technical, financial and organisational)

The assessment is based on the analysis of existing research and innovation projects, integrating the expert knowledge and networks of the PROMINENT consortium and the input of key stakeholders (see “Stakeholder integration” on the following page).

Regarding the second assessment criterion (Range of applicability, i.e. impact), a match was made between main ship types in operation on the European waterways and their navigational profiles (number of trips, power demand, fuel consumption, stream velocities, etc.), which have been identified in SWP 1.1 of PROMINENT:

The following steps have been taken in SWP 1.2:

1) Desk research on the state-of-the-art of greening technologies and concepts starting with the PLATINA 2 – Research and Innovation Roadmap (DST et al., 2015) and PLATINA 2 Greening Toolkit[1]
2) Identification of additional promising technologies: specific inputs by PROMINENT partners and consultation of stakeholders (e.g. Innovation Lab partners of EICB)
3) Compilation of a long list of greening technologies and concepts including a rough state-of-the-art analysis
4) Specification of selection and assessment criteria oriented on PROMINENT objectives
    - Effects on energy consumption and emissions
    - Range of impact seen from economic feasibility for the ship owner
    - Range of impact seen from technical feasibility for the majority of the European inland fleet
    - Availability for mass implementation (technological and non-technological maturity)
    - Topical focus of PROMINENT: ship technological and ship operational measures
5) Selection of a short list of best available technologies and concepts according to the criteria defined above
6) “Technology fact sheets”: Assessment of the short listed technologies and concepts along detailed criteria, taking the main European fleet families and their operational profiles into account, if applicable (link to the results of SWP 1.1)
7) Development of an overview matrix of the best available technologies and qualitative assessment
8) Outline of next steps towards further activities in the following work packages of PROMINENT

Based on the expertise of the PROMINENT consortium, four approaches have been pre-selected for in-depth analysis in the project as they have already been assessed to be particularly promising: LNG (Liquefied Natural Gas) as alternative fuel, modular diesel after treatment systems (selective catalytic reduction (SCR) and Diesel particulate filters (DPF)), energy efficient navigation support systems as well as model development for right sizing and hybrid propulsion systems.
Furthermore, besides the actual greening technologies applied on the vessels, also technologies to monitor emissions play a major role in the process. Effective on-board monitoring is a prerequisite

[1] http://greeningtool.naiades.info/web/

for ship and fleet optimization and proof of environmental performance. As options for (improved) certification for new engines and engines with retrofit emission control systems will be assessed in PROMINENT as well. The state-of-the-art assessment of this technology is undertaken in WP3. However, PROMINENT also keeps its view open beyond the preselected topics towards further greening technologies and concepts. Such additional promising technologies will be identified in this report and further elaborated in the project, particularly in WP6.

Stakeholder integration

Several ways were used to integrate the perspective of the various relevant stakeholder groups in the analysis done in this Sub work package. The main tools are described below:

- The PLATINA 2 Research and Innovation Roadmap (DST et al. 2015), a starting point of the analysis, was based on outreach to the relevant stakeholders: three workshops with key experts and stakeholders took place on national level in the beginning of 2015 in The Netherlands, Germany and France.
- The PROMINENT team had access to the expertise of 20 leading industrial companies that are active the “Innovation Lab” coordinated by the PROMINENT partner EICB.
- Another key reference for SWP 1.2 is the study “Contribution to impact assessment of measures for reducing emissions of inland navigation” (Panteia 2013) for which a European Common Expert Group including representatives from organisations such as EBU, ESO, EC, ESC, EUROMOT and AECC met in Brussel 5 times for discussions.
- Particularly as regards LNG, the discussions of the roundtable meetings within the framework of the TEN-T LNG Masterplan project for the Rhine-Main-Danube axis have been taken into account, where all stakeholder groups relevant for LNG implementation participated.
- The PROMINENT project partners Wartsila and Multronic are among the leading suppliers of LNG technologies and SCR / DPF after treatment systems and have provided direct contributions and validation from the manufacturer`s side.
- Direct input from the end users was provided by the project partner NAVROM (Romanian River Navigation Company) who operates a large fleet of pushboats and barges on the Danube as well as Viking River Cruises, a passenger vessels operator.
- The programme “VoortVarend Besparen” by the Dutch Government was a major source of information for the topic of energy efficient navigation. Within this programme, potential users of the system were integrated via a series of round table meetings and a “energy saving competition”.
- The flagship project “Innovative Danube vessel” was regularly discussed on broad scale in public working group meetings within the Danube Region Strategy.

3. Greening technologies and concepts for inland vessels: state-of-the-art and promising technologies

In this chapter, the screening analysis of state-of-the-art greening technologies and concepts will be presented. Based on the PLATINA 2 Research and Innovation Roadmap and PLATINA 2 Greening Toolkit, additional analysis of the PROMINENT consortium and assessment by further key stakeholders, a longlist of technologies and their key characteristics was elaborated. Specific selection criteria [2] (see below) were applied to select a short list of particularly promising technologies. This short list will be used as basis for analysis of the best available technologies for the European inland fleet in chapter 4.

3.1 Selection criteria

Criterion 1: Effects on energy consumption and emissions

This criterion considers the expected maximum degree of emission reduction (in % of the current value)[3]. In most cases, this relates to a reduction of the fuel consumption and hence, a reduction of all emissions[4]. In some cases, the reduction potential relates to air pollutants (NOx or PM); these cases are marked in the list.
Technologies reaching less than 5 % emission reduction in favourable conditions will not be selected to the short list of particularly promising technologies.
As in reality the average value might be lower than in most favourable conditions, this >5% filter is needed to make sure that significant emission reductions are met in regular conditions (5% under favourable conditions might only be 1 % or 0% under regular conditions).
Reduction of fuel consumption does no only result in reduced emissions but also in reduced cost. This is an important aspect to consider, as it contributes to a return on investment for the ship owner/operator and therefore increases the attractiveness for take-up by the market and roll-out of the technology.

Criterion 2: Range of impact

Criterion 2a: Range of impact seen from economic feasibility for the ship owner
This criterion relates to the payback period (in years)[5]. Payback periods between 1 and 5 years are considered as highly feasible (green bullet), periods from 6 till 10 years as still favourable (yellow bullet) and those above 10 years as a non-viable option (red bullet). For measures analysed in the Move It guidelines, this evaluation is available, for others not.

Criterion 2b: Range of impact seen from technical feasibility

[2] These criteria are based on the PLATINA 2 Research and Innovation Roadmap (DST et al. 2015)
[3] Based mainly on viadonau et al. 2013: "Technical support for an impact assessment on greening the inland fleet" report within the FP7 project PLATINA I
[4] The indicated figures refer to certain individual cases and hence depend on the corresponding particular circumstances. Since they describe the maximum emission reduction, lower figures are also possible under less favorable conditions. Further it has to be considered, that a simple summing up of the reduction figures in case of a combination of different measures is not possible;
[5] In line with the results of the FP7 research project 'Move It' ()

It needs to be assessed if a measure can be applied on large scale or if it is rather considered as specific solution for a particular case. Accordingly, this criterion evaluates the 'applicability on the share of the fleet' as follows[6]:

1: >50% (indicated with green bullet)

2: 10-50% (indicated with yellow bullet)

3: <10% (indicated with red bullet)

Technologies that are applicable to less than 10% of the European inland fleet will not be selected to the short list of particularly promising technologies.

Criterion 3: Availability for mass implementation

Criterion 3a: Technological Maturity

For this classification, the 'Technology Readiness Levels' used in the EU Research and Innovation program Horizon 2020 are applied as follows (leading to 9 technology readiness levels):

1 - Basic research
2 - Technology formulation
3 - Experimental proof of concept
4 - Validation: Small scale prototype / in lab
5 - Validation: large scale prototype / in relevant environment
6 - Demo in relevant environment
7 - Demo / system prototype in operational environment
8 - System complete and qualified
9 - Full commercial application[7]
Technologies in stage 8 and 9 are more or less ready for commercial application and can be implemented on the market. However, there might be the need for regulatory or financial support (e.g. subsidies, see next criterion).
Technologies in state 5 to 7 still need some additional R&D in order to achieve technological maturity (and market readiness)
Technologies in stage 1 to 4 are in a rather initial stage and need basic R&D.

Technologies reaching only a TRL level of 4 or lower will not be selected to the short list of particularly promising technologies.

The PROMINENT project focuses on technologies that can be ready for mass introduction by the year 2020 (=TRL level 9) and a pilot project by 2017 the latest (=TRL 7). Limited time is available for extensive R&D work. Therefore, only technologies are considered that currently have a TRL level of 5 or higher in order to qualify for further development and roll-out in PROMINENT. This implicates that technologies that still require basic R&D are excluded from the selected technologies and concepts.

[6] This first assessment is not yet related to the results of SWP 1.1 (i.e. does not yet take the main fleet families and operational profiles into account)

[7] In this last step 9, it is important to note that for greening tools full commercial application strongly relates to prices resulting from serial production and further standardisation (e.g. LNG, SCR, DPF systems). Current tailor-made installed LNG, SCR, DPF systems in vessels do not comply with this condition.

Criterion 3b: Non-technical maturity and other hindrances

This criterion gives attention to the following cases:

1. Regulatory or financial support needed (indicated with blue background)
2. Overcapacity (indicated with red background)

Ad 1) Besides pure technical and research related criteria, also the non-technological maturity needs to be considered as some measures are facing significant further barriers for general market implementation. This relates to e.g. high costs due to lack of standardisation and low demand from the market. So, complementary to corresponding research, additional support (e.g. in terms of dedicated subsidies and/or fiscal incentives, improved legal framework conditions) is needed.

Ad 2) Furthermore, some measures concern an increase of the transport capacity, i.e. a scale enlargement of vessels and (e.g. building of new large vessels, barges and convoys or lengthening of vessels). As there is an existing overcapacity in the segment of large vessels in the European inland navigation market (CCNR 2014), more than sufficient vessels of this type are already available to serve the clients to accommodate the expected freight flows towards the year 2020. As a result, this type of measures is discarded from further analysis in PROMINENT.

Technologies that would add transport capacity (more overcapacity) on the market will not be selected to the short list of particularly promising technologies.

3.2 Long list of promising technologies

On the following pages, a long list of technologies and concepts is presented that show potential to improve the environmental performance of inland navigation. The basis of this long list is the PLATINA 2 Research and Innovation Roadmap[8]. If deemed necessary, the PROMINENT experts adapted values and added further technologies (marked x in the last column), according to their latest knowledge.
The criteria described in the previous chapter will be applied in order to select a short list of promising technologies that will be taken up for further analysis in PROMINENT. The longlist and the assessment by the PROMINENT experts are presented on the following three pages.

[8] Please note that for some measures and certain criteria an assessment is not available or not applicable and that there are overlaps between certain measures.

Type of measure	Area	Measure	Criterion 1: Emission reduction potential (max. %) (not cumulative)	Criterion 2a: Applicability on share of the European fleet 1: > 50% 2: 10-50% 3: <10%	Criterion 2b: Economic potential payback period (years)	Criterion 3a: Technological Maturity (TRL) 1: basic R&D needed till 9: full commercial application	Criterion 3b: Non-technical Maturity & other hindrances exclusion if overcapacity	Technology added by PROMINENT (marked x)
Infrastructure	Ports & mooring places	Shore side power	5%	1	n.a.	5	reg. & fin.support	
		Optimisation of locking procedure/ traffic mgt.	5%	1	n.a.	6		
	Waterway information	Better pred. of av. water depth (c.f. load factor)	10%	1	n.a.	4		
		Electronic ECDIS charts with actual depth information	5%	1	n.a.	7		
		Real time info on fairw. data (link to energy.eff.nav.)	10%	1	n.a.	5		
	Waterway Infrastructure	Improve fairway conditions (upgrading)	65%	1	n.a.	9		
		Technologies for waterway maintenance	n.a.	1	n.a.	4		
Ship-related technical measures	Fleet structure	Use larger vessel units	75%	2	n.a.	9	overcapacity	
		Use more coupled convoys	20%	2	7	9	overcapacity	
		Lengthening (+25%; Europe type vessel) + nozzle	15%	2	2	9	overcapacity	
		Lengthening (+10%; smaller than Europe type vessel)	5%	2	26	9	overcapacity	
	Fuels, standardised solutions	Use LNG (Liquefied Natural Gas) (PM reduction)	90%	2	n.a.	6	reg. & fin.support	
		Apply dual fuel (LNG and diesel) (PM reduction)	90%	1	n.a.	6	reg. & fin.support	
		Apply GTL fuel (PM reduction)	60%	1	n.a.	9	reg. & fin.support	x
		Apply CNG (PM reduction)	95%	3	n.a.	5	reg. & fin.support	x
		Apply Methanol (PM Reduction)	95%	1	n.a.	3	reg. & fin.support	x
		Use hydrogen / fuel cells	100%	1	n.a.	2	reg. & fin.support	
	Propulsion system, standardised solutions	Right sizing	10%	1	n.a.	9		x
		ReDeNox (NOx reduction)	95%	1	n.a.	4	fin.support	x
		NoNox Engine air control by addional valve per cilinder in inlet manifold)	50%	1	n.a.	3	reg. & fin.support	x
		Use waste heat energy recovery (from exhaust gas, by Rankine cycle)	5%	2	25	4		
		Apply SCR (selective catalytic reduction) (NOx red.)	90%	1	n.a.	8	reg. & fin.support	
		Use emulsified fuels (PM reduction)	20%	3	6	7	reg. & fin.support	
		Hydrogen injection (NOx, CxHy)	0%	1	n.a.	4		x
		Apply diesel particulate filters (PM reduction) Wall flow DPF	90%	2	n.a.	7	reg. & fin.support	
		Partial flow DPF	70%	n.a.	n.a.	n.a.	reg. & fin.support	x
		Combine SCR and DPF (Nox+PM reduction)	90%	1	n.a.	7	reg. & fin.support	
		Exchange of main diesel engine (red. of NOx & PM)	90%	1	4	9		x
		Overhaul of existing engines	10%	1	n.a.	9		x
		Diesel-electric prop. (truck engines; no buffer batt.)	10%	2	n.a.	7	fin.support	
		Hybrid prop. (diesel [or gas]-electric + buffer batt.)	10%	1	n.a.	9	fin.support	x

Type of measure	Area	Measure	Criterion 1: Emission reduction potential (max. %) (not cumulative)	Criterion 2a: Applicability on share of the European fleet 1: > 50% 2: 10-50% 3: <10%	Criterion 2b: Economic potential payback period (years)	Criterion 3a: Technological Maturity (TRL) 1: basic R&D needed till 9: full commercial application	Criterion 3b: Non-technical Maturity & other hindrances exclusion if overcapacity	Technology added by PROMINENT (marked x)
Ship-related technical measures	Propulsion system, propeller	Improved propeller systems	30%	3	5	9		
		Pre Swirl stator	5%	3	n.a.	5		
		Improved wake field	5%	1	n.a.	7		
		Pump propeller	10%	2	6	8		x
		Applying nozzle	25%	2	n.a.	8		
		Propelling bow thruster	0%	3	n.a.	8		
		Multiple propeller propulsion	10%	2	n.a.	4		
	Hydro-dynamics	Apply air lubrication	10%	2	n.a.	6		
		Apply wake field separation plate	25%	3	n.a.	8		
		Apply adjustable tunnel apron	10%	2	4	6		
		Apply coupling point optimisation	20%	2	5	7		
		Optimise hull dimension and form	15%	3	n.a.	8		
		Nozzle strut removal	5%	2	11	8		
		Remove flanking rudders	5%	3	4	8		
		Alternative rudder concepts	5%	2	25	7		
		Improved aft-ship gondolas	3%	3	25	7		
		Coatings	0%	1	n.a.	9		
		Bow thruster valve	5%	3	n.a.	7		
		Adjustable bulbous bow	0%	3	n.a.	3		
		Optimise trim and heel	5%	1	n.a.	8		
	Ship structures & weight	ADN double steel hull	0%	3	7	9		
		λ-shaped steel double hull	0%	3	8	8		
		Steel-Foam-Steel double hull	0%	3	10	4		
		Lengthening with composite mat. (instead of steel)	1%	2	5	3	overcapacity	
		Reduce vessel weight	5%	3	n.a.	4		

Type of measure	Area	Measure	Criterion 1: Emission reduction potential (max. %) (not cumulative)	Criterion 2a: Applicability on share of the European fleet 1: > 50% 2: 10-50% 3: <10%	Criterion 2b: Economic potential payback period (years)	Criterion 3a: Technological Maturity (TRL) 1: basic R&D needed till 9: full commercial application	Criterion 3b: Non-technical Maturity & other hindrances exclusion if overcapacity	Technology added by PROMINENT (marked x)
Ship-operational	Sailing behaviour	Smart and energy-eff.nav. (speed adaption)	10%	1	n.a.	5		
		Automation	10%	1	n.a.	1		x
		Smart and energy-eff.nav. (optimised track choice)	5%	1	n.a.	5		
	Maintenance	Clean underwater bodies/ hull/ ballast/ bilges	5%	3	n.a.	8		
		Clean and undamaged propellers	10%	3	n.a.	9		
		Engine system condition monitoring	n.a.	1	n.a.	8		x
Education & Qualification		Mobile Learning	0%	1	n.a.	5		
		Integration of IWT into logistics education	n.a.	1	n.a.	5		
		Simulator training (related to energy eff. nav.)	10%	1	n.a.	5		
Logistics		Organise downstream navigation in formations	10%	3	n.a.	n.a.		
		Best practices in collaboration (e.g. hub & spoke)	15%	2	n.a.	9		
		Gain sharing models (increased payload)	15%	2	n.a.	8		
		Collaborative planning (red. of empty km)	15%	2	n.a.	9		
		Info exch.syst. betw. operators (red. of empty km)	5%	3	n.a.	8		
		Innov. transhipm. & transp. systems & load units	10%	3	n.a.	2		
		New log. concepts incl. vessels & ports (Q-barge)	10%	2	n.a.	4		

Table 1 PROMINENT long list of promising technologies

Technologies marked **blue** in the longlist are selected due to reaching the thresholds defined by PROMINENT and will be further elaborated in the project ("Short list of promising technologies" in chapter 3.3 and the related "Description of Best Available Technologies" in chapter 0).

Technologies marked **grey** in the longlist also reach the threshold of the criteria. However, they will not be further elaborated within PROMINENT, as they **are not within the focus of the project** (see following pages).

Measures excluded from further analysis:

Technologies marked **grey** in the longlist also reach the threshold of the criteria. However, they will not be further elaborated within PROMINENT, as they **are not within the focus of the project**, which is set on:

- Fuels
- Propulsion systems, standardised solutions (as listed in Table 1)
- Ship-operational measures

This results in the exclusion of the following technologies and concepts from further analysis:

- Waterway infrastructure-related:
    - **Improving fairway conditions** (upgrading)

- Logistic improvements:
    - **Improved collaboration** (e.g. hub and spoke, collaborative planning to reduce empty kilometres)
    - **Gain sharing models** (increased payloads)

- Propulsion systems, propeller
    - **Pump propeller**
    - **Nozzle**

- Hydrodynamic measures:
    - **Air lubrication**
    - **Adjustable tunnel apron**
    - **Coupling point optimisation**

- **Simulator training** will be dealt with in Work Package 4

Fuel water emulsion and **H2 injection on diesel engines** have been promoted for, among others, road vehicles in the past years. The PROMINENT experts however assessed them as not qualifying for further analysis within PROMINENT:

- **Fuel Water Emulsion**

FWE has also been promoted for road vehicles and mobile machinery during the past decades. The share of water in diesel fuel usually ranged from 10% to 20%. NOx reduction was usually moderate (10-30%) (Lukas & Wagenmaker, 2014). PM reduction was quite dependent on the engine type (0 – 50% or even higher with high water shares of 25% or 40%). It should be noted that the fuel injection settings should be changed, or even replaced, otherwise the power output will be reduced proportionally to the water percentage. Engine manufacturers are usually against the use of FWE and wave engine warranty, especially with respect to fuel injection equipment. This, in combination with the relatively poor emission reduction (not able to reach the target emission levels) and the low costs-effectiveness, leads to the conclusion that the market share will be much lower than minimum 10% needed for the short list. There is at the moment only one supplier (Exomission) that develops and installs the technology for inland navigation.

- **H2 injection on diesel engines**

H2 injection in the inlet manifold of diesel engines has been promoted for road vehicles and ships for the past years. There were no measurement reports available which proof any emission reduction. Several reports available show no reduction or contradictory results (probably due to changed engine or ambient conditions). Also no scientific sound explanation is available for a possible emission reduction. With diesel engines, the combustion process and parameters are primarily determined by the injection timing, duration and rate shape. Small amounts of hydrogen injected in the inlet air do not significantly change the combustion parameters and heat release. Consequently no effect on NOx, PM or CO2 is expected (Wetzels & van Rijn 2015).

- **Engine overhaul**

Furthermore, the PROMINENT experts assessed engine overhaul (although reaching the threshold) as not qualifying for further specific analysis within the project. This technology is commonly used to repair a damaged engine or engine parts and for this already used on a regular basis. Although it could result in reduction of air pollutant emissions by the engine, it can be considered as a necessary activity being carried out anyhow already today. For this reason, engine overhaul will not be further elaborated.

3.3 Short list of promising technologies

As a result of the filter applied in the previous chapter, the following technologies have been selected for further analysis in PROMINENT. Some of the measures focus on reduction of energy consumption and CO2 while others are focussed on the reduction of pollutant emissions.

Focussed on pollutant reduction:

- **LNG** as fuel in single or dual-fuel engines
- **GTL** (synthetic diesel made from natural gas) as fuel
- Installation of an **SCR diesel after-treatment system** and/or **diesel particulates filter**
- **Installation of new engines** complying with CCNR II or the future Stage V

Focussed on CO2 reduction:

- **Support tool for energy efficient navigation** with speed and/or track advice
- **Diesel hybrid propulsion**
- **Right engine size** (install a smaller engine)

Measures which lead to a reduction in energy consumption and CO2 would likely show a proportional pollutants reduction (although small compared to the specific pollutant reduction measures). Pollutant reduction measures can have a small effect on CO2, either negative or positive and quite dependent on boundary conditions and calculation method.

The support tool for energy efficient navigation is in fact a concept of several technologies which will be taken into account in the light of their potential for combination:

- Real-time waterway information (a waterway information – related measure)
- Advice on speed adaption
- Advice on track choice

As PROMINENT aims to produce physical results already during project lifetime, preparations for **pilot tests** have already been started in the proposal phase. These pilots in WP5 of PROMINENT will focus on the real world testing and validation of technologies. The designs of the technologies are being standardised to reduce the investment costs. The technologies which have proven the highest potential to meet the objectives of PROMINENT are:

- LNG (dual fuel)
- SCR diesel after-treatment system and/or diesel particulates filter (wall flow)
- Support tool for energy efficient navigation

PROMINENT also pays specific attention to hybrid drivetrains and right sizing of the engine. The feasibility of technologies as seen from a business economic perspective is very much case specific as it is strongly related to the operational profile and the type of waterways. Therefore, the following technologies will be included in the model developments in WP3.

- Diesel hybrid propulsion
- Right sizing

The following technologies have not been pre-selected for pilot development, but have shown potential due to the analysis done in SWP 1.2. They are mainly already mature technologies (TRL 9) but show uncertainties on their real world impact on reductions of energy consumption and emissions. Furthermore, they were not assessed to qualify as “stand-alone” technology, but show potential to reach significant emission reduction in combination with other technical options (e.g. after-treatment). The added value can therefore be investigated and validated in PROMINENT by integrating it in the pilots regarding on board measurements to be executed in WP5.

- GTL fuels (“Gas to liquid”)

  This fuel type has shown potential to reduce NOx and PM. However, more measurements are needed to proof this potential.

- Installation of new diesel engines (CCNR II)

In the near future, engine manufacturers are expected to offer new engines complying with the upcoming Stage V Non Road Mobile Machinery Directive[9], i.e. having strongly reduced NOx and PM emissions. However, the development of such engines will depend on the final limit values of

[9] EU Council Proposal, 30 June 2015:
http://www.europarl.europa.eu/oeil/popups/ficheprocedure.do?lang=en&reference=2014/0268(COD)

the directive and engine manufacturers are reluctant to develop new Stage V engines for inland vessels specifically before a formal decision on limit values is made.

The basic technologies that are expected to be applied on these Stage V engines are SCR, DPF or LNG, which are already in the focus of PROMINENT. Therefore, PROMINENT will limit its analysis to the “installation of new CCNR II engines”, which can have a big impact on reduction of NOx and PM emissions as well, if replacing a CCNR 1 or older engine (see figures 1 and 2). However, as soon as the Stage V legislation comes into force (expected by 2019/2020), it will not be possible anymore to install a CCNR II engine in a vessel.

4. Best available greening technologies and concepts for the European inland fleet

In this chapter, the best available greening technologies and concepts for the European inland fleet are identified and described based on the selection process in the previous chapter. Key characteristics of the technologies will be assessed, taking the main European fleet families - those having a major share in ton kilometre performance - into account. An overview and qualitative ranking of the technologies concerning the key characteristics will be given at the end of this report as basis for further elaboration of technologies in the project.

4.1. Targets

PROMINENT shall result in improved environmental performance and more competitive IWT services.

Emission limits

New technological solutions are to be developed and deployed to achieve emission levels in IWT that reflect the state of the art and are at least similar to those of road transport.

Most attention is paid to the NOx and PM emission from the propulsion system. For inland waterway vessels, the current legislation (CCNR Stage II and EU NRMM Stage IIIA) specifies the limit values for new engines installed in inland waterway vessels. The PM emissions for the propulsion engines (> 130 kW power) shall be lower than 200 milligram per kWh in the test cycle. For NOx the limit value of the CCNR Stage II standard is more complex and depends on the maximum revolutions per minute (RPM)[10] of the engine and, for NRMM Stage IIIA, also depending on the displacement.

Engine size	Carbon monoxide	Hydrocarbons	Nitrogen oxides	Particulate matter
Engine brake power	(CO)	(HC)	NOx	PM
P_B [kW]	[gram/kWh]	[gram/kWh]	[gram/kWh]	[gram/kWh]
$18 \leq P_B < 37$	5.5	1.5	8.0	0.8
$37 \leq P_B < 75$	5.0	1.3	7.0	0.4
$75 \leq P_B < 130$	5.0	1.0	6.0	0.3
$130 \leq P_B < 560$	3.5	1.0	6.0	0.2
$P_B \geq 560$	3.5	1.0	if $RPM \geq 3150 = 6.0$ if $343 \leq RPM < 3150 = 45 \times RPM^{(-0.2)} - 3$ if $RPM < 343 = 11.0$	0.2

Table 2 Emission limits for CCNR Stage II

[10] RPM = engine speed in number of revolutions (n) per minute

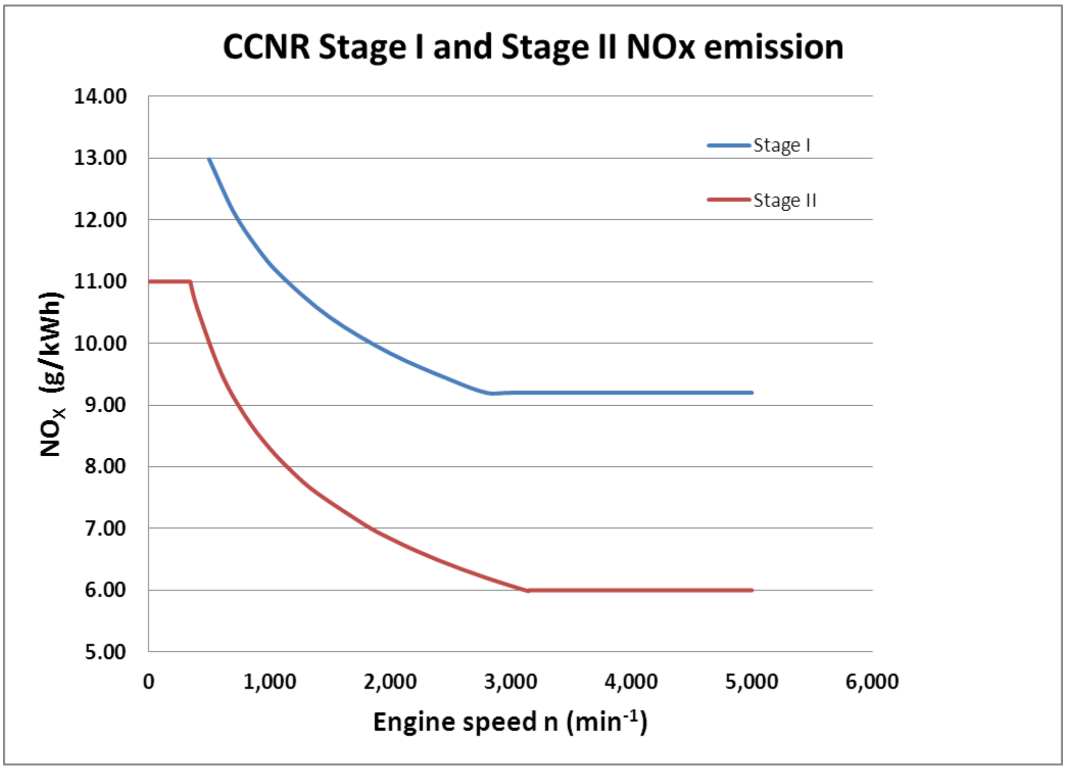

Figure 1: NOx limits for Stage I and Stage II of CCNR depending on RPM (engine speed)

However, there is a huge gap with regard to the current state-of-the-art compared to the emission limits for engines in road haulage as regards NOx and PM. This is made visible in the following figure, indicating also the date when the legislation came into force. It can be concluded that IWT is running far behind road transport concerning emission legislation.

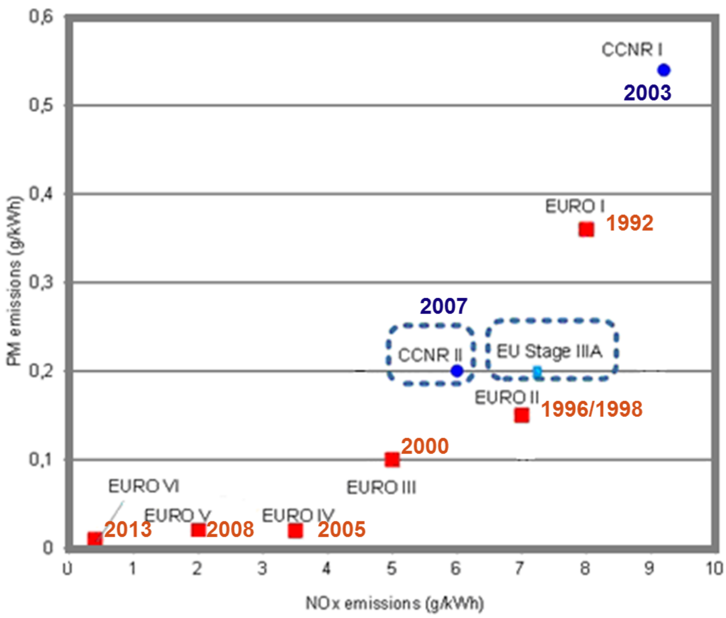

Figure 1: Comparison of emission limits
(source: Panteia et al. 2013)

The comparison with a new engine in road haulage (Euro VI) between the emission limits according to the official test cycles leads to the conclusion that the limit values applied in IWT (CCNR Stage II) are approximately 15 times higher as regards gram NOx per kWh and 20 times higher as regards emission of PM. Although inland waterway transport has a much better fuel efficiency in terms of the amount of energy required to transport 1000 tons of goods, this gap in emission limit values leads to the conclusion that IWT is losing quickly on its environmental performance compared to road haulage. Even if the emissions are expressed in gram per ton kilometre, a new Euro VI truck can perform better than an inland waterway vessel with a stage II CCNR engine. Therefore, in order to close this gap and to reinforce the policy to promote inland waterways, there is a discussion ongoing already since 2008 on the revision of the legislation, the so called Stage V Non-Road Mobile Machinery Directive. More stringent (future) emission standards for new engines will require reductions of NOx and PM emissions between 60 and 90%, depending on the outcome of the political discussion between European Commission, EU Member States, European Ministers of Transport and the European Parliament.

In addition, since the number of installed engines per year is limited, also the existing fleet (legacy fleet) shall be targeted in order to ensure results on short term. Input from the side of PROMINENT is expected to provide information on the emission levels that can be expected as a result of promising retrofitting technologies.

In terms of CO2 emissions, inland waterway transport already has a very favourable performance compared to road haulage, but further reductions are possible.

PROMINENT therefore aims to support the massive implementation of innovative greening solutions in inland waterway transport in order to improve environmental performance. Furthermore, the economic dimension of the technologies need to be considered as well: in order to further develop IWT as a cost attractive transport solution on the one hand and in order to identify solutions that are attractive business cases from the perspective of the ship owner on the other (e.g. cost savings through less fuel consumption or reduction of port dues). Only through this, the measures will be taken up by the market.

Emission Reduction

Since the outcome of the revision of the NRMM Directive is still uncertain, the PROMINENT consortium defines a number of possible (voluntary) emission standards in order to analyse the spectrum of favourable technologies and combinations of technologies. Moreover, the emission standards for PROMINENT shall mainly aim at the EXISTING vessels, and therefore focus on standards applicable by means of retrofitting technologies.

The following table presents the three selected options to take into account for the targets regarding NOx and PM. These targets shall also be discussed with CESNI[11].

[11] Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure - CESNI , http://www.ccr-zkr.org/10110000-en.html

Proposal limit values to be used for PROMINENT retrofit scenarios:

No	Emission limits In gram per kWh	Reference	Diesel / Emission control technologies assumed: (or PROMINENT target)
1	NO_x < 1.8 PM: no INCREASE	NO_x requirement of Latest proposal NRMM Stage V for IWP > 300 kW	Retrofit solution for SCR
2	NO_x < 1.8 PM < 0.045	EPA Tier 4 marine diesel (for engine > 600 kW)	Target for LNG engines (dual-fuel)
3	NO_x < 1.8 PM < 0.015 Particle Number limit: PN $<1x10^{12}$ per kWh	Latest proposal NRMM Stage V for IWP > 300 kW	Retrofit solution for SCR + DPF

Table 3 Proposed emission targets within PROMINENT

The following additional requirements apply:

- A Not To Exceed limit (NTE) for NOx: Above 25% power (for shipping also referred to as 'load'). The NOx emissions in individual points in the engine map shall not exceed 150% of the limit value.
- With application of SCR: average NH_3 emission must be lower than 10 ppm.
- With application of natural gas (LNG): CH_4 emission must be lower than approximately 6 g/kWh (A limit = 6, with reference to latest NRMM Stage V proposal).

- Option 1: No increase of PM emissions must be demonstrated on an engine test bed and durability must be guaranteed by the engine manufacturer (or system integrator) in the following cases:
  - If the base engine settings and/or configuration is adapted such as with EGR and with injection timing change
  - Any retrofit measure which may affect PM emissions or durability in a negative way (EGR, fuel-water emulsion, etc.)

Option number 1 can be seen as a cost-efficient option to at least cut down NOx emissions significantly, as this is possible through the application of SCR only.
Option 2 is especially suitable for LNG dual-fuel.
Option 3 requires a more advanced technical solution: SCR and a diesel particulate filter to reduce dramatically the emission of PM and NOx. This target can most probably also be achieved by single fuel gas engines (with spark ignition).

The further impacts and feasibility of the technologies and the emission standards will be further investigated in PROMINENT, also by means of application of technologies on the pilot vessels.

Tangible results and wide-spread impact
Hand- in- hand with emission reduction, the following targets are to be met in order to produce physical results already during project lifetime as well as solutions that are taken up by the market on larger scale no later than 2020:

- ➔ Develop solutions that are applicable to at least 70% of the European inland navigation market, measured in fuel consumption

- ➔ Reduce implementation costs of innovative greening solutions by 30%

- ➔ Produce results on the ground during the project lifetime (2017) and provide a roll-out plan for implementation of project results by 2020 with a focus on retrofit solutions in order to ensure results on this short term.

Consequently, the base criteria that were used to select the short list of promising technologies and concepts have been refined (details are given in chapter 0):

- Criterion 1: (Effects on energy consumption and emissions) has been separated for CO2 and CH4 reduction (climate change emissions) and the NOx and PM emission reduction (air pollutant emissions).
- Criterion 2a: (Economic feasibility) has been investigated concerning attractive business cases for the ship owners, which are a prerequisite for the desired broad market uptake.
- Criterion 2b: (Technical feasibility) evaluates the range of impact from the technical side against the main European fleet families and operational profiles identified in SWP 1.1. Those vessel types shall be addressed that have a major share in ton kilometres, fuel consumption and related emissions.
- Criterion 3a: (Technological maturity) was not specified any further. At least Technology Readiness Level 5 is desired in order to integrate a technology or concept in the envisaged roll-out plan (WP6).
- Criterion 3b: (Non-technological maturity) has been detailed regarding financial and regulatory barriers to implementation of the PROMINENT results until 2020. The basis for developing counter-measures in SWP 1.3 and WP6 is outlined.

Topical focus
Due to the topical focus of PROMINENT, just ship-related measures will be selected for further elaboration (technical and operational ones). Measures addressing other fields will only be taken into account in case they are to be applied in combination with selected ship-related measures. Therefore, the following measures have been excluded from further analyses:

- Improve fairway conditions (upgrading):
  This specific topic relates to waterway infrastructure lies out of the focus of PROMINENT. Other infrastructure-related measures like “Real-time information on fairway data” are however an essential part of the combined measure “Smart and energy-efficient navigation”, which is one of the key concepts of PROMINENT (see 0).

- Mobile Learning:
  Mobile learning is part of the education topic and is therefore dealt with in Work Package 4. Simulator training related to “Smart and energy-efficient navigation” however, is dealt with in the further analyses in WP1.

4.2 Detailed assessment criteria

The criteria listed below are based on the selection criteria in the previous chapter. Those have been further specified and will be used to describe the short-listed technologies in greater detail. Some criteria are quantitative, for others, qualitative descriptions are more suitable. This assessment will be compiled in a "short list" of best available technologies. For each of these, "fact sheets" will illustrate a basic assessment in more detail. Each technology will be assessed taking the main European fleet families and their operational profiles (as identified in SWP 1.1) into account, if this is necessary. At the end of the chapter, an overview matrix and qualitative ranking of the best available technologies and concepts for at least 70% of the European inland fleet by the year 2020 is prepared.

Criterion 1: Effects on energy consumption and emissions

Different technologies address different types of emissions. This is why two sub-criteria are set out:

<u>1a: Target for air pollutant emissions</u> (NOx, PM)
Greening solutions in PROMINENT aim at reducing air pollutant emissions in order to become competitive towards road transport in this field. The aim is to identify technologies that would lead to the emission levels presented in the table 3

<u>1b: Target for energy consumption and climate change emissions</u> (CO_2, CH_4)
There is no specific PROMINENT target value for reduction of climate change emissions. In any case, the net impact for climate change / greenhouse gas emissions (including methane slip emissions) should not deteriorate. The inclusion of methane slip is relevant to set targets for the LNG technology.
However, energy (fuel) savings (and proportional CO_2 reduction) also directly influence the benefit for the ship owner. This is expected to be a prerequisite for the uptake of technologies by the sector.
The aim in this field is to at least reach a saving of 5% on the fuel consumption, also taking the possibility of combinations of technologies into account.

Criterion 2: Range of impact

The PROMINENT target is to have as much uptake of the greening technologies by the market as possible. This is influenced by two sub fields: first of all, the technology needs to be applicable on large shares of the fleet from a technical perspective, having a focus on retrofitting. Secondly, the business case has to be attractive for the ship owner.

<u>2a: Technical feasibility</u>
Applicability to large parts of the fleet (segmentation by vessel size, operational profile, and by type/age of installed engines)

Proven technology:

- Emission reduction should be proven with a range of engines by a number of independent research or technical services organisations, both on engine test beds as well as in practise (in normal operation).

- Focus on retrofit possibilities (indicators: required space, state of the engine, type of engine, stability, operational profile, further technical prerequisites for installation)

2b: Economic feasibility for the ship owner

- Investment needed (e.g. ratio of investment related to the capital value of the vessel)
- Impact on revenues (e.g. higher payload, more trips)
- Share of savings on annual operational variable costs (%)
- Risk of investment (sensitivities, uncertainties)

Criterion 3: **Availability for mass implementation by 2020**

3a: Technology status

- Technologies in stage 8 and 9 are more or less ready for commercial application and can be implemented on the market. - TRL 7 or 8 show prototypes in normal operational environment or system formally qualified for inland shipping.
- Technologies in state 5 to 7 still need some additional R&D in order to achieve technological maturity (and market readiness).However, there might be the need for regulatory or financial support (e.g. subsidies, see next criterion).

The TRL level might be different for different fleet families as for some vessel types and operational profiles the technology might be more challenging compared to others. Therefore, attention will be paid to the technology status for the particular fleet family and experiences already available with the technologies (e.g. pilot projects).

3b: Non-technological maturity

The significance of barriers will also be different for the different fleet families and operational profiles as regards the need for financial and regulatory support to reach emission reductions. Therefore, the barriers will be described and assessed separately for the various fleet families in a qualitative way, addressing technical, legal, financial barriers as well as such related to knowledge, market or culture.

4.3 Main European fleet families and their requirements towards greening technologies and concepts

The information presented in this section is based on selected results of WP 1.1 of PROMINENT. For more information, see PROMINENT Deliverable 1.1 (EICB et al., 2015).

In this section, some of the elements in WP1.1 are highlighted which are of relevance for the technologies. This enables a first rough assessment on the share of the fleet where the technology would be applicable. In the factsheets for the description of the promising technologies, reference will be made to the fleet families, where necessary.

In order to conclude on the most important vessels that are reflecting the target to reach at least 70% of the market, an analysis was done as regards:

- The number of vessels in a certain vessel class
- The fuel consumption of a certain vessel class
- The transport performance (ton kilometres) of certain vessel class

A distinction was made between Rhine, Danube and other waterways in Europe.

An overview of the results is presented in the following table.

Fleet families	Total number of vessels	Number of vessels:	
Vessel type		Rhine and other waterways countries	Danube countries
Passenger vessels (hotel/cruise vessels)	2553	2357	196
Push boats <500 kW (total engine power)	890	798	92
Push boats 500-2000 kW (total engine power)	520	332	188
Push boats >=2000 kW (total engine power)	36	25	11
Motor vessels dry cargo >=110m length	610	580	30
Motor vessels liquid cargo >=110m length	602	599	3
Motor vessels dry cargo 80-109m length	1802	1713	89
Motor vessels liquid cargo 80-109m length	647	631	16
Motor vessels <80 m. length	4463	4285	178
Coupled convoys (class Va + Europe II lighter)*	140	140	*
Total	**12263**		
Other type of vessels	*5179*		
Total database	17442		

Table 4: Main fleet families of the European inland fleet
(source: PROMINENT D1.1)

However, the total number of vessels is not the most appropriate indicator to derive the fleet families. Since the main target of PROMINENT is to focus on emission reduction, the target groups shall be derived based on the fuel consumption and transport performance share (see following figures).

The following figures present the same structure, but then with the pie-chart for the fuel consumption. Through the comparison, it can be seen that mainly the larger vessels have high fuel consumption and are, therefore, also the main target group for PROMINENT.

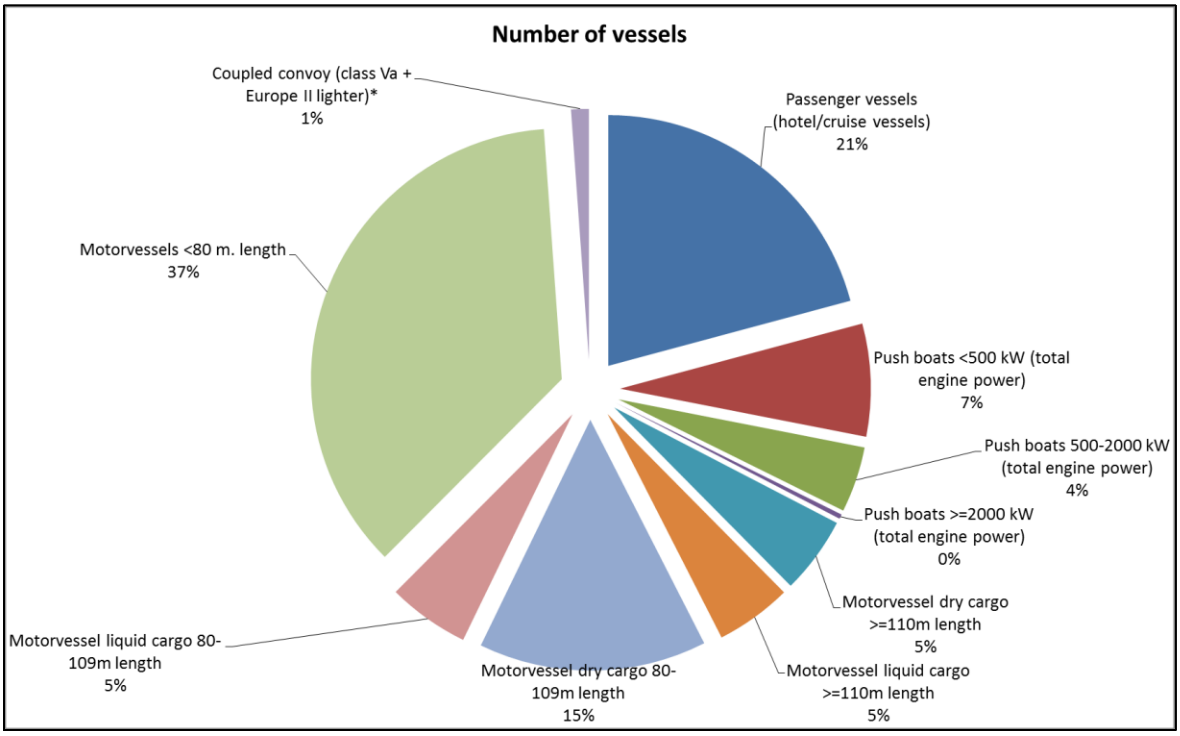

Figure 2: Share of main fleet families in Europe
(source: PROMINENT D1.1)

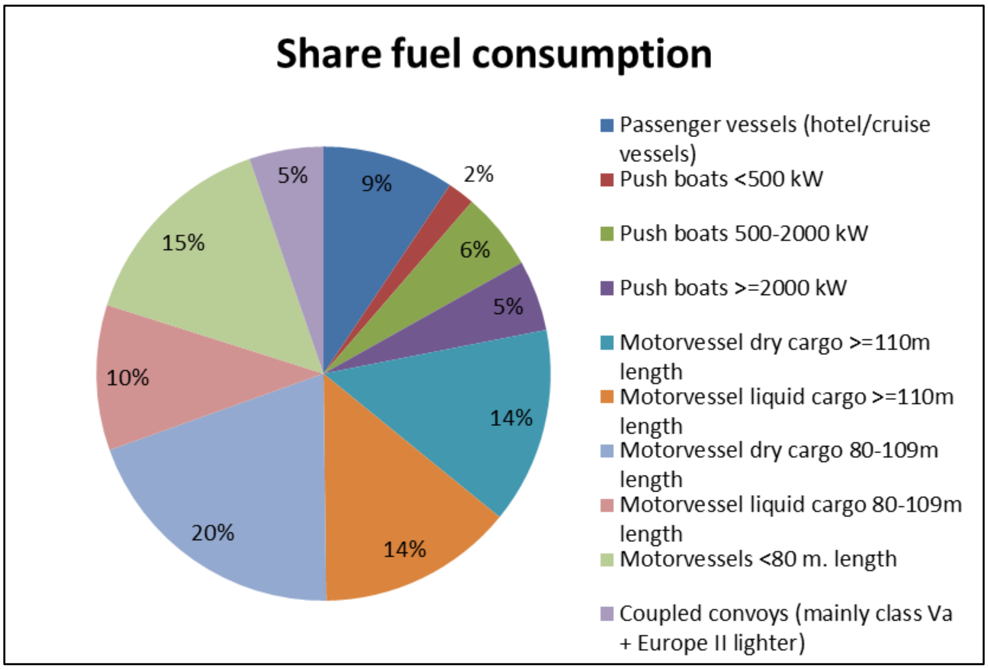

Figure 3: Share of main fleet families in Europe regarding fuel consumption
(source: PROMINENT D1.1)

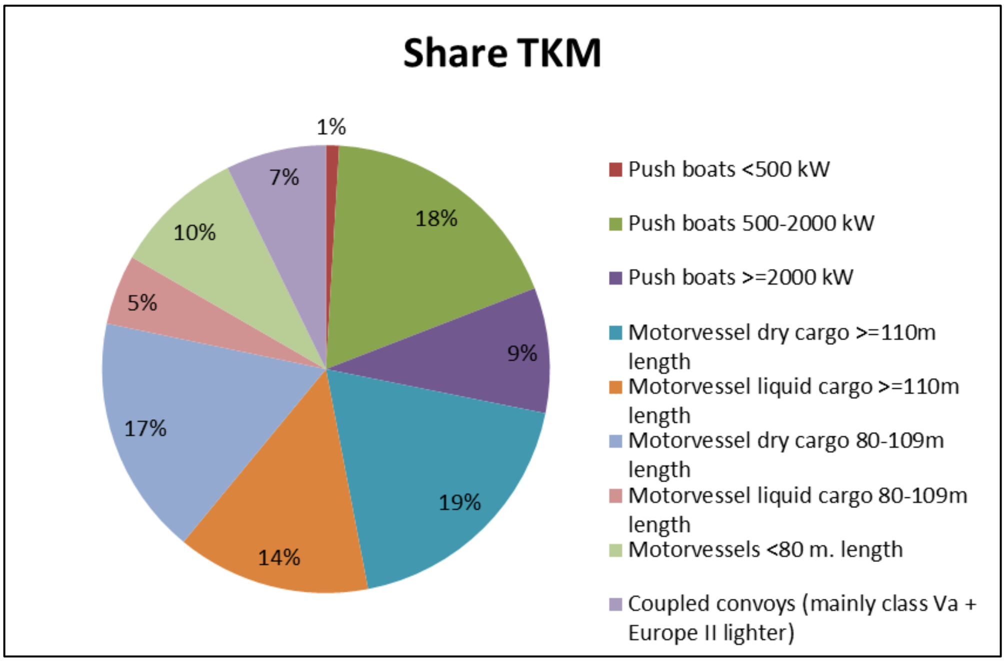

Figure 4: Share of main fleet families in Europe regarding ton kilometres transported (source: PROMINENT D1.1)

As regards the fuel consumption, the following boxplot gives the overview on the average fuel consumption per year for the main fleet families. The boxplot presents the 25% - 75% interval of the observed data (source: CDNI data[12]). The information on the fuel consumption is a relevant input for the business case of LNG (a fuel consumption of at least 250 m^3 per year could result in a positive business case for LNG).

[12] Convention on the collection, deposit and reception of waste produced during navigation on the Rhine and Inland Waterways of 9 September 1996, http://www.cdni-iwt.org/en/presentation-of-cdni/

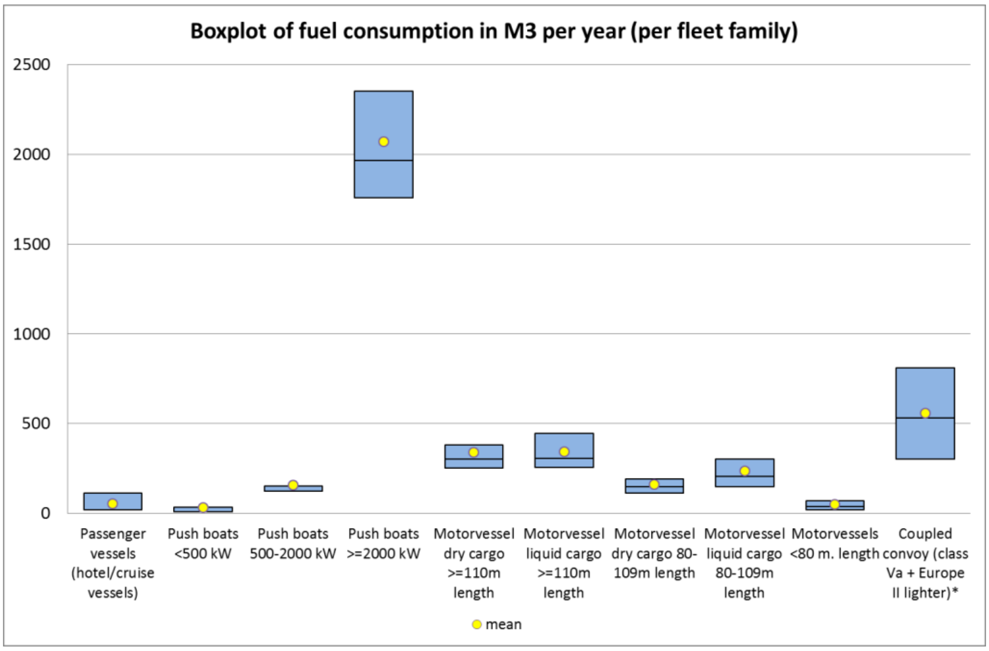

Figure 5: Fuel consumption per year and main fleet family
(source: PROMINENT D1.1)

It can be seen that in particular the large push boats, the coupled convoy have high fuel consumption figures per year. Obviously for these fleet families, saving on fuel costs is very important. Therefore technologies such as efficient navigation and LNG can bring benefits for the ship owner/operator. On the other hand, additional costs for GTL will have a more negative impact if the operational profile concerns a lot of fuel consumption. In addition, the fuel consumption gives an indication on the level of urea consumption for application of SCR and the maintenance costs of technologies and their technical lifetime (capital cost).

Another important characteristic is the engine power and the number and type of engines. For example this is relevant for the design and the related costs of SCR and DPF equipment and LNG retrofit of existing engines. Low RPM engines are more difficult and therefore expensive to equip with DPF because of the low back-pressure. The following two boxplots present the results for the fleet families.

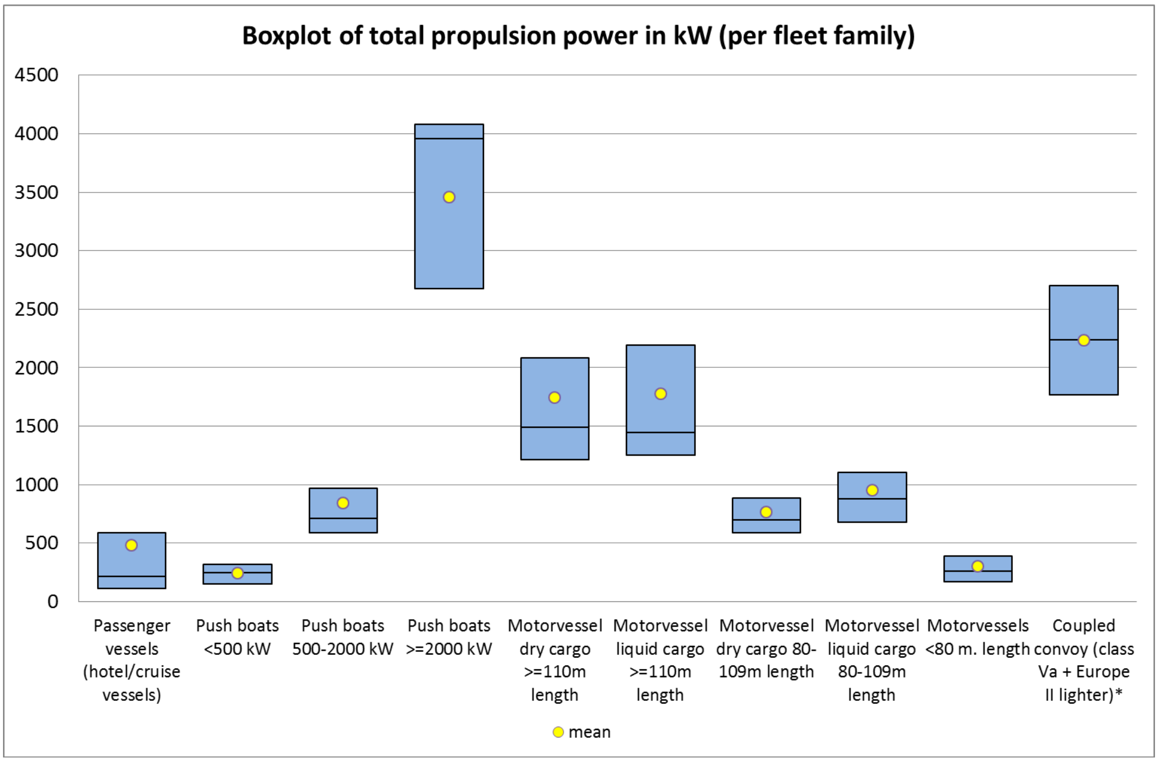

Figure 6: Propulsion power of main fleet families
(source: PROMINENT D1.1)

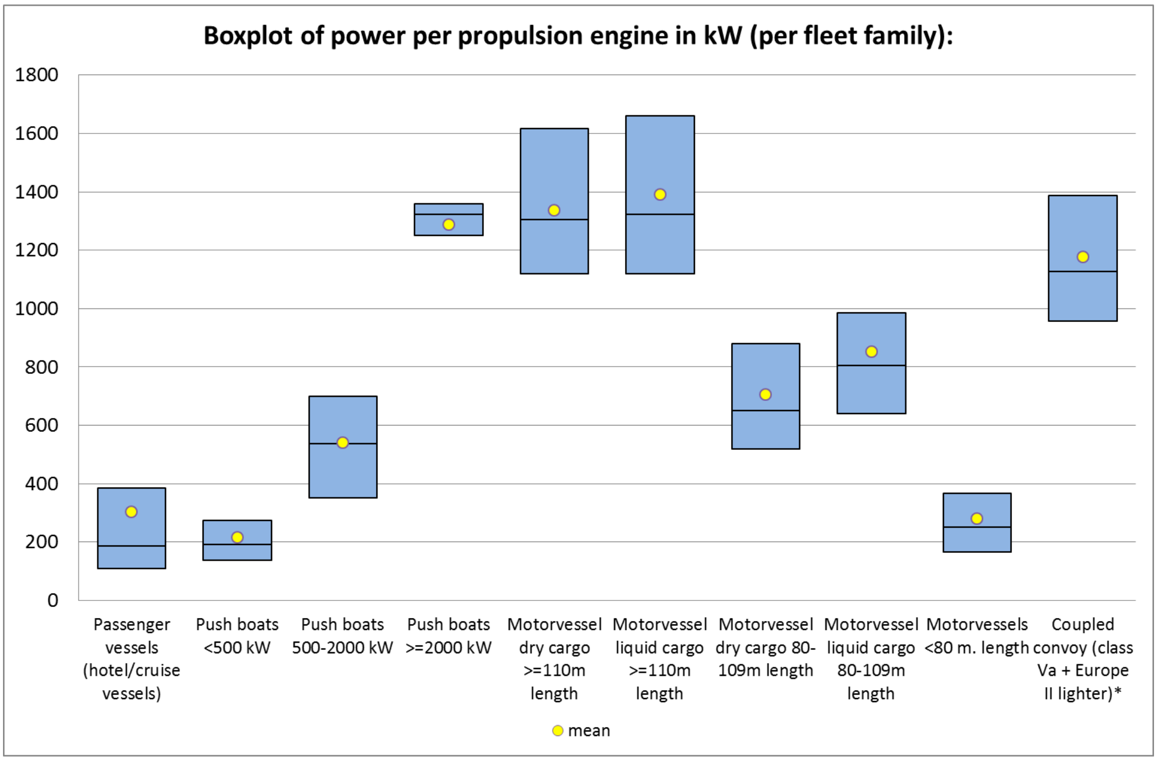

Figure 7: Power of propulsion engine per main fleet family
(source: PROMINENT D1.1)

It can be concluded from these tables that mainly the push boats, coupled convoys and large motor vessels have a high total engine power. Furthermore it can be concluded that these also use more than one engine for their propulsion.

The following table presents the characteristics of the propulsion engines.

Fleet families	Number of vessels:			*Engine data averages based on detailed information from Western-European countries.*								
Vessel type	Total no. of vessels	Rhine and other waterways countries	Danube countries	Average number of engines installed	Size per propulsion engine installed (kW)			Average total engine power installed (kW)	Engine speed			Average fuel consumption per year (in m3)
					Lower 25% perc.	Mean	Upper 75% perc.		Low (<500 RPM)	Med. (500-1250 RPM)	High (>1250 RPM)	
Passenger vessels (hotel/cruise vessels)	2553	2357	196	1.4	110	304	385	482	1%	1%	98%	54
Push boats <500 kW (total engine power)	890	798	92	1.2	137	216	275	247	10%	12%	79%	32
Push boats 500-2000 kW (total engine power)	520	332	188	1.6	351	542	700	847	0%	14%	86%	158
Push boats >=2000 kW (total engine power)	36	25	11	2.7	1251	1288	1360	3458	0%	67%	33%	2070
Motor vessel dry cargo >=110m length	610	580	30	1.3	1118	1337	1617	1742	2%	13%	85%	339
Motor vessel liquid cargo >=110m length	602	599	3	1.3	1118	1390	1660	1780	1%	29%	70%	343
Motor vessel dry cargo 80-109m length	1802	1713	89	1.1	520	707	880	764	30%	14%	55%	162
Motor vessel liquid cargo 80-109m length	647	631	16	1.1	640	853	985	954	10%	13%	77%	237
Motor vessel <80 m. length	4463	4285	178	1.1	165	280	368	302	13%	13%	74%	49
Coupled convoy (class Va + Europe II lighter)*	140	140	*	1.9	956	1178	1388	2237	1%	18%	81%	558

Table 5: Engine characteristics of main fleet families
(source: PROMINENT D1.1)

Moreover, it is relevant to know which emission reduction is possible by means of the retrofitting of engines. Furthermore, the DPF technology will only work if the engine-out emissions of PM are not too high and for SCR application the urea consumption depends not only on the fuel consumption but also on the absolute level of grams NOx that need to be reduced between engine-out and tailpipe.

The following graph presents the estimation on the emission performance depending on the year of construction of the engine. It can be seen that in particular the introduction of the CCNR Stage II was effective to reduce NOx emissions.

Year of construction of main engine	NOx [g/kWh]	PM [g/kWh]
<1974	10.8	0.6
1975-1979	10.6	0.6
1980-1984	10.4	0.6
1985-1989	10.1	0.5
1990-1994	10.1	0.4
1995-2002	9.4	0.3
2003-2007*	9.2	0.3
>2007* ** CCNR I from 2002, NRMM Stage IIIA / CCNR II from 2007*	6	0.2

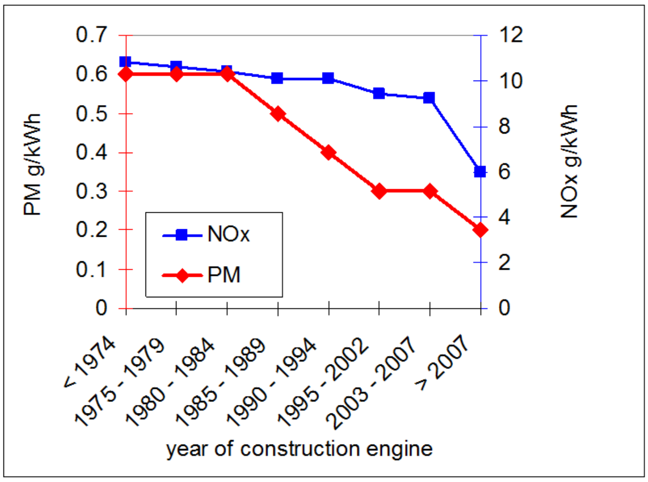

Figure 8: Relation between engine year of construction and emission factors for inland shipping (The Netherlands) (source: Panteia et al. 2013 and Hulskotte et al. 2012)

On the basis of the IVR database[13], the following information presents the estimates on the year of construction of the engines (in case of known information (approximately 3200 observations).

	Unregulated (before 2003)	CCNR stage I engine (2003-2007)	CCNR stage II engine (>2007)
Passenger vessels	70%	12%	18%
Other push boats <500 kW	87%	7%	6%
Push boats 500-2000 kW	53%	29%	18%
Push boats >=2000 kW	36%	27%	36%
Motor vessel dry cargo >=110m	13%	52%	34%
Motor vessel liquid cargo >=110m	11%	32%	57%
Motor vessel dry cargo 80-109m	73%	18%	9%
Motor vessel liquid cargo 80-109m	44%	19%	37%
Motor vessel <80m	77%	16%	7%
Coupled convoy	12%	42%	45%

Table 6: Estimates on the year of construction of engines based on the IVR database.

[13] International Association for the representation of the mutual interests of the inland shipping and the insurance and for keeping the register of inland vessels in Europe., http://www.ivr.nl/statistics

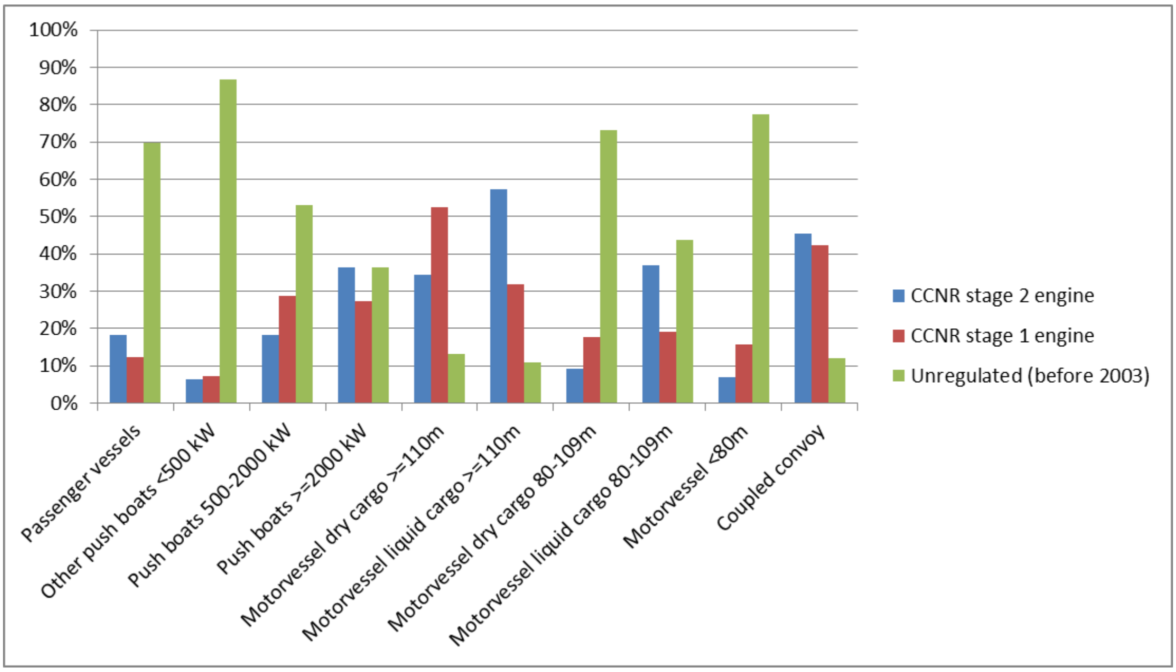

Figure 9: Engine type per main fleet family

It can be seen that mainly the larger vessels have already a high share of CCNR Stage I or stage II engines. In particular passenger vessels, small push boats and small motor vessels are still largely equipped with old engines that are assumed to have high NOx and PM emissions per kWh.

However, as it can be seen in figure 4 on the fuel consumption, these vessel types with older engines are not the most dominant vessels.

For more information, please see PROMINENT Deliverable 1.1.

4.4 Description of the best available greening technologies and concepts

4.4.1 Alternative fuels

MEASURE:

- ***Use LNG (Liquefied Natural Gas)***
- ***Apply dual fuel (LNG and diesel)***

Description of technology

Liquefied natural gas or LNG is natural gas that has been converted to a liquid form for the ease of storage or transport by cooling natural gas to approximately −162 °C. Afterwards, it is stored at essentially atmospheric pressure. Liquefied natural gas takes up about one six hundredth the volume of natural gas in the gaseous state at atmospheric pressure or about 2.5 times less volume than CNG at 250 bar pressure.

Inland waterway vessels have a variety of engine configurations on board, this being partly determined by the size of the ship, the route and the distribution of the engine's part load and full load periods. LNG power offers a number of engine configurations for inland waterway vessels. The following engine suppliers have LNG-powered engines: Wärtsilä, PON Power/Caterpillar, Rolls Royce and Scania. These four engine manufacturers each have their own engine configurations. More engines may become available in the future (van der Burg 2014).

Dual fuel engine: 80% LNG and 20% diesel

These Dual-Fuel engines are based on diesel engines. The engines have been converted so they can also be powered by LNG fuel. The fuel is a mix of 80% LNG and 20% diesel.

Dual fuel / pilot diesel engine: 99% LNG and 1% diesel

In this case the engine is fully optimized for natural gas combustion. This LNG Dual-Fuel system has already been in use for more than 10 years in coastal and ocean shipping. The engines are now also supplied for inland shipping. The LNG Dual-Fuel engines are specifically designed as Dual-Fuel systems so only a limited quantity of pilot fuel is required. The Dual-Fuel engine can nevertheless run fully on diesel. This involves proportions of 1% diesel and 99% LNG.

Spark ignition natural gas engine

This engine is also referred to as ‘pure gas engine’. It uses only natural gas and cannot run on diesel fuel. In ships it is usually used in a gas-electric drive.

Gas-electric engine

The latest development in inland shipping engine configuration is the gas-electric drive. The gas-electric drive is a system whereby an inland waterway vessel uses one or a number of gas engines that drive generators (gensets) that generate electricity. This electricity goes to electric motors that drive the ship (LNG 24, 2015).

Impacts

- **Effects on energy consumption (fuel) and emissions / In comparison to diesel, typical emissions savings associated with natural gas (spark ignition and dual fuel) are:**
    - Energy consumption (%)
        - More or less equal to diesel engines
    - GHG emissions (CO2, CH4)
        - CO2 reduction (CO2 only): 20-25%
        - Greenhouse gas reduction of between 0% and 10% (TNO, 2015; Verbeek et al., 2013; TNO 2011;) both conclude around 0% GHG saving due to relatively high CH4 slip. Looking into the bandwidth of TNO 2015 GHG saving could be up to 10% in best cases
        - The emission of CH4 (the methane slip) problem has to be addressed by the relevant stakeholders
        - The expected range of methane slip emissions: 6 gram per kWh for dual fuel (Wärtsilä 99%-1) and 3 gram per kWh for monofuel (gas-electric)
    - Air pollutant emissions (NOx, PM)
        - Pure gas engines or dedicated LNG (dual fuel) engines are expected to stay within test cycle limits of 1.8 gram NOx and 10 mg PM per kWh
    - Emission limits that could be achieved
        - for NOx emissions at least 70% reduction is possible compared to CCNR II diesel engine, some studies indicate that 80% is possible (1.2 gram NOx per kWh);
        - up to 95% reduction of particulate matter (PM) as compared to CCNR II diesel engines is possible

- **Range of impact : Technical feasibility**
    - Technical applicability to fleet families
        - Technically, LNG as fuel can be implemented in all fleet families of the inland fleet as listed in SWP 1.1 (around 10-50% of the European fleet measured in tkm), although engine availability may be a problem. A switch to a gas electric drive may be necessary for most fleet families due to the very limited availability of dual-fuel engines.
    - Technical requirements for installation (e.g. required space, type/age and state of the engine etc.)
        - In the TEN-T project "LNG Masterplan for Rhine-Main-Danube"[14] one vessel was retrofitted and one new-build was equipped with Wärtsilä 20 dual fuel engines. The different types of the Wärtsilä 20 dual fuel engines have the dimensions as shown in the table below (*source: Wärtsilä homepage*, 16.07.2015,http://www.wartsila.com/products/marine-oil-gas/engines-generating-sets/dual-fuel-engines/wartsila-20df). As of comparison the Wärtsilä 20 engine data is also highlighted from the company´s website in the 2nd figure.
        - A few inland ships are equipped with Scania pure gas, spark ignition (in gas-engine - electric configuration).

          In addition all vessels need to be equipped with the LNG tank, whose size is depending on the user requirements (40, 60, 80 etc. m^3). For

[14] http://www.lngmasterplan.eu/

retrofitting, this will reduce the payload of the vessels slightly while retrofitting existing push boats is impossible due to stability requirements.

Wärtsilä 20DF		IMO Tier III	
Cylinder bore	200mm	**Fuel specification:**	
Piston stroke	280 mm	Fuel oil	700 cSt/50oC
Cylinder output	185 kW/cyl		7200 sR1/100 F
Speed	1200rpm	ISO 8217, category ISO-F-DMX, DMA & DMB	
Mean effective pressure	21.0 bar	BSEC 7700 kJ/kWh at ISO cond.	
Piston speed	11.2m/s		

Dimensions (mm) and weights (tonnes)							
Engine type	A*	A	B	C	D	F	Weight
6L20DF	3 254	3 108	1 705	1 690	1 800	624	9.4
8L20DF	3 973	3 783	1 705	1 824	1 800	624	11.1
9L20DF	4 261	4 076	1 705	1 824	1 800	624	11.7

Rated power	
Engine type	kW
6L20DF	1 110
8L20DF	1 480
9L20DF	1 665

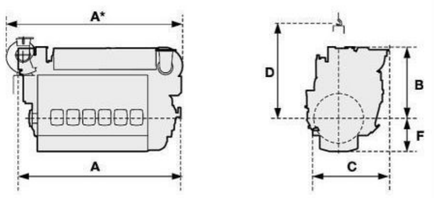

Figure 10: Wärtsilä 20 DF engine data
(source: wartsila.com)

Wärtsilä 20		IMO Tier II	
Cylinder bore	200 mm	**Fuel specification:**	
Piston stroke	280 mm	Fuel oil	700 cSt/50oC
Cylinder output	200 kW/cyl		7200 sR1/100oC
Speed	1000rpm	ISO 8217, category ISO-F-RMK 700	
Mean effective pressure	27.3 bar	SFOC 185 g/kWh at ISO condition	
Piston speed	9.3m/s		
Option: Common rail fuel injection.			

Dimensions (mm) and weights (tonnes)									
Engine type	A*	A	B*	B	C*	C	D	F	Weight
4L20	-	2510	-	1348	-	1483	1800	725	7.2
6L20	3254	3108	1528	1348	1580	1579	1800	624	9.3
8L20	3973	3783	1614	1465	1756	1713	1800	624	11.0
9L20	4261	4076	1614	1449	1756	1713	1800	624	11.6

Rated power	
Engine type	kW
4L20	800
6L20	1 200
8L20	1 600
9L20	1 800

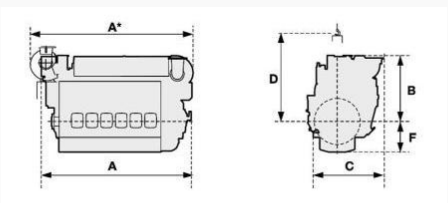

Figure 11: Wärtsilä 20 engine data
(source: wartsila.com)

- Possible combination with other technologies and achievable results
  - All infrastructure and ship-operational measures can further support the achievement of better results
  - LNG engines can be equipped with SCR deNOx after treatment. In that way very low NOx (and PM) levels can be achieved (e.g. < 0.4 g/kWh).

Range of impact: Economic feasibility for the ship owner

- Investment needed (e.g. ratio of investment related to the capital value of the vessel)
  - The investment cost for the LNG-related equipment is about 1 million EUR. It is therefore an expensive solution to be used as a retrofit option. Most of the costs are related to the LNG tank, whereas the gas engine is appr. +20-30% EUR more expensive compared to diesel engines. Costs depend on the type of the vessel and the type of the engine (LNG or dual fuel), the required tank size etc.
- Impact on revenues (e.g. higher payload, more trips)
  - Savings in fuel costs (depending on the price gap between LNG and diesel)
  - Increased attractiveness due to reduced environmental effects (carbon footprint)
  - Slight reduction of payload and turnover as a consequence of the space and weight needed for the LNG tank in case of retrofitting
- Share of savings on annual operational variable costs (%)
  - Based on operational experience between end of 2011 and 2014, on average 30% of fuel cost saving was possible compared to diesel (data from MTS Argonon, Deen Shipping; de Jong 2015), however in 2015 the price gap is much smaller, resulting in smaller savings.
- Risk of investment (sensitivities, uncertainties)
  - The main risk of investment is the price gap between LNG and diesel. LNG must be at least 15% cheaper to make the business case viable. There is high uncertainty with regard to the price development of LNG as a fuel, which results in a high financial risk for both the ship-owners and the financial sector. Consequently, there is no willingness from the financial sector to finance the solution itself as the benefits are too uncertain still.
- Payback period
  - The payback time significantly depends on the price gap between diesel and LNG, thus the range is 5 to 10 years or more.

- **Availability for mass implementation by 2020**
  - Technology status (TRL level)
    - TRL 6. Technology demonstrated in relevant environment, but the availability of engine types is rather limited, there are question about the emission performance and also the equipment and installation costs are relatively high due to the small market and lack of standardisation.
  - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others
    - The LNG Masterplan for Rhine-Main-Danube TEN-T project is consolidating the barriers and related actions / measures by the end of 2015. The project consortium is elaborating the Masterplan document

that will contain strategy & recommendations. The five main themes where barriers are collected (with some main barriers in brackets):

- Markets & Financing (no transparent pricing, uncertainty in price gap, need for financing instruments to support ship owners in making the investment)
- Vessels & Equipment (high investment costs, longer bunkering time than in case of normal bunkering,)
- Jobs & Skills (limited number of personnel trained as of today)
- LNG Infrastructure (lack of bunkering facilities, LNG-related safety risks are often over-estimated)
- LNG Governance & Legislation (lack of clear air emission regulations for both new and existing vessels, there is no overall legal framework yet available which makes it burdensome to acquire the required certificates

Points of attention

- Significant price gap LNG – Diesel fuel essential for sustainable business case
    - Extremely high prices for LNG equipment (> 30-50% above estimated budgets)
    - High logistics costs (10-15€/MWh on top of TTF c. 20€/MWh)
    - Transparent and competitive pricing requested
- Despite proven “technologies” still many technical challenges (vessels)
- New air emission targets are currently being discussed (NRMM Directive) and an element that influences the payback time and economic attractiveness is the question whether exhaust after-treatment is needed to comply with new NRMM standards. The emission performance of LNG engines is rather unknown. This is an issue to be further elaborated within PROMINENT to find out which emission limits would be possible with LNG without costly after-treatment equipment
- Mobile bunkering solutions are favourable to reduce the time-loss when bunkering (→ bunkering during sailing)
- Permits for on-shore infrastructure (NIMBY, realization time)
- Public/Politicians/Authorities tend to overestimate safety risks of LNG – more information needed
- Multi-client strategy (maritime & road sector, off-road, peak shavers, off-pipeline clients, etc.) for deployment of LNG hubs required
- Public co-funding essential to ensure business case
- More availability of BioLNG could be an interesting development in order to significantly reduce the environmental footprint.

MEASURE: ***Gas to liquid fuel (GTL)***

Description of technology

GTL is created by transforming natural gas towards a liquid substance. This gives a benefit in terms of energy efficiency per cubic meter. The difference with LNG, however, is that LNG does not transform the fuel (it stays natural gas in the end) while in the case of GTL, another fuel type is created: natural gas is converted towards diesel or petrol.
Considering the use of GTL, it offers some benefits compared to conventional fuels. Shell claims it reduces PM by 20%. Also, it would reduce NOx by 12%. To its advantage one could notice that conventional engines do not have to be modified. On the other hand, GTL would be 10 % more expensive compared to standard fuel.

Impacts

- **Effects on energy consumption (fuel) and emissions**
  - PM can be lowered by 20% or possibly more (TNO 2014)[15].
  - Between 10% - 12% NOx reduction could be achieved.
  - Emission measurements performed on two inland vessels, showed NOx reductions of 8 and 13% on one vessel and 10% on the other vessel (CCNR-I type-approved engine). The PM reductions were respectively 37%, 16% and around 60% (the last one for a CCNR-I type-approved engine).
  - CO_2/CH_4 reduction: 0
  - With these reductions, it isn't possible to bridge the gap between CCNR-II requirements and the proposed EU NRMM Stage V requirements.

- **Range of impact: Technical feasibility**
  - Conventional engines do not need to be modified.
  - Currently (Q3 2015) the application of GTL in field tests, aiming to reach CCNR-II levels on older vessels, show a promising outlook. It is applicable to almost the entire fleet, as there aren't modifications needed to use it.
  - Possible combination: While reducing already air pollutant emissions, it could be used in combination with e.g. after-treatment, with the possibility of the reduction of urea consumption.

- **Range of impact: Economic feasibility for the ship owner**
  - Although there are no investment costs, GTL would be 10% more expensive compared to standard fuel.

[15] Limited data available but highest PM reduction reported is around 60%

- **Availability for mass implementation by 2020**
    - Technology status (TRL level)
        - TRL: 9, as GTL has a high technological readiness and is already applied in several fleets. However, more emission measurements are needed to investigate potential reduction.
    - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others
        - Financial: More expensive than fossil fuel, however no reduction in overall fuel consumption is realised (additional cost for the ship-owner).
        - Market: Market is still under development, so GTL is not yet widely available on the market.

Points of attention

NO_X and PM reduction is possible with fuelling GTL. There are no investment costs, making implementation easy, however, the current price difference compared to conventional fuel may be a bottleneck for mass implementation. Besides, the market for GTL is still under development, so it is not yet widely available and more measurements are needed to show the potential effect on the emissions. GTL could be considered as interesting, when bridging a small gap between emission levels to get some incentives (like lower port dues) or in combination with e.g. after-treatment.

4.4.2 Propulsion systems

MEASURE: *Right sizing*

Description of technology

Engines in ships are often over dimensioned. Sailing profiles often show that the available power is hardly used. Engines perform better in terms of NOx, PM2.5 and CO2 emissions when the engine is used where the engine is designed for (at a relatively high engine power; 50% or higher). The key of 'Right sizing' is to design/ use engines with the optimum combination of power/ torque delivery, in line with the operating characteristics (requested power of the ship in use).

Impacts

- **Effects on energy consumption (fuel) and emissions**
  - Right sizing has a significant impact on GHG emissions and/or fuel consumption from a system perspective (0-10%).
  - NOx and PM emissions will most likely improve simultaneously with the fuel consumption (0-10%). Especially with future engines (Stage V), the improvement with a right size engine may be very large (more than 25% or 50% for NOx, based on experience with trucks). For PM main benefits will be improved DPF lifetime and reduced maintenance costs.
- **Range of impact : Technical feasibility**
  - Right sizing is not in itself an innovative concept but a mature and proven technology and therefore it has often been applied. Taking the technical requirements and composition of the fleet families (link to SWP 1.1) into account, the technology can be applied to >50% of the fleet.
- **Range of impact: Economic feasibility for the ship owner**
  - The economic advantage of a smaller engine should be lower fuel costs and lower installation and maintenance costs, although there are possible additional costs such as change of gear box. It will be mainly applied if the existing engine is in need of replacement or complete overhaul. Economics have to be calculated on a case by case basis.
- **Availability for mass implementation by 2020**
  - Technology status (TRL level):9
    - Mass implementation on existing vessels is not to be expected when other alternatives are available who deliver more benefits and cost less.
  - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others
    - There seems to be no barriers from an economic, legal or market perspective as the solution is a minor adaptation.

Points of attention

Implementation of the right engine taking the sailing profile into account might in time lead to a ship that is economically not interesting to be used in accordance with other sailing profiles or in other sailing areas.

MEASURE: ***Exchange of main diesel engine (by Stage V engine)***

Description of technology

In case the damage of the existing main diesel engine cannot be overhauled or from an economical point of view such overhaul is not advisable, the option is an exchange of the engine with a new engine, taking into account right sizing and/or a hybrid solution. This new engine needs to fulfil the CCNR-II or EU NRMM Stage-IIIa emission standards according to current legislation. Another option is to take into account the coming NRMM Stage-V emission measures and to install a new engine according to this standard (as soon as they are available on the market).

Impacts

- **Effects on energy consumption (fuel) and emissions**
  - Exchange of main diesel engine (CCNR-I (or older) or CCNR II / EU NRMM Stage-IIIa by NRMM Stage-V engine) has a large impact on the emissions (NOx: 70%; PM: 80-90% and also extensively reducing the number of particulates). These will be lower referring to the NRMM Stage-V standard.
  - CO2 and CH4 reduction is 0%
  - To get to the level of NRMM Stage-V, the (new) engine will be equipped with emission control technologies. The fuel consumption might be slightly lower, however with the application of amongst other SCR, there is consumption of urea to be taken into account instead.

- **Range of impact : Technical feasibility**
  - Taking the technical requirements and composition of the fleet families (link to SWP 1.1) into account, the technology can be applied to over 50% of the fleet. Exchange of main diesel engine (CCNR I by NRMM Stage-V engine) is not in itself an innovative concept. Stage V engines are or can be built into IWT vessels. However, these engines are not yet on the market for IWT, new engines have to meet only the level of CCNR-II or NRMM Stage III-a.

- **Range of impact: Economic feasibility for the ship owner**
  - Depending on the sailing profile, 'Exchange of main diesel engine (by NRMM Stage-V engine)' can be economically feasible also taking into account 'Right sizing'. However the investment cost of the engine will be higher compared to older engines, as result of emission control technologies to reach low emission values (e.g. SCR, DPF)

- **Availability for mass implementation by 2020**
  - Technology status (TRL level): 5. Most likely, starting around 2020, Stage V engines will be on the market. Before 2020, engines may be made available by manufacturers if there is a significant commercial interest (with trucks this happened with Euro V; these trucks were 3 years earlier available than required by legislation).
    - Mass implementation on existing vessels is to be expected when NRMM Stage-V emission measures come into practice, depending also on

incentives and financial instruments to become available for ship owners.

- Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others
  - Financial: The price of a new engine is high. The IWT sector does not have sufficient financial means available to invest in new engines. Also the financial sector is not willing to provide the funds needed.
  - Legal: There is no legal obligation to reduce current emission levels further (legal incentive is missing). Currently it is unclear what the actual limit for the new NRMM engines will be in 2019/2020 (depending on outcome of ongoing discussions)

Points of attention

As the discussion on the new NRMM standards are still ongoing, it is not clear what the limits for NOx, PM and PN will be. Currently these engines are not yet on the market. Probably they will be on the market around 2020. A mass implementation by 2020 is not realistic, also considering the circumstance that there is no urge to invest in these types of engines. Most of the reduction in emissions will be achieved by other technologies, such as SCR/DPF for conventional diesel engines or applying LNG engines.

MEASURE: *Exchange of main diesel engine (CCNR-I/non-type approved by CCNR-II engine)*

Description of technology

In case the damage of the existing main CCNR-I (or older) diesel engine cannot be overhauled or from an economical point of view such overhaul is not advisable, the option is an exchange of the engine with a new engine, taking into account right sizing and/or a hybrid solution. This new engine needs to fulfil the CCNR-II or NRMM Stage-IIIa emissions criteria according to current legislation.

Impacts

- **Effects on energy consumption (fuel) and emissions**
  - Exchange of main diesel engine (CCNR-I or non-type approved by CCNR-II engine or equivalent) has a significant impact on emissions. Considering the emission factors, the emission values of a CCNR II engine will be much lower than for older engines (NOx: 35% or more, PM: 33% or more)
  - Fuel consumption and CO2 emissions are indirectly affected by the pollutant emissions optimisation. Fuel consumption and CO2 emissions may slightly go up although engine manufacturers will try to balance this by technical measures with a positive influence. Precise information is not available.

- **Range of impact : Technical feasibility**
  - Exchange of main diesel engine (CCNR-I by CCNR-II engine) is not in itself an innovative concept but a mature and proven technology and therefore it has often been applied.

- **Range of impact: Economic feasibility for the ship owner**
  - Depending on the sailing profile, ‘Exchange of main diesel engine (CCNR-I by CCNR II engine)’ can be economically feasible also taking into account ‘Right sizing’ and the fact that an overhaul of the old engine is then not necessary.

- **Availability for mass implementation by 2020**
  - Technology status (TRL level): 9
    - Mass implementation on existing vessels is to be expected as long as the CCNR-II emission standard is in force (until 2019/2020), partly by the regular replacement of CCNR-I or older engines.
    - For the port of Rotterdam, the engines of all vessels, new and old ones, have to comply at least with the CCNR-II standard in 2025.
  - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others
    - Financial: The price of a new engine in general and a CCNR II engine in particular is high. The IWT sector does not have sufficient financial means available to invest in new engines. Also the financial sector is not willing to provide the funds needed.
    - Legal: There is no legal obligation to reduce current emission levels further (legal incentive is missing).

Points of attention

The price of a new engine is high, although replacement of the engine may be the most economical solution at a certain engine age or running hours (the engine life time is usually much shorter than the ship life time, so engines are replaced anyhow). The IWT sector does not have sufficient financial means available to invest in new engines at a large scale at this moment, and the financial sector is probably only interested in providing financing for this, if replacement is unavoidable. The CCNR-II standard is not very ambitious as this is already the status quo for a share of the fleet and a current requirement for all the new engines. As the NRMM Stage V will be most likely implemented in 2020, the implementation of CCNR-II engines will remain limited till 2020.

MEASURE: Hybrid propulsion

Description of technology

Hybrid propulsion makes it possible to use engines more efficiently, by switching off a propulsion or auxiliary engine when they are not needed. This results in a higher average engine load which usually leads to higher fuel efficiency. This is also very beneficial to a proper operation of engine emission control systems such as an SCR catalyst and a DPF. A disadvantage is: energy losses occur due to conversion from mechanical to electric power and visa-versa. Therefore, careful optimisation of the hybrid system fitting the ship and its operation profile is necessary.

Impacts

- **Effects on energy consumption (fuel) and emissions**
  - Hybrid propulsion can significantly reduce energy consumption and emission since it makes it possible to adjust propulsion needs to actual operational conditions.
    (NO_x, PM, CO_2 and CH_4: 0-10%)

- **Range of impact: Technical feasibility**
  - Hybrid propulsion is a proven technology. Taking the technical requirements and composition of the fleet families (link to SWP 1.1) into account, the technology can be applied to10-50% of the fleet.

- **Range of impact: Economic feasibility for the ship owner**
  - Depending on the sailing profile substantial savings can be reached in terms of fuel usage (especially when sailing on canals, which only requires 20% of total installed power).

- **Availability for mass implementation by 2020**

  - Technology status (TRL level) TRL = 9, a considerable number of hybrid configurations *without batteries* are all in normal service. Also hybrids *with batteries* are in service for special applications like ferries, work-ships, etc. The Components are available and can be installed (number of installations is limited). Batteries are suitable especially for applications with short term energy needs which can be serviced by batteries along with a normal engine. Batteries are not expected to show up very fast in regular inland ships for long trips.Non-technological maturity, barriers and requirements:

    Hybrid propulsion is quite common nowadays on newly built vessels. For existing vessels, the application of this technology would be rather dependent on the underlying business case.
    However, even then, with a lack of willingness from financial sector to provide financing for this new solution, it is difficult to implement hybrid propulsion on a mass scale.

Points of attention

Substituting diesel with an alternative fuel like LNG or installation of an after treatment system can lead to even more environmental benefits.

4.4.3 Emission reduction technologies

MEASURE: *Selective Catalytic Reduction*

Description of technology

Selective Catalytic Reduction of NOx (SCR deNOx) is a technology applied on diesel engines to reduce the NO_x emissions, by adding a reductant (urea-water solution) to the exhaust gas, which is absorbed onto the catalyst, converting NO_x in diatomic nitrogen (N_2) and water (H_2O).

Impacts

- **Effects on energy consumption (fuel) and emissions**
  - With the application of an SCR, it is aimed to reduce NO_x, which is possible up to 70-90%. Depending on the current emissions, but with this reduction the level of NO_x emissions can be reduced to 1.2-1.8 g/kWh, the latter is the latest proposal of the EU NRMM Stage V standard for engines with an installed power of above 300 kW. (EPA, 2014; MECA, 2014; Recklinghausen, 2013)
  - PM reduction is estimated to be 0-20%
  - CO2 and CH4 reduction is about 0%, Effect of SCR on GHG emission could be slightly positive if the engine settings are re-optimised for the SCR system. Fuel consumption could be reduced up to 5% which leads to a 4-5% GHG savings (including CO2 emission of urea/AdBlue)
  - With SCR it may be beneficial to adjust the engine settings (usually injection timing) such that the energy (fuel) consumption is reduced and (as a result) the NOx is increased. The economic benefit of the lower fuel consumption may be higher than the costs of additional urea injection.
  - Urea consumption: To reduce the NO_x, the consumption of urea is needed. This depends on amongst others the engine power output and the mass of NO_x emissions needed to be reduced, based on data from Wärtsilä within the MoVeIT! research project (the formula for the urea consumption was used:

$$\dot{V}_{urea} = \frac{\mathrm{P}_{engine} \cdot \dot{m}_{NO_2} \cdot \dfrac{M_{urea}}{2 \cdot M_{NO_2}} + P_{engine} \cdot 0.1}{10 \cdot C_{urea} \cdot \rho_{urea}}$$

  - Where: $\dot{V}_{urea}$ is urea volume flow [l/h] ; P_{engine} is engine power output [kW]; $\dot{m}_{NO_2}$ is NO_2 mass difference through the reactor [g/kWh] ; M_{urea} is urea molar mass [g/mol] = 60 ; M_{NO2} is NO2 molar mass [g/mol] = 46 C_{urea} is urea solution concentration [%] ; ρ_{urea} is urea density [kg/l] = 1.1.
  - In practice this results in a urea consumption of about 0.8% of the fuel (v/v) per 1 g/kWh of NOx reduction. In order to reach the target NOx emissions of 1.8 g/kWh about 6% urea is needed as percentage of fuel.
- To simplify the price of urea consumption, assuming a cost of €0.36 per litre and an average use of the installed power, for a subsidy scheme for the Dutch province Zuid-Holland the following formula was used for 5 years of urea consumption:

€ 0.014 x *sailing hours per year* x *installed power* x *a certain percentage for the type-approval of the engine* (100% for non-type approved, 90% for CCNR-I and 50% for CCNR-II)

- **Range of impact : Technical feasibility**
    - Technical applicability to fleet families: Taking the technical requirements into account, an SCR is technically applicable on a large share of the fleet (10-50%) Probably its applicability is only dependent on the availability of space for the catalyst and the urea tank. If the catalyst is kept reasonably compact, it should fit into most (90%) of the vessels. The size is dependent on efficiency and life time requirements.
    - Technical requirements: There is some space needed in the engine room.
    - Possible combination with other technologies and achievable results: DPF.

- **Range of impact: Economic feasibility for the ship owner**
    - Investment: Based on estimations made in MoVeIT! on data from Wärtsilä, within the Greening Tool of Platina 2 and some current cases, the estimated investment costs are at €30-€50 per kW for purchasing, with additionally installation costs of approximately 20,000 euro. Costs are relatively high as a result of lack of market volume and tailor mode solutions (lack of standardisation). Moreover the certification of the system is costly (on board measurement of emission performance).
    - Impact on revenues: On the other side, the application of an SCR has no main impact on revenues, except for some (some rare) cases that the application of an SCR resulted in long-term transport contracts.
    - With application of SCR (and certification) the cost for port dues can be reduced as some ports (e.g. Rotterdam) give discounts to vessels with low emissions. However in general the port dues take only a very limited share in the overall operational costs.
    - Share of savings on annual operational variable costs (%): The application of an SCR does not result in any savings, but in higher operational costs. The consumption of urea accounts for about 90% or more of these operational costs (source: MoVeIT!). Minor cost savings can be achieved by incentive schemes for the port dues in some ports (e.g. in Rotterdam, calculated at €1.500 per year for a pusher of TKVeerhaven (source: MoVeIT!).
    - Payback period: There is mostly no payback period (higher operational expenditure). Investments made to equip vessels with SCR are mainly driven by opportunities to acquire subsidies from public authorities as well as by specific shippers that request low polluting vessels to transport their cargo.

<u>Impacts</u>

- **Availability for mass implementation by 2020**
    - Technology status (TLR level): 8
    - Non-technological maturity, barriers and requirements: There is mainly a financial barrier for mass implementation of SCR. Emission standards for existing engines (legal requirement) or financial incentives could result in mass implementation. Standardisation and mass production could also result in a more cost-efficient technology.

<u>Points of attention</u>

SCR is one of the most effective applications to reduce NO_x of diesel engines, however with higher operational expenditure and mostly no payback period.

MEASURE: ***Wall flow Diesel Particulate Filter***

Description of technology

A Diesel Particulate Filter reduces the PM emissions. The most efficient DPF is the wall flow DPF, commonly made from ceramic materials with a honeycomb structure with alternate channels plugged at opposite ends. According to the Manufacturers of Emission Controls Association (MECA)[16], particulate matter is captured by interception and impaction of the solid particles across the porous wall. Important is a sufficiently high average temperature such that the stored particle matter is regenerated (converted to CO2) and the filter is kept clean. Alternatively a special active regeneration system can be installed, which increases the filter temperature periodically to high temperature for fast regeneration.

Impacts

- **Effects on energy consumption (fuel) and emissions**
    - Air pollutant emissions (NOx, PM): PM could be reduced by 90% or more (MoVeIT! project). Also reduction of HC and CO (according to EPA: respectively 85-95% and 50-90%). In a report commissioned by the Manufacturers of Emission Controls Association (Gladstein, Neandross & Associates, 2013), it is claimed that 99.9% of the Particulate Numbers could be reduced.
    - NOx reduction: 0%

      CO2 and CH4 reduction is about 0%, DPF can lead to a fuel consumption and GHG emission increase of 1-2% due to the increased back pressure and possible active regenerations
    - Emission limits that could be achieved: The proposed NRMM Stage V limits the PM emissions for high-power engines (>300 kW) to 0.015 g/kWh, which corresponds to a required reduction of respectively 92.5% and 97.2% compared to the limits of CCNR II and CCNR I standards for the same engines (Arcadis & Transport & Mobility Leuven, 2009).

- **Range of impact : Technical feasibility**
    - Technical applicability to fleet families (link to SWP 1.1): Taking the technical requirements and composition of the fleet into account, the share of the fleet on which a DPF is applicable is around 10-50%.
    - Technical requirements for installation (e.g. required space, type/age and state of the engine etc.): There are some restrictions in the application of DPF. For application, an engine may not be too polluting, a maximum limit is 250 mg/kWh, and should not contain too much oil. Moreover, the back pressure is an issue and the required space for DPF is much larger for low RPM engines compared to medium and high speed engines (Panteia et al., 2013).Successful application is dependent on the engine condition (PM mass emission and oil consumption) and the average exhaust gas temperature.
    - Possible combination with other technologies and achievable results: Usually, a DPF is combined with an SCR.

[16] The Manufacturers of Emission Controls Association (MECA) includes leading manufacturers of emission control technology for a variety of sources; www.meca.org

- **Range of impact: Economic feasibility for the ship owner**
    - Investment needed: The price for the hardware of the DPF (without installation was between 15 and 30 € per kW and in addition 10,000 € for design and installation). However, costs are relatively high as a result of lack of market volume and tailor made solutions (lack of standardisation). Moreover the certification of the system is costly (on board measurement of emission performance).
    - Maintenance costs: Periodic cleaning of the filter is necessary, especially to remove anorganic components (ash).
    - Impact on revenues (e.g. higher payload, more trips): No main impact on revenues.
    - Share of savings on annual operational variable costs (%): No savings, higher operational costs (replacement/maintenance cost). With application of DPF (and certification) the cost for port dues can be reduced as some ports (e.g. Rotterdam) give discounts to vessels with low emissions. However in general the port dues take only a very limited share in the overall operational costs.
    - Payback period: As there are higher investments as well as operational costs, there is no payback period. Investments made to equip vessels with SCR are mainly driven by opportunities to acquire subsidies from public authorities as well as by specific shippers that request low polluting vessels to transport their cargo.

- **Availability for mass implementation by 2020**
    - Technology status (TRL level): 7

      Non-technological maturity, barriers and requirements: Mainly a financial barrier, which eventually could be stimulated by either legislation or more financial incentives. Standardisation and mass production – due to increased demand - can lead to a more cost-efficient system.

<u>Points of attention</u>

Wall-flow DPF is one of the most effective solutions to reduce PM, however there are investment and operational costs involved without real benefits for the owner/operator of the vessel.

MEASURE: *SCR plus DPF*

Description of technology

SCR and DPF are often combined because then all gaseous and particulate emissions are reduced (by 70% or more) and usually the most stringent (future) emission legislation can be met. SCR and DPF often work together nicely leading to an increased SCR efficiency. One of the technical options is the "SCR on DPF technology", where the DPF part acts as an SCR catalyst as well. This can lead to a more compact configuration.

Impacts

- **Effects on energy consumption (fuel) and emissions**
    - Air pollutant emissions (NOx, PM): NO_x could be reduced up to 80-90% and PM could be reduced around 90% (PN (Number of Particles) by the DPF with 99.9%).
    - CO2 and CH4 reduction is around 0%
    - Emission limits that could be achieved: With a reduction of PM of around 92.5%, it could result in achieving the proposed EU NRMM Stage V requirements (1.8 g/kWh NO_x and 0.015 g/kWh PM for >300 kW) for a CCNR-II type-approved engine).

- **Range of impact : Technical feasibility**
    - Technical applicability to fleet families (link to SWP 1.1): Considering the technical requirements and composition of the fleet, the technology is technically applicable to 10-50% of the fleet.
    - Technical requirements for installation (e.g. required space, type/age and state of the engine etc.): The application of SCR/DPF increases the exhaust back pressure. For low RPM engines this may require the application of larger after-treatment systems. On smaller vessels, available space may be a problem due to small engine rooms and small exhaust systems. (Panteia et al., 2013).
    - The SCR and DPF usually require a volume of two or three times the volume of displacement of the engine and it will often require a case-by-case / tailor made approach. The engine-out emissions of PM may vary strongly, depending on engine type, size and maintenance and operation history of the engine. (Panteia et al., 2013)

- **Range of impact: Economic feasibility for the ship owner**
    - The economic feasibility is in line with that of SCR and DPF separately. Investment costs cannot be earned back, because of increased operational costs.

- **Availability for mass implementation by 2020**
    - Technology status (TRL level): 7
    - Non-technological maturity, barriers and requirements: In line with SCR and DPF, so mainly a financial barrier. This eventually could be stimulated by either legislation or more financial incentives. Standardisation and mass production - due to increased demand - can lead to a more cost-efficient system.

Points of attention

This is the combination of the most effective applications to reduce the air pollutant emissions. However, there is currently mostly no positive business case, as there are not any legal requirements for existing engines to reduce these emissions and only minor financial incentives.

4.4.4 Smart and energy-efficient navigation

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, …), 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:

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

The greatest impact on 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 or to maximize the amount of cargo to be taken onboard. Therefore, the three measures listed above are described separately in the following.

MEASURE: Speed adaptation

Description of technology

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 stream velocity of the river. The energy consumption of a vessel rises disproportionately in shallow and narrow waters (confined conditions) and in areas with higher countercurrent 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 adaptation of the vessel speed to the changing navigation conditions e.g. by reducing the speed in unfavorable 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.

Impacts

- **Effects on energy consumption (fuel) and emissions**
  (compare measures 'waterway information' and 'optimised track choice')
  - Energy consumption: 3 up to 25.4% reduction, on average around 14 % (as a result of facilitating 'speed adaptation' and 'optimised track choice, not cumulative) (minimum value achieved in Topofahrt[17], maximum value (te Winkel, 2008) and average value (Gille & de Vries, 2011) achieved in the Dutch VoortVarend Besparen programme[18]);
  - GHG emissions (CO_2, CH_4): 3 up to 25.4 %, on average around 14 %
  - Air pollutant emissions (NO_x, PM): In part load condition, the specific fuel consumption and PM emissions in g/kWh are expected to increase little. However, a more substantial increase might take place for the specific NO_x emissions in g/kWh, which seems to demand a closer evaluation. Based on investigations of TNO, with conventional engines such as CCNR II or older, NO_x emissions are generally more or less linear proportional with CO_2 emissions in kg, while PM will probably be reduced somewhat less than proportional. As a first guess, it may be assumed that the total PM and NO_x emissions in kg are reduced by the same percentage as the total CO_2 emissions and fuel consumption in kg.

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[17] Topofahrt was a research project led by the German Entwicklungszentrum für Schiffstechnik und Transportsysteme (http://www.dst-org.de/projekte/projekte/land.shtml)
[18] Within the VoortVarend Besparen (Full Sail Ahead with Savings) platform by the Dutch Ministry of Transport, Public Works and Water Management, an "Inland shipping fuel saving competition" was launched hosted by the Maritime Research Institute Netherlands (MARIN).

- Emission limits that could be achieved: Not applicable with respect to regulated exhaust gas emissions as only the total emissions are reduced but not the specific ones related to the engine output energy in kWh, and the emission limits are usually referred to kWh.

- **Range of impact : Technical feasibility**
  - Technical applicability to fleet families (link to SWP 1.1): In general, the principle applies to all vessels. Limitations result from the time schedule to be kept, as well as local waterway and traffic conditions. Until now, no convincing real-life demonstration of a system giving advice on the optimum speed or rate of revolutions has been carried out for an inland waterway vessel, considering locally changing navigation conditions like water depth and flow velocities.
  - Technical requirements for installation: Availability of data storage, exchange and processing of present and future navigation conditions, as well as optimisation procedures for calculation of transport time at minimum fuel consumption, giving advice on the necessary local speed or rate of revolutions of the vessel considered. The coverage of the system has to include also cross-border stretches on the route.
  - Possible combination with other technologies and achievable results concerns mainly the usage of real-time waterway information e.g. derived from echo-sounder measurements, as well as inclusion of the technology in voyage-planning tools.

- **Range of impact: Economic feasibility for the ship owner**
  - Investment needed: Most tools are still under development (e.g. economy planner) and the actual investment costs are not yet clear. Most developers estimate that the costs range between 10,000 up to 20,000 EUR.
  - Impact on revenues (e.g. higher payload, more trips): not applicable.
  - Share of savings on annual operational variable costs (%): On average around 14 % in agreement with the reduction of yearly fuel consumption (in combination with ‘waterway information’ and ‘optimised track choice’ (not cumulative)).
  - Risk of investment (sensitivities, uncertainties): The fuel savings may be not as high as anticipated due to traffic interruptions caused by other vessels or obstacles, changing time schedules and operational areas, accuracy of navigation conditions processed, little knowledge of engine-system characteristics in part load condition (e.g. losses in gearboxes), as well as limited practical experience of the person operating the vessel.
  - Payback period: Less than 1 year for yearly fuel costs of around 200,000 EUR.

- **Availability for mass implementation by 2020**
  - Technology status (TRL level): 5
  - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others:
    - Financial: Most tools are still under development (e.g. economy planner) and the actual investment costs are not yet clear. Most developers estimate that the costs range between 10,000 -20,000 EUR. It is not clear if ship-owners are willing to make this investment.
    - Applicability: Most tools available on the market do not cover all waterways in Europe in the same level of detail. Therefore tools are difficult to use in cross-border transport.

Development and applicability shall be objective of PROMINENT SWP 5.4 (Pilot on energy efficient navigation). The knowledge gained from this pilot Shall be used as important step towards large-scale application.

Points of attention

For a large scale implementation, as well as for usage in voyage planning tools, knowledge on the navigation conditions at a certain time and location of interest is necessary to be provided for the main European waterways.

MEASURE: Optimized track choice

Description of technology

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, which, however, is not necessarily to be found in a river cross section, leading to the demand of proper estimation and balancing the effects due to changing water depths as well as flow velocities.

Impacts

- **Effects on energy consumption (fuel) and emissions**
  (compare measure 'speed adaptation')
  - Energy consumption: 3% up to 25% reduction (in association with 'Speed adaptation', not cumulative)
  - GHG emissions (CO_2, CH_4): see above.
    Air pollutant emissions (NOx, PM): In part load condition, the specific fuel consumption and PM emissions in g/kWh are expected to increase little. However, a more substantial increase might take place for the specific NOX emissions in g/kWh, which seems to demand a closer evaluation. Based on investigations of TNO with conventional engines such as CCNR II or older, NOx emissions are generally more or less linear proportional with CO_2 emissions in kg, while PM will probably be reduced but less than proportional. As a first guess, when optimised track choice is being applied in association with speed adaptation, it may be assumed that the total PM and NOx emissions in kg are reduced by the same percentage as the total CO_2 emissions and fuel consumption in kg. If the engine load is not changed, and optimised track choice is applied as a stand-alone solution, as a first guess, it may be assumed that the PM and NOx emissions are reduced by the same percentage as the CO_2 emissions and the fuel consumption, caused by the reduction in sailing time. Due to lack of better information, the maximum value derived from the longlist is given for the reduction of pollutant emissions accounting for 5%.
  - Emission limits that could be achieved: Not applicable with respect to regulated exhaust gas emissions as only the total emissions are reduced but not the

specific ones related to the engine output energy in kWh, and the emission limits are usually referred to kWh.

- **Range of impact : Technical feasibility**
  - Technical applicability to fleet families (link to SWP 1.1): In general, the principle applies to all vessels. Limitations result from local waterway and traffic conditions. Until now, no convincing real-life demonstration for finding the optimum track has been carried out for an inland waterway vessel, considering locally changing navigation conditions like water depth and flow velocities. In the MoVe IT! project, the optimum track was determined for a part of the river Waal as track where the water depths are largest. It was neither reported that flow velocities were considered nor documentation on the fuel savings achieved in real-life was given.
  - Technical requirements for installation: Availability of data storage, exchange and processing of present and future navigation conditions comprising information on water depths and flow velocities across the entire cross section, as well as procedures for calculation of transport time and fuel consumption, allowing for determination of the optimum track.
  - Possible combination with other technologies and achievable results concerns mainly the usage of real-time waterway information e.g. derived from echo-sounder measurements, as well as inclusion of the technology in voyage-planning tools.

- **Range of impact: Economic feasibility for the ship owner**
  - Investment needed: Selected tools are on the market already. The actual investment costs are not yet clear.
  - Impact on revenues (e.g. higher payload, more trips): Depending on the accuracy and extent of available information on the navigation conditions, a higher payload may be realised, as well as the sailing time may be reduced.
  - Share of savings on annual operational variable costs (%): Not known.
  - Risk of investment (sensitivities, uncertainties): The fuel savings may be not as high as anticipated due to traffic interruptions caused by other vessels or obstacles, changing operational areas, accuracy of navigation conditions processed, as well as limited practical experience of the person operating the vessel.
  - Payback period: Not known yet.

- **Availability for mass implementation by 2020**
  - Technology status (TRL level): 5
  - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others:
    - Financial:

      Selected tools are on the market already, however it is unclear what the investment costs are.
    - Applicability:

      The tools available on the market do not cover all waterways in Europe in the same level of detail. Therefore the tools are difficult to use in cross-border transport. For many parts of the main European waterways complete up-to-date information on the requested navigation conditions is not available yet, demanding still substantial efforts.

The knowledge gained from PROMINENT SWP 5.4 (Pilot on energy efficient navigation) shall be used as important step towards large-scale application.

Points of attention

For a large scale implementation, as well as for usage in voyage planning tools, knowledge on the navigation conditions at a certain time and location of interest is necessary to be provided for the main European waterways.

MEASURE: Waterway information

Description of technology

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 temporal) enables the application of energy-efficient sailing via adaptation of the vessel speed to the changing navigation conditions and choice of the optimum track for minimum fuel consumption.

Besides, the lowest section of the whole transport route determines the possible draught and thus the maximum payload and the load-factor of the 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.

Impacts

The impacts are a result of implementing energy-efficient sailing by application of speed adaption to changing navigation conditions and choice of the optimum track comprising the route where the fuel consumption of the vessel under consideration becomes a minimum.

- **Effects on energy consumption (fuel) and emissions**
  (compare measures ‘speed adaptation’ and ‘optimised track choice’)
  - Energy consumption: 3 up to 25.4% reduction, on average around 14 % (as a result of facilitating ‘speed adaptation’ and ‘optimised track choice, not cumulative) (minimum value achieved in Topofahrt[19] research project (DST, 2011), maximum value (te Winkel, 2008) and average value (Gille & de Vries, 2011) achieved in the Dutch VoortVarend Besparen programme[20]);
  - GHG emissions (CO_2, CH_4): 3 up to 25.4 %, on average around 14 % reduction
  - Air pollutant emissions (NOx, PM): In part load condition, the specific fuel consumption and PM emissions in g/kWh are expected to increase little. However, a more substantial increase might take place for the specific NOX emissions in g/kWh, which seems to demand a closer evaluation. Based on investigations of TNO, with conventional engines such as CCNR II or older, NOx

[19] Topofahrt was a research project led by the German Entwicklungszentrum für Schiffstechnik und Transportsysteme to reduce fuel consumption and emissions by topograpy oriented sailing of inland vessels (http://www.dst-org.de/projekte/projekte/land.shtml)

[20] The Maritime Research Institute Netherlands (MARIN) hosted the launch of the “Inland shipping fuel saving competition” initiated by the VoortVarend Besparen (Full Sail Ahead with Savings) platform, the brainchild of the Dutch Ministry of Transport, Public Works and Water Management.

emissions are generally more or less linear proportional with CO2 emissions in kg, while PM will probably be reduced somewhat less than proportional. As a first guess, it may be assumed that the total PM and NOx emissions in kg are reduced more or less by the same percentage as the total CO2 emissions and fuel consumption in kg. Emission limits that could be achieved: Not applicable with respect to regulated exhaust gas emissions as only the total emissions are reduced but not the specific ones related to the engine output energy in kWh, and the emission limits are usually referred to kWh.

- **Range of impact : Technical feasibility**
  - Technical applicability to fleet families (link to SWP 1.1): In general, the principle applies to all vessels. Limitations result from the time schedule to be kept, as well as local waterway and traffic conditions. First applications regarding the usage of echo-sounder measurements for the creation of real-time-water-depth information have been implemented in the projects COVADEM[21] (van Wirdum & van Laar 2015), MoVe IT! and Newada Duo[22] (Radl & Hartl 2014). Until now, no convincing real-life demonstration of a system giving advice on the optimum speed or rate of revolutions has been carried out for an inland waterway vessel, considering frequently changing navigation conditions like water depth and flow velocities.
    Further, no convincing real-life demonstration for finding the optimum track including a proof of the fuel savings achieved has been carried out for an inland waterway vessel, considering changing navigation conditions. In the MoVe IT! project, the optimum track was determined for a part of the river Waal as track where the water depths are largest. It was neither reported that flow velocities were considered nor documentation on the fuel savings achieved in real-life was given.
  - Technical requirements for installation:
    - Properly working measurement equipment,
    - availability of positioning systems,
    - possibility to place the measurement equipment on a vessel in a way that undisturbed measurements are possible,
    - availability of data storage,
    - exchange and processing of present and future navigation conditions comprising information on water depths and flow velocities across the entire cross section as well as
    - optimisation procedures for calculation of transport time and fuel consumption, giving advice on the necessary local speed or rate of revolutions of the vessel considered, as well as the choice of the optimum track.
    - The coverage of the system has to include also cross-border stretches on the route.

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[21] The COVADEM project a research project supported by Rijkswaterstaat and launched in 2013. It aimed at sharing current navigable depth measurements to enable shipmasters to find optimized sailing tracks to reduce energy consumption.(http://www.covadem.eu/en/)

[22] The project NEWADA duo (2012-2014) supported the waterway management authorities of the Danube riparian states in achieving a common level of service in waterway management along the Danube and its navigable tributaries. It was funded by the South East Europe Transnational Cooperation Programme.

- Possible combination of providing real-time waterway information with other technologies and achievable results concerns mainly the usage for energy-efficient sailing, as well as inclusion of the technology in voyage-planning tools.

- **Range of impact: Economic feasibility for the ship owner**
    - Investment needed: Most tools are still under development (e.g. COVADEM) and the final investment costs are not yet clear. According to COVADEM and NEWADA duo, the investment costs for co-operative echo-sounder measurements may be in the range between 2,000 and 40,000 EUR, depending on the approach used and the technical equipment already installed in the vessel.
    - Impact on revenues (e.g. higher payload, more trips): Depending on the accuracy and extent of available information on the navigation conditions, a higher payload may be realised, as well as the sailing time may be reduced.
    - Share of savings on annual operational variable costs (%): On average around 14 % in agreement with the reduction of yearly fuel consumption (in combination with measures 'energy efficient navigation' and optimised track choice' (not cumulative)).
    - Risk of investment (sensitivities, uncertainties): The fuel savings may be not as high as anticipated due to traffic interruptions caused by other vessels or obstacles, changing time schedules and operational areas, accuracy of navigation conditions processed, little knowledge of engine-system characteristics in part load condition (e.g. losses in gearboxes), as well as limited practical experience of the person operating the vessel.
    - Payback period: Less than 3 years for yearly fuel costs of around 200,000 EUR if costs for the speed advice tool are also considered (around 20,000 EUR).

- **Availability for mass implementation by 2020**
    - Technology status (TRL level): echo-sounder measurements: 7, comprehensive surveying: 5 (due to development needs with respect to water level and hydro-morphologic models covering the entire waterway)
    - Non-technological maturity, barriers and requirements: Legal, financial, knowledge, market, culture, others:
        - Legal:

          Information is in most initiatives voluntarily shared. No legal obligation to share the information exists. Liability issues in the case of accidents caused by the usage of the data provided have to be solved. Otherwise the implementation by e.g. waterway authorities can be prevented.
        - Financial:

          Most tools are still under development (e.g. economy planner) and the actual investment costs are not yet clear. Ship-owners do need to see benefits in order to share their information derived from e.g. echo-sounder measurements. In case they do not see clear benefits, the willingness to share is less.
        - Applicability:

          The tools available on the market do not cover all waterways in Europe in the same level of detail. Therefore the tools are difficult to use in cross-border transport. For many parts of the main European waterways

complete up-to-date information on the requested navigation conditions is not available yet, demanding still substantial efforts.
This shall be objective of PROMINENT SWP 5.4 (Pilot on energy efficient navigation). The knowledge gained from this pilot shall be used as important step towards large-scale application.

Points of attention

For a large scale implementation, as well as for usage in voyage planning tools, knowledge on the navigation conditions at a certain time and location of interest is necessary to be provided at all locations for the main European waterways. The usability of the data derived from echo-sounder measurements is depending on the amount of the vessels involved in the measurements, as well as the accuracy of the equipment and models used. Comprehensive surveying using dedicated surveying vessels is usually limited to certain river stretches. Extension to surveying of entire waterways demands proper equipment and resources, often not available sufficiently.

4.4.5 Overview of best available technology key characteristics

Type of measure	Area	Measure	NOx	PM	CO2 only	GHG (CO2 & CH4)	Applicability on the fleet	Economic feasibility (ship owner)	Technical maturity	Non-techn. maturity (barriers)
			%	%	%	%	% of fuel consumption in Europe	+ + + / - - -	TRL level	+ + + / - - -
Ship-related technical measures	Fuels, standardised solutions	Use LNG (Liquefied Natural Gas) - single fuel/ spark ignition	70-80	up to 95	20-25	0-10	10 - 50%	++	6	---
		Apply dual fuel (LNG and diesel)	50-65	50-90	20-25	0-10	10 - 50%	++	6	--
		Apply GTL fuel	10	20	0	0	> 50%	-	9	0
	Propulsion system, standardised solutions	Apply SCR	70-90	0-20	≈ 0	≈ 0	10 - 50%	--	8	-
		Wall flow DPF	0	90	≈ 0	≈ 0	10 - 50%	---	7	-
		Combine SCR and DPF	80-90	90	≈ 0	≈ 0	10 - 50%	---	7	-
		Exchange of main diesel engine (CCR I by CCR II engine)	15-35	40-60%	0	0	> 50%	0/-	9	0
		Exchange of main diesel engine (by Stage V engine)	65	80-90	0	0	> 50%	-	5	--
		Right sizing	0-10	0-10	0-10	0-10	100%	++	9	0
		Diesel-hybrid prop. (no buffer batt.)*	0-10	0-10	0-10	0-10	10 - 50%	+	7	0
		Diesel-hybrid prop. (+ buffer batt.)*	0-10	0-10	0-10	0-10	10 - 50%	+	9	0
Infrastructure	Waterway Information	Real time info on fairw. data	14 (3-25)				>50%	+	5/7	-
Ship-operational measures	Sailing behaviour	Speed adaption					>50%	+	5	-
		Optimised track choice					>50%	+	5	-

The average emission reduction values refer to vessels equipped with a drive train including a CCNR II diesel engine.

Maturity:

The Technology Readiness Leve (TRL) reaches from 1: basic R&D until 9: full commercial application.

The non-technological maturity is assessed qualitatively from --- (very strong barriers) to +++ (no barriers)

Diesel-hybrid propulsion:

* optionally, Stage V or other clean diesel or gas engines can be used

Table 7: Summarising overview of short listed technologies and their characteristics

5. Conclusions and recommendations for next steps

The analysis undertaken in SWP 1.2 showed that:

- LNG as fuel is mainly an opportunity for large vessels that have a lot of fuel consumption per year. In that case the high investment costs of the LNG tank and fuel system can be earned back in savings in fuel costs. Although these vessels have a relatively big share in the emissions of IWT in Europe, the number of vessels suitable for LNG is relatively limited. Moreover, investing in a 100% LNG engine is risky because of the current uncertainty on the price gap between LNG and Diesel. The dual fuel engine is more likely to be selected by ship-owners. Therefore, the efforts to reduce costs by means of standardisation shall be combined with the dual fuel engine and needs to be validated in the pilot.

- SCR/DPF is mainly a cost-effective solution to reduce NOx and/or PM emissions for all vessels, and is attractive for environmentally conscious clients and/or in sensitive environments (e.g. urban areas). However, cost for periodic maintenance (once a year or more) are high. Additional incentives are needed to increase the acceptance among ship-owners. In the meantime, also efforts shall aim at cost reductions by means of standardisations and development of modular systems.

- Energy efficient navigation is considered as a promising technology, in particular if the vessel makes a lot of sailing hours such as push boats and large motor vessels, and it is manoeuvring on free flowing sections with dynamic waterway conditions (strongly influencing fuel consumption). The payback time of investing in equipment will strongly depend on the fuel consumption savings.

- Hybrid drivetrains and the right sizing of engines are very much depending on the specific journey and the related operating profile. These technologies are more seen as niche solutions rather than large scale applications. Furthermore, they are found to have little effect on air pollutant emissions.

- Other technologies such as GTL and replacement with new CCNR II engines can have an additional benefit to reduce emissions, but are not stand-alone solutions to bring down the emission levels to one of the three target options defined in PROMINENT. However, it may still be a cost effective solution in terms of costs per kg of pollutant reduction. It can also be used in combination with other technologies and by this achieve one of the three target levels. This should be further investigated.

In PROMINENT WP5, pilots will test and validate the promising technologies in a real world environment and situations that are most common and representative for the inland waterway transport market. This will be an essential step in the preparation of the roll out in WP6.

LNG, SCR, DPF and energy efficiency navigation technologies will get the main attention and these have been identified as being key technologies already in the pre-project phase. They are the main pillars of the pilot tests in WP5 which will be prepared in WP2.

The remaining technologies assessed as particularly promising- **installation of new engines** and **hybrid and right sizing concepts -** will be integrated in the pilots by measurements on existing (hybrid) vessels and consequent validation. Various configurations of the drivetrain will consequently be simulated related to specific sailing profiles.
GTL will be monitored on vessels that are already equipped with this technology for validation purposes of the achieved emission levels.

The technologies need to be certified regarding their emission performance by means of on board measurements. Therefore, also low cost certification and enforcement procedures providing sufficient accuracy and reliability, and, therefore, getting acceptance from all involved stakeholders are required. WP3 of PROMINENT will focus on this issue.

The next steps will be to select the detailed technology/vessel combinations for the pilot tests, based on the results of SWP 1.1 (Fleet families and operational profiles) and this SWP (SWP 1.2).

SWP 1.3 will elaborate further on the existing barriers towards implementation and prepare counter-measures to be taken up in the roll-out plan in WP6.

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