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

D3.5: Ex-ante cost/benefit analysis of systems for certification, monitoring and enforcement

Certification, monitoring and enforcement

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Summary

PROMINENT is a multiannual research and implementation program for the inland navigation industry which is funded by Horizon 2020. PROMINENT focusses on researching, testing and introducing alternative energy concepts and technologies for the European industry of inland navigation which are economically viable, safe and environmentally friendly.

PROMINENT aims at providing solutions to make inland navigation as competitive as road transport in terms of air pollutant emissions by 2020 and beyond. In parallel, PROMINENT aims at further decreasing the energy consumption and carbon footprint of IWT. This is an area where IWT performs better than road transport.

Work Package 3 explores the technical options for certification, monitoring and enforcement procedures for inland vessel engines emissions, suitable for a range of 'greening technologies' and to comply with stringent legislation.

This report presents the economic assessment of the options for certification and for monitoring and enforcement as described in deliverables D3.2 and D3.3.

An important element to secure low Real Sailing Emissions is the certification of the Retrofit Emission Control (REC) devices. The proposed procedure consists of a laboratory test procedure of the REC with a very broad engine family definition and an on board validation of the NOx performance on each vessel. Annual costs for such a certification and monitoring process for REC are estimated between 2% to 9% of emission control costs[1] depending on the type and number of engines and the engine hours per year. It is recommended to set-up a working group, possibly hosted under the umbrella of CESNI to develop the procedures for the certification of Retrofit Emission Control devices for propulsion engines applied in inland vessels.

For the In service Monitoring (ISM) a combination is proposed of continuous monitoring of NOx level through a voluntary EPM system (Environmental Performance Measurement), which can be prescribed if public organisations provide grants for installing retrofit emission control systems to ship-owners. Annual costs for the EPM are estimated between 3,400 and 8,200 euro. There can be a business case for these systems as result of a better marketing position and increased insight on fuel consumption may lead to adapted behaviour resulting in fuel cost savings.

For the In Service Monitoring, data from EPM and on board validations can be combined with the data from periodic independent SRM/PEMS measurements. The costs for these periodic independent SRM/PEMS measurements are estimated between 6,000 and 20,000 euro. The sample size for such periodic measurements will have to be determined at a later stage, depending also on the details of the certification procedure for REC and the number of EPM systems to be expected in the market, possibly linked to subsidy schemes for roll-out of after treatment systems and LNG.

[1] Consists of annual capital costs for the investment for purchasing and installation of an emission control system as well as the annual maintenance costs and reagent / urea / AdBlue consumption

Table of Contents

1. Introduction

1.1 Introduction to Prominent

PROMINENT is a multiannual research and implementation program for the inland navigation industry which is funded by Horizon 2020. PROMINENT focusses on researching, testing and introducing alternative energy concepts and technologies for the European industry of inland navigation which are economically viable, safe and environmentally friendly.

Previous projects are, amongst others, PLATINA and PLATINA II. These projects supported the European Commission with the implementation of NAIADES and NAIADES II. The NAIADES II programme will facilitate long-term structural changes in the inland waterway transport sector. It also includes short term actions currently being undertaken by the Commission to address the difficult economic situation of the sector. Regarding new directives the European Commission is aware of the complexity of the existing market and makes [NAIADES IIa] & [NAIADES Iib] a few statements regarding emissions.

"The approach to be adopted on emission limits should be strictly technology neutral from the perspective of engine technology and fuel choice. Due to this, it is assumed that the technology with the best cost/benefit characteristics would prevail".

"When defining new emission limits for the IWT engines, it may be necessary to differentiate between small and large vessels and between existing and new engines because of the technological and economic limitations that existing engines and small vessels face. The Commission is also aware that sufficient time must be allowed for the sector to adapt to more ambitious emission limits."

"Although IWT emits much less CO_2 than road transport, the external costs of its emissions to air (air pollutants and CO_2) are roughly equal to those of road transport. This is due to the higher cost of IWT air-pollutant emissions."

1.1.1 Innovations improving the environmental performance of IWT

The European IWT fleet consists of approximately 18,000 vessels (and 40,000 crew members) and plays a crucial role in major transport chains. The sector has a large potential to become more environmentally friendly (i.e. reduction of Green House Gases and pollutants) and transport chains can also be improved by shifting more cargo to the IWT sector, which reduces congestion on the European roads. During the last years, the European Commission and the partners of the PROMINENT consortium have been investing in the promotion of (technological) innovations in the inland navigation industry. For more information on these innovations, the reader is referred to other PROMINENT reports, including reports D1.2 and D3.1.

1.1.2 PROMINENT objectives

PROMINENT aims at providing solutions to make inland navigation as competitive as road transport in terms of air pollutant emissions by 2020 and beyond. In parallel, PROMINENT aims at further decreasing the energy consumption and carbon footprint of IWT. This is an area where IWT performs better than road transport.

For inland waterway vessels, the current engine emission standards are CCNR Stage II and EU NRMM Stage IIIA. More stringent (future) emission standards like EU NRMM Stage V for inland vessels will require reductions of NOx and PM emissions up to 95%. PROMINENT aims to support the widespread implementation of innovative and environmentally friendly solutions in IWT to improve the sector's economic competitiveness and environmental performance. In addition to the development of "hardware" solutions, PROMINENT will focus in particular on improving the "orgware". In other words, PROMINENT will also focus on improving the framework conditions, which are primarily

responsible for the current stagnating innovation levels in the IWT sector. This will be done by setting clear and achievable targets.

1.1.3 Targets of PROMINENT

The goals of PROMINENT are:

1. Developing cost-effective solutions and standardised applications (reducing required investment costs):
   - ➔ 70%+ coverage – Developing solutions that are applicable to at least 70% of the European inland fleet and their operating areas.
   - ➔ 30% costs reductions – Reducing implementation costs of innovative greening solutions by 30%.
2. Involving all relevant actors concerned in the research and innovation process
   - ➔ 100% inclusive - All stakeholders required for the full coverage of the innovation cycle from initial concept to real-life deployment are to be taken on board.
3. Actively addressing and removing current implementation barriers by 2020
   - ➔ Visible and physical results by 2017 – Producing results on the ground during the project lifetime

PROMINENT has 2020 as ultimate time horizon. With respect to this time frame, another goal is:

4. Setting up a roll-out strategy which is geared towards producing the required full impacts by no later than 2020.

1.1.4 PROMINENT WP3 scope and definition

Work Package 3 explores the technical options for certification, monitoring and enforcement procedures for inland navigation vessel engines emissions, suitable for a range of 'greening technologies' and to comply with stringent legislation. Key aspect is the demonstration of effectiveness in practice. This is referred to as Real Sailing Emissions, the equivalent of Real Driving Emissions of cars and trucks.
New stringent emission limits require the drastic reduction of harmful emissions of NO_x and PM by up to 80 - 95% and the related reduction of external costs (negative health impact, damage to nature and buildings).

Certification for inland vessel engines can learn from certification of road vehicles. However, there are some important differences:
- a much longer lifetime of vessels and their engines;
- engines are replaced by new engines or rebuilt engines during the lifetime of a vessel;
- a larger need to clean up existing vessels, because of the lifetime;
- a larger need for retrofit solutions or clean fuel options (clean diesel, LNG, etc.);
- also a possible wish to separately purchase a new engine and the emission control systems;
- large differences in engine load for inland vessels, due to upstream and downstream sailing and other waterway characteristics.

The focus of WP 3 with the pilots in WP5 is to develop and test well-designed procedures for the certification, monitoring and enforcement of emission limits in the near future for a range of different vessel types, different operating profiles and different types of situations (new engine, engine overhaul, retrofit). This includes certification, (real life) verification, portable on-board measurements and continuous on-board monitoring. The options for collection of on-board monitoring results in a central database will be investigated. This is done for the enforcement of air pollutant emissions (NOx, PM) as well as for the creation of incentives for the vessel owner to benchmark and demonstrate its vessel's environmental performance. For this latter purpose, on-board monitoring data will be combined with open-source data such as AIS data and data on the waterway characteristics.

Already during this phase of technical research and development within PROMINENT, the views and opinions of stakeholders will be taken into account (notably in WP3, WP5 and WP6), including those of:

- the European Commission
- national and regional authorities
- providers of technical services
- classification societies
- manufacturers of engines, systems and inland navigation vessels and their organisations (e.g. Euromot, AECC, CESA and national organisations)
- vessel owners/ operators and their associations
- clients of transport such as shippers and multinationals interested in the environmental performance of their transport operations.

The following table shows the deliverables of WP3.

Name / sub WP	Main Deliverables
3.1 Improved certification, monitoring & enforcement	D3.1, State-of-the-art report
	D3.2, Assessment of certification procedures
	D3.3, Assessment of options for monitoring and enforcement
3.2 Prepare and Evaluate real life testing	D3.4, Design and project plan for the real-life testing
	D3.5, Ex-ante cost/benefit analysis of systems for certification, monitoring and enforcement

Table 1.1: Deliverables of Work Package 3

This report presents deliverable D3.5.

1.2 Objectives of certification, monitoring & enforcement

The main objective of WP3, certification, monitoring and enforcement is:
- To develop options for certification procedures for new engines and retrofit solutions for compliance with strict air pollutant emission limits (Stage V), both for laboratory and on-board certification;
- To evaluate certification & monitoring options to secure low Real Sailing (Pollutant) Emission (RSE, equivalent to Real Driving Emissions, or RDE, for trucks).

More specific goals for certification and monitoring & enforcement are:

- The goal of certification is to check if an engine with advanced emission control system (new or retrofit) or with an alternative or clean diesel fuel, complies with the emission regulations, to secure low Real Sailing Emissions and to facilitate monitoring and enforcement;
- The goal of monitoring and enforcement is to collect data on the Real Sailing Emissions and to verify if the engine complies with the certification. Presentation of emissions both in g/kWh as well grams per ton.km (CO_2, NO_x, PM).

This Deliverable 3.5 presents the analyses and comparison for the various options as regards their costs.

In order to achieve emission reduction, and the related benefits for society, it is a precondition to have a solid system for certification, monitoring and enforcement. Therefore, the costs of the certification, monitoring and enforcement shall be seen in view of these societal benefits. Furthermore, the costs can be compared with the cost of the hardware for greening technologies such as SCR, DPF and LNG. Moreover, the costs shall also be compared with the costs for the current

process of certification, monitoring and enforcement in order to get clear what the additional costs are for more advanced and reliable systems compared to the current ones.

The views and acceptance of stakeholders is of key importance. The project team of WP3 already represents several types of stakeholders such as Technical Services, inspection and certification, after-treatment system supplier and research institutes . The project team has been in dialogue with stakeholders such as CCNR and its Member States, European vessel owners organisations (EBU, ESO) and EUROMOT.

Further in-depth stakeholders' consultation is planned in the ongoing PROMINENT project and will be included in Deliverable 5.6. Main stakeholders which can provide valuable input include EC (DG GROWTH, DG MOVE), CCNR/ CESNI, engine manufacturers and after-treatment system manufacturers.

1.3 Relation between certification, monitoring and enforcement

There is an inseparable relation between certification, monitoring and enforcement. The only goal of 'stringent' legislation is low Real Sailing Emissions or low Real Driving Emissions, for respectively ships and road vehicles. The experience with road vehicles over the past decades shows that specific and stringent test and requirements for Real Driving Emissions are necessary to reach this goal, as discussed in Section 4.2 of the first PROMINENT report of certification, monitoring and enforcement (D3.1 the state-of-the-art). So, it is very desirable that requirements for Real Sailing Emissions are included in the formal type approval. This does not have to be very complex as shown in Deliverables D3.2 and D.3.3.

For monitoring and enforcement, the possibilities for economical and independent testing on-board of vessels is very desirable. An on-board test procedure described, can be used both as independent (in-use compliance) test as well as a test for retrofit emission control systems. Also the on-board monitoring, can be seen as an important option to secure low Real Sailing Emissions.

The history with trucks and cars proves that stringent legislation often does not lead to low Real Driving Emission. For diesel cars, NO_x emission in real world operation seems to be much higher than during the certification test cycle[2][3]. NO_x emissions of EURO V trucks under city driving conditions were typically a factor of three higher than the limit values[4]. For passenger cars the NO_x emissions are often 5 to 10 times higher. For trucks, the test procedures have been enormously improved with EURO VI, which has led to low real world NOx emissions, in line with the limit value[5].

[2] NO2-utslipp fra kjøretøyparken I norske storbyer: Utfordringer og muligheter frem mot 2025. Rolf Hagman, Karl Idar Gjerstad, Astrid H Amundsen. TØI rapport 1168/2011. November 2011. ISBN 978-82-480-1275-7 Electronic version
[3] TNO report MON-RPT-2010-02278 Verkennende metingen van schadelijke uitlaatgasemissies van personenvoertuigen met Euro-6 dieseltechnologie (exploratory measurements on pollutant emissions of Euro 6 diesel cars), W.A. Vonk en R.P. Verbeek, 8 september 2010
[4] Real-world NOx emissions of Euro V vehicles, Ruud Verbeek, Robin Vermeulen, Willar Vonk, Henk Dekker. TNO report MON-RPT-2010-02777, November 2010
[5] Robin Vermeulen, Jordy Spreen, Norbert Ligterink, Willar Vonk: The Netherlands In-Service Emissions Testing Programme for Heavy-Duty 2011-2013, TNO report : TNO 2014 R10641-2. May 2014

1.4 Criteria for assessment of certification and legislation

The following criteria are chosen for the evaluation of the measuring methods for certification and for monitoring & enforcement. Representativeness and accuracy are important for all purposes. However 'independent testing' and 'costs' are more important for (In Service Conformity, ISC) monitoring than for certification.

Criteria	Clarification
Representativeness of real-world emissions or 'Real Sailing Emissions'	How good is the relation between emissions of the formal test and normal operation?
Accuracy / Reproducibility	Assessment of accuracy of all parameters used and the effect of inaccuracy on the end result
Cost of certification to end-user or manufacturer	Especially tests for retrofit systems should be low, because these are usually single systems. Also for OEM products costs should be relatively low due to the small market size.
Independent testing and quality check	The possibility for independent testing from the manufacturers is important for in-use compliance tests, for monitoring and for enforcement
Suitability for Certification	Is the quality of the test (measurement) high enough for certification? An accuracy of 5% to 10% could be sufficient in certain cases
Suitability for Monitoring & Enforcement	Especially the costs should be low. Accuracy is usually less important. The limit value can be increased with measurement uncertainty.

Table 1.1 Criteria for assessment of certification

1.5 Definitions and list of abbreviations

Certification
Certification according to the European Directives 97/68/EC and 2004/26/EC, is the technical and formal determination of exhaust gas emissions according to a prescribed procedure of every new type of combustion engine with or without an exhaust after-treatment system. Certification contains an administrative and technical part. The emission tests are normally carried out in an engine laboratory, however for retrofit systems also on-board certification tests are carried out. The tests must be accurate and reproducible. In the type approval documents and emission certificates the specification of the engine and the emission test, results are reported.

Monitoring
Monitoring is the collection and storage of on-board 'real' sailing emissions and/or operating data. The monitoring system which contains sensors and a data logger is (permanently) installed on board and collects and stores continuously all the real time engine operating parameters and emission data.

Enforcement
Enforcement deals with activities which are dedicated to in-use compliance of combustion engines and aims to secure emission levels which are set in the classification phase. The enforcement activities are related to administrative and technical issues. It must contain test procedures and criteria to check the engine configuration and to criticize the measured engine emission.

Type approval
Type approval of engines and after-treatment systems means that only one system must be tested for all the same systems to have the certificate. When the to-be-certified system meets the type-approval emission requirements all these systems are automatically approved. Therefore type-approval tests happen before the market introduction of the system.

Compliance
Compliance is about actually meeting the legal technical requirements laid down in Regulations. It deals with the situation after a system's market introduction, e.g. the retrofit emission control system or a new engine provided by an Original Engine Manufacturer (OEM).

Retrofit
Retrofit refers to adding technology or features to an existing system. In the automotive industry this can be interpreted as any type of emission after-treatment system (e.g. SCR, DPF). For vessels, retrofitting is a much broader concept. Retrofitting can be any type of (large) change to a vessel and does not always relate to emission after-treatment systems. Elongation of a vessel, turning a tanker into a bulk carrier, changing the deck house of a bulker into a moveable superstructure so that the vessel can also carry containers: these are all examples of retrofits. These changes are fairly common in the inland navigation industry due to the long lifetime of vessels.

COP Conformity of Production
Engine manufacturers must apply in engine mass production emission conformity tests. In these tests some selected new produced engines are tested on an engine test bed and emission performances must be within a certain bandwidth. In the future, this practice can be continued because it serves very well mass production purposes. However, upgraded engines or retrofit equipment will probably be tested on board and the test possibilities of these individual engines differ per vessel. Due to this variety of test conditions the conformity of production methodology cannot be applied on board.

ISC In Service Conformity
IUC In-Use Compliance
ISC and IUC refer to investigations whether engines in practice comply with the emissions legislation.
According to [EC-CION 2016] these tests should be done for non-road mobile machinery engines.

RSE **Real Sailing Emissions**
RSE Factor

RSE is a new word in the context of NRMM, engines for Inland Waterway Transport. It is the equivalent to RDE, Real Driving Emissions for Road Vehicles. For HD vehicles and cars, specific RDE test procedures are in place. This is necessary to obtain a better correlation between type approval emissions and emissions in practice. Main differences between type approval and real life include the difference in load pattern and difference in ambient conditions (weather conditions).
Real sailing emissions are the average emissions in g/kWh during normal sailing (in the engine control area). The RSE factor is applied to the official limit values based on standard test cycles (E3, E2).

ECU **Engine Control Unit**

ECU's are electronic systems which are in place to control a combustion engine and its auxiliary systems. ECU's for example control the air-fuel mixture and ignition timing.

OBD **On Board Diagnostics**
NCD **NOx Control Diagnostics**
DTC **Diagnostic Trouble Codes**

OBD and NCD are basically the same. They are diagnostics securing compliant engine emissions during normal operations. If the OBD finds anomalies or problems it shows Diagnostic Trouble Codes. DTC will be stored electronically and an amber light will indicate the skipper that there are emissions problems.

EPM **Environmental Performance Monitoring**
OBM **On-Board Monitoring system**

Environmental Performance Monitoring uses an on-board monitoring system for the transmission of data on the environmental performance of a vessel to a central database and the relevant stakeholders. Data may include the performance of NO_x, CO_2, fuel consumption, power and location of a vessel to be used for several purposes. The stakeholders include competent authorities.

SRM **Standard Reference Material**
PEMS **Portable Emissions Measurement System**
SEMS **Smart Emissions Measurement System**

Standard Reference Material (SRM) is measurement equipment used in tests like those which are performed by SGS. SRM must be used for type approvals in a laboratory. PEMS was specially developed for road vehicles for measurement of Real Driving Emissions (RDE), an official part of the type approval. SRM, PEMS and SEMS can be used to test emissions on vehicles, vessels and machines in their real application. These 'portable laboratories' have analysers and equipment to measure the environmental performance of engines in real sailing conditions.

SEMS **Smart Emissions Measurement System**

SEMS is a smaller and simpler version of PEMS. SEMS combines data from the ECU with emission sensors to measure/compute the emission performance of engines in real sailing conditions.

DCU **Dosing Control Unit**

The Dosing Control Unit controls the dosing of reagent (urea, HC) in emission treatment systems like SCR catalysts.

Table 1.2 Abbreviations

AIS	Automatic Identification System
BTL	Bio-To-Liquid
CCNR	Central Commission for the Navigation of the Rhine
CESNI	Comité Européen pour l'Élaboration de Standards dans le Domaine de Navigation Intérieure
CI	Compression Ignition
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CoP	Conformity of Production
DCU	Dosing Control Unit
DOC	Diesel Oxidation Catalyst
DM	Diagnostic Message
DPF	Diesel Particulate Filter
DTC	Diagnostic Trouble Codes
EC	European Commission
EGR	Exhaust Gas Recirculation
EPM	Environmental Performance Monitoring
GHG	Green House Gas
GTL	Gas-To-Liquid
IMO	International Maritime Organization
ISC	In Service Conformity
ISO	International Standardization Organization
IWT	Inland Waterway Transport
LNG	Liquefied Natural Gas
NCD	NOx Control Diagnostics
NRMM	Non-Road Mobile Machinery
NTE	Not To Exceed value
OBD	On Board Diagnostics
OBM	On Board Monitoring
OCE	Off Cycle Emissions
OEM	Original Equipment Manufacturer
PM	Particulate Matter
PN	Particulate Number
RDE	Real Driving Emissions
RSE	Real Sailing Emissions
REC	Retrofit Emissions Control device
RPM	Rotations Per Minute
SCR	Selective Catalytic Reduction
SEMS	Smart Emissions Measurement System

2. Options for effective certification, monitoring and enforcement

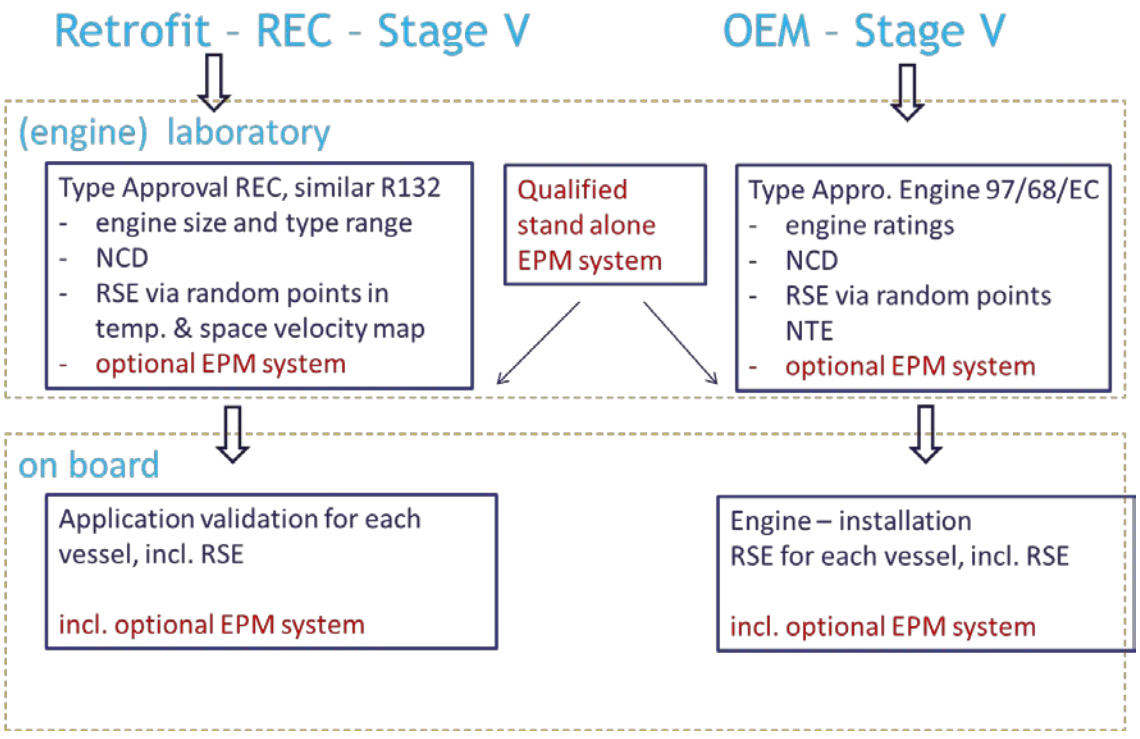
This chapter presents the main situations and options for emission certification, monitoring and enforcement. These are based on the detailed analyses which have been presented in the reports D3.2 and D3.3.

PROMINENT does focus on the existing fleet in particular as regards the challenge to reduce the emission to air, both air pollutant emissions such as NOx and PM as well as climate change emissions such as CO2 and methane (CH4).

It shall be noted however that the air pollutant emissions and also CH4 are subject to the Stage V emission limit legislation while for CO2 there is not a legislative framework in place as regards the limit values. However, CO2 is a major issue for the shippers and therefore suggested to be included on a voluntary basis in the monitoring of emissions.

In order to reach Stage V emission limits, existing vessels may be equipped with a new engine or a retrofit emission control system can be installed for the existing engine. Such systems shall be certified in view of the ship certificate to be granted. Furthermore, during operation, it is foreseen to have also on board monitoring systems for monitoring the performance and enforcement of emission limits. Moreover, there may also be a voluntary Environmental Performance Monitoring, for example to strengthen the attractiveness of the vessel for shippers with a strong interest to use vessels with low emission levels, notably CO2 (e.g. shippers active in the B2C markets with a CSR policy addressing the emissions of their transport operations).

Figure 2.1 Proposed scheme for Type Approval and on board validation for engines with Retrofit Emission Control device (REC). This is also recommended for new Stage V OEM engines.



In summary the following situations/options are:

1. Retrofit system for inland vessels (for Stage V);
2. Separate test for in service monitoring and enforcement;
3. Environmental Performance Monitoring (voluntary).

An EPM (Environmental performance monitoring system) can help to ensure that the Real Sailing Emissions (RSE) of IWT can be made transparent to the operator of the vessel and to other stakeholders. Such a system can transmit the relevant data of the vessel's environmental performance to a central database of e.g. administrations of the member states involved.

2.1 Retrofit system for inland vessels (for Stage V)

A retrofit after treatment system for an inland vessel shall be certified based on type approval. A broad family definition shall be pursued based on the temperature and space velocity range of the exhaust gasses. This also allows the application of retrofit systems for multiple engine types and brands. Certification tests shall be applied for the worst cases to ensure the proper functioning over the range of engines. These certification costs are a 'one-off' cost for the range of engines.

In addition to the certification it is foreseen to validate the proper functioning of the retrofit system by means of an on-board measurement after the installation. It shall be ensured that the on-board measurement can be done in a safe way.
Each 20,000 engine hours the system shall be checked by means of such an on-board measurement to see if the limit values are kept.

Furthermore, at periodic inspections to renew the vessel certificate, it shall be checked by the authorities that the specified components are used.

The costs of validation can be dependent of the type of equipment which is used. On-board tests with sensor based equipment is considered to be sufficient for this purpose, provided the equipment used is certified and calibrated.

2.2 In service monitoring

In service monitoring is meant as independent quality check on the emissions performance (whether they meet the required limit value x Conformity Factor). It is assumed that this is organised by and paid for by the European Commission or by member states.

It is envisioned that single measurements are done on a sample basis (not each vessel). This will take into account HC, NOx, CO, Particle Matter (PM) also the counting of the Particle Number (PN). The continuous monitoring of these air pollutant emissions is however not feasible for continuous monitoring.

It was concluded from research that in particular the NOx emissions need a more detailed monitoring since the NOx emission may fluctuate in practice while the NOx emission is a rather harmful emission. Furthermore, in particular the PM and PN requirements are relevant to ensure compliance with the NRMM Stage V limits. For vessels using LNG also methane slip is a relevant emission type to monitor.

The costs usually will be taken by authorities. If 'monitoring' would be a part of the type approval requirements, then the manufacturer would need to carry the costs

2.3 Environmental Performance Monitoring (voluntary)

Another option is to combine NOx and CO2 emissions via on board continuous monitoring. This may be an extension of the in service monitoring of NOx. It will require as well an independent validation. In addition the data shall be stored and visualised for the vessel owner and for possible clients (e.g. shippers) who would like to have an aggregated report on the emissions caused by the transport of their goods. The Environmental Performance Monitoring (EPM) will also require a periodic maintenance and check if the on-board measurement system is functioning properly.

3. Cost specification

3.1 Introduction

3.1.1 Current situation

It is important to acknowledge that there are costs as well in the current situation. The costs for certification for the current CCNR 2 engines are estimated to be between 50,000 and 70,000 euro. However these costs are already included in the purchasing price while there is no on-board validation or periodic check to ensure the proper functioning of the engine and the related emissions. This obviously includes a risk that the real sailing emissions of the CCNR2 engine deviate significantly from the engine test emissions according to the measurement points at the E2 or E3 cycle.

Another example of current costs is the measurement/certification to acquire a Green Award certificate in order to get a reduction of the port dues, for example in the Port of Rotterdam. These measurements are done by means of PEMS/SRM. Currently NOx, CO, HC and PM are measured on board. CH4 (methane slip) can also be measured. The costs of such a periodic on-board measurement are around 4500 euro based on expertise and experience by PROMINENT partners SGS, TÜV and TNO. It has to be noted that this is a basic measurement according to the E2 / E3 cycle with, in most cases, a simplified approach for the power output to estimate the output of the engine in kWh.

3.1.2 Future situation

The costs for the future situation shall be seen from the viewpoint to reach a better quality and reliability of the real sailing emissions. For the Stage V OEM engines, it is expected that certification costs will be rather high and certification will be needed for each engine brand and type. In particular as there are concerns about the very limited demand for new (expensive) engines, the certification costs being part of the total purchasing price are expected to be relatively high per engine. These high costs added on top of the additional costs for the SCR and DPF systems are, according to EUROMOT, a barrier for engine manufacturers to develop and bring new Stage V engines on the European market for usage in inland vessels.

Through the in service monitoring after installation of a new Stage V engines, the real sailing emissions shall be kept low and ensured though regular checks. Furthermore it is recommended that retrofit systems will be checked by means of on-board monitoring if they are properly installed, resulting in low emission levels. In addition, continuous monitoring of NOx can be applied as part of EPM (Environmental Performance Measurement), resulting in an increased reliability of low emission levels for NOx. In particular the NOx levels may vary in practice and therefore a continuous monitoring makes sense in addition to in service monitoring by means of periodic checks.

Costs to take into account are the initial costs for such hardware and also the periodic check and maintenance of on-board sensors and equipment. Furthermore, time is needed for on-board measurements and possibly the vessel would be out-of-service during these measurements.

3.2 Specification for Retrofit system certification and validation after installation

This specification is based on a thorough type approval of the REC (Retrofit Emission Control device) similar to UNECE R132 which was developed for road vehicles and land based NRMM.
It is also assumable that one laboratory type approval can be done for a wide range of engine families, including different engine manufacturers and a power range of 300 to 1000 kW. This is only possible if such a retrofit system has a modular configuration, in which e.g. standard catalyst blocks and DPF (diesel particulate filter) blocks are varied in number to fit it to the engine power rating and exhaust mass flow. The detailed sizing calculations and installation instructions shall be a part of the type approval, which also includes the evaluation of NOx Control Diagnostics, testing of DPF regeneration and durability testing.

The type approval (TA) costs are estimated as follows based on expertise and experience from the PROMINENT partners (notably TNO, TÜV, Multronic):

- Type approval in laboratory: 100,000 to 150,000 euro, including costs of the prototype system.
- Durability test on-board: 60,000 to 110,000 euro.

⇨ This makes a total of: 160,000 to 260,000 euro.

The durability test can also be done in the laboratory, but the costs would be much higher (some 500,000 EUR or more for a 2500 hrs durability test). For an on-board test the engine load factor should be taken into account. This will usually be lower on-board than in the lab. It is proposed that for the on-board test, the number of engine hours is doubled, or that the number of hours is multiplied by the ratio of the load factors (load lab/load on board).

The total type approval costs (160,000 to 260,0000 euro) shall be divided over the number of retrofit systems to be sold. For example if 100 units are sold, the costs per unit for the certification are estimated at about 2000 euro each. These costs will be included in the sales-price of the retrofit system.

Also relevant are the costs for the on-board validation (as part of the certification) after the installation of the retrofit system for the existing engine. These costs are estimated by PROMINENT partners (TNO, TÜV, SGS) at around 6,000 to 12,000 euro per vessel, depending on the number of engines. Moreover there is some uncertainty about the precise desired scope of validation procedure. This is still to be specified in details by an external working group, possibly hosted by CESNI.

Consequently the total certification costs (laboratory + on-board) are estimated in the range of 8,000 to 20,000 euro for ships. The following costs are estimated, depending on the number of propulsion engines:
1 engine: 6,000 € for on board validation + 2,000 € contribution to laboratory TA = 8,000 euro
2 engines: 8,000 € for on board validation + 4,000 € contribution to laboratory TA = 12,000 euro
3 engines: 10,000 € for on board validation + 6,000 € contribution to laboratory TA = 16,000 euro
4 engines: 12,000 € for on board validation + 8,000 € contribution to laboratory TA = 20,000 euro

We are aiming for a net time needed for executing these on board validation checks of approximately 4-8 hours. This is based also on the current procedures followed by SGS and others for on-board measurements for Green Award certificates, which is applied by ship-owners in order to get discount on the port dues. Depending on the desired scope as mentioned and the number of engines to be checked, it may be 1 day longer. The calculations and (formal) reporting can probably be done in one day, provided a clear format and calculation procedures are used.
During this validation also other elements for environmental performance can be checked and validated. These are for example fuel consumption meter(s) and the Environmental Performance Monitoring system.

For doing this validation, the necessary access points to exhaust pipe and engine signals shall be formally specified and build in and easy accessible to allow a safe and swift measurement.

Furthermore, a periodic check is proposed each 20,000 engine hours by means of an on board validation, with costs between 6,000 and 12,000 euro depending on the number of propulsion engines.

3.3 Specification for In Service Monitoring

In Service Monitoring is defined as independent measurements on a **sample bases**, initiated by the EC or by the member states. These measurements are recommended for ships with retrofit Stage V system or OEM Stage V engines which have been in service for some time (e.g. one or two years)

These tests **should be more extensive** than the on-board validation of new systems right after the installation. It is recommended to use PEMS/SRM equipment and include all gaseous components and also PM and/or PN emissions. The costs for these measurements will then range from about 6000 euro to 20,000 euro per ship based on expertise and experience by TNO and TÜV. The lower value is for mostly manual recordings of individual measurement points (within one day such as currently done to apply for Green Award certificates), while the higher number is for measurements with automatic continuous data recordings for several days (up to a week), for ships with more than one propulsion engine and with more extensive data analysis.

3.4 Specification for Environmental Performance Monitoring (voluntary)

This system will continuously monitor the fuel consumption, CO2 emissions and NOx emissions. The system costs including installation are estimated at 10,000 to 20,000 euro by TNO. This is excluding the fuel consumption meter itself, which is often already installed on the vessel or can be taken from the engine management system. If the latter is used, the values should be validated in the laboratory or on-board of the vessel. An additional 10,000 euro is estimated by TNO, if the fuel consumption meter needs to be specially installed.

The costs for a periodic check and maintenance (e.g. for calibration, sensor check/ cleaning/ renewal) are estimated at 1250 euro at each 5000 engine hours (source Multronic).

The costs for storage in database, visualisation of data and reporting of (aggregated/average) performance to stakeholders are estimated to be between 150 and 200 euro per month / 1800 to 2400 euro per year (estimation based on TNO expertise and experience).

Time needed for the initial installation of the system is 24 hours, while the periodic maintenance is estimated to take 8 hours (including cooling down of the equipment). During these hours the vessel will be out-of-service. As a result the opportunity costs shall be taken into account (fixed costs per day for the vessel which cannot be covered by turnover as result of transport services carried out during this time).

The table on the next page presents the estimated annual costs for operating the EPM system for the PROMINENT fleet families.

Table 3.1 Overview of annual costs for Environmental Performance monitoring

Vessel type / PROMINENT fleet family			Annual costs for the EPM system for continuous monitoring of fuel consumption, CO2 emissions and NOx emissions and reporting
Passenger vessels (hotel/cruise vessels)	1	PAX 135m	€ 4,923
Push boats <500 kW	2	Push boats <500 kW	€ 3,401
Push boats 500-2000 kW	3a	PushB2L	€ 4,549
	3b	PushBII-1	€ 3,934
Push boats >=2000 kW	4a	Push B4	€ 7,389
	4b	Push B6	€ 8,220
Motorvessel dry cargo >=110m length	5a	MVS 110m	€ 3,663
	5b	MVS 135m	€ 4,181
Motorvessel liquid cargo >=110m length	6a	MTS 110m	€ 3,823
	6b	MTS 135m, M11	€ 4,616
	6c	MTS 135m, M12	€ 4,766
Motorvessel dry cargo 80-109m length	7a	MVS 80m	€ 3,428
Motorvessel dry cargo 80-109m length	7b	MVS 86m	€ 4,401
Motorvessel dry cargo 80-109m length	7c	MVS 105m	€ 4,485
Motorvessel liquid cargo 80-109m length	8	MTS 86m	€ 4,465
Motorvessels <80 m. length	9a	MVS 67m	€ 4,351
	9b	MVS 55m	€ 4,320
	9c	MVS 50m	€ 4,302
	9d	MVS 38,5m	€ 4,340
Coupled convoys (mainly class Va + Europe II lighter)	10	C3L/B	€ 6,043
Push Barge, 4 units, Danube			€ 6,438
Push Barge, 8/9 units, Danube			€ 6,165

3.5 Summarising overview of costs

The following table summarises the costs for the various options.

Table 3.2 Overview of costs for on board validation for retrofit systems, In Service Monitoring and Environmental Performance monitoring

Type	On board validation/ certification Retrofit systems (REC)	In service monitoring (ISM), PEMS/SRM for NOx, CO, HC, PM, PN and CH4 for gas engines	Environmental Performance Monitoring, Continuous for fuel consumption, CO2 and NOx
Initial investment	-		15,000 euro*
Certification (lab type approval)	2,000 euro per engine		
Out-of-service time at installation	-	-	24 hrs
Periodic costs, In service monitoring-/enforcement	6,000 -12,000 euro, depending on number of engines (1-4)	6,000 -20,000 euro per vessel	150 to 200 euro per month and 1,250 euro @ each 5,000 engine hrs
Out-of-service time periodic maintenance	8 hrs	8 hrs	8 hrs
To be paid by	Supplier or ship owner	EC or member state	ship owner

* 15000 EUR based on the assumption that fuel consumption meter is already installed

4. Comparison with investment costs of green technologies

As part of certification for retrofit systems fulfilling stringent emission limits, a check shall take place after installation whether the emission levels are compliant with the type approval. The major technology for retrofitting is the application of SCR and DPF systems on existing engines. For these installations the certification needs to be provided and an in service conformity check shall be executed by means of periodic on-board monitoring.

It is suggested by PROMINENT to have these on-board measurements (validation) as obligatory part of certification for the retrofit emission control systems. This shall be done directly after installation and subsequently after each 20,000 engine hours. The cost for the certification (estimated at 2,000 euro per engine) and on-board monitoring can be compared with the overall annual cost for running the application of SCR and DPF for various configurations and vessel types.

A calculation was therefore made based on the ex-ante Cost / Benefit assessment made in WP2 for these after-treatment technologies, differentiated to high/low speed engines and CCR1/CCR2 low or high engines.

Since the cost for the certification and the on-board measurement are fixed, the highest cost share is found at the application CCR2 and high speed engines, applied for small vessels. For the CCR2 high speed engines the REC system requires a bit less urea and the back pressure is less of an issue resulting in a smaller size of the DPF. However, a CCR1 engine would require a bit more urea to bring the NOx levels down to the Stage V limits while the allowed back pressure is more stringent, which requires a larger DPF unit to be installed.

It can be concluded from the table that there are rather high costs for the annual operation of an SCR-DPF system. For large push boats this can run up to figures well over 200,000 euros.

The detailed results are presented in the following tables on the next pages.

It can be concluded that for application of SCR and DPF at the CCR2 high speed engine, the costs for the certification and monitoring are within a range between 3.0% and 9.9%. The highest share (9.9%) is seen for a very small motor vessel with small engines and low number of engine hours. The lowest share (3.0%) is seen at application of SCR and DPF on push boats with large engines and a lot of sailing hours per year.

It can be seen in table 4.2 that the range for CCR1 low speed engines is slightly lower. For this engine type the bandwidth is between 2.3% and 8.5%.

Table 4.1 Comparison of costs for the on board monitoring for Retrofit Emission Control devices (REC) compared to the annual running cost of the devices (SCR and DPF) for CCR2 high speed engines

Vessel type / PROMINENT fleet family costs of periodic measurement each 20,000 hrs			Interval periodic check (years)	Cost share per year for certification and on board measurements	Total cost per year application SCR-DPF at **CCR2 high speed engine**	Share in cost for certification incl. on board validation
Passenger vessels (hotel/cruise vessels)	1	PAX 135m	6.9	€ 1,826	€ 38,520	4.7%
Push boats <500 kW	2	Push boats <500 kW	13.8	€ 576	€ 8,496	6.8%
Push boats 500-2000 kW	3a	PushB2L	5.7	€ 2,054	€ 32,211	6.4%
	3b	PushBII-1	6.9	€ 1,656	€ 29,077	5.7%
Push boats >=2000 kW	4a	Push B4	2.8	€ 5,008	€ 137,417	3.6%
	4b	Push B6	2.8	€ 5,180	€ 172,784	3.0%
Motorvessel dry cargo >=110m length	5a	MVS 110m	10.3	€ 777	€ 22,624	3.4%
	5b	MVS 135m	6.2	€ 1,870	€ 41,979	4.5%
Motorvessel liquid cargo >=110m length	6a	MTS 110m	10.3	€ 848	€ 24,504	3.5%
	6b	MTS 135m, M11	6.2	€ 1,945	€ 45,637	4.3%
	6c	MTS 135m, M12	6.2	€ 1,970	€ 45,851	4.3%
Motorvessel dry cargo 80-109m length	7a	MVS 80m	13.0	€ 610	€ 10,962	5.6%
Motorvessel dry cargo 80-109m length	7b	MVS 86m	11.7	€ 736	€ 13,560	5.4%
Motorvessel dry cargo 80-109m length	7c	MVS 105m	10.6	€ 821	€ 21,559	3.8%
Motorvessel liquid cargo 80-109m length	8	MTS 86m	11.7	€ 684	€ 18,664	3.7%
Motorvessels <80 m. length	9a	MVS 67m	12.0	€ 757	€ 10,094	7.5%
	9b	MVS 55m	12.9	€ 612	€ 7,449	8.2%
	9c	MVS 50m	13.4	€ 591	€ 6,812	8.7%
	9d	MVS 38,5m	11.8	€ 665	€ 6,689	9.9%
Coupled convoys (mainly class Va + Europe II lighter)	10	C3L/B	3.5	€ 3,235	€ 73,749	4.4%
Push Barge, 4 units, Danube			3.3	€ 3,145	€ 93,671	3.4%
Push Barge, 8/9 units, Danube			4.6	€ 2,621	€ 80,304	3.3%

Table 4.2 Comparison of costs for the on board monitoring for Retrofit Emission Control devices (REC) compared to the annual running cost of the devices (SCR and DPF) for CCR1 low speed engines

Vessel type / PROMINENT fleet family costs of periodic measurement each 20000 hrs			Interval periodic check (years)	Cost share per year for certification and on board measurements	Total cost per year application SCR-DPF at **CCR1 low speed engine**	Share in cost for certification and on board measurements
Passenger vessels (hotel/cruise vessels)	1	PAX 135m	6.9	€ 1,826	€ 47,974	3.8%
Push boats <500 kW	2	Push boats <500 kW	13.8	€ 576	€ 10,352	5.6%
Push boats 500-2000 kW	3a	PushB2L	5.7	€ 2,054	€ 38,970	5.3%
	3b	PushBII-1	6.9	€ 1,656	€ 35,418	4.7%
Push boats >=2000 kW	4a	Push B4	2.8	€ 5,008	€ 174,991	2.9%
	4b	Push B6	2.8	€ 5,180	€ 222,493	2.3%
Motorvessel dry cargo >=110m length	5a	MVS 110m	10.3	€ 777	€ 28,826	2.7%
	5b	MVS 135m	6.2	€ 1,870	€ 52,304	3.6%
Motorvessel liquid cargo >=110m length	6a	MTS 110m	10.3	€ 848	€ 31,261	2.7%
	6b	MTS 135m, M11	6.2	€ 1,945	€ 56,918	3.4%
	6c	MTS 135m, M12	6.2	€ 1,970	€ 57,189	3.4%
Motorvessel dry cargo 80-109m length	7a	MVS 80m	13.0	€ 610	€ 13,563	4.5%
Motorvessel dry cargo 80-109m length	7b	MVS 86m	11.7	€ 736	€ 16,844	4.4%
Motorvessel dry cargo 80-109m length	7c	MVS 105m	10.6	€ 821	€ 27,363	3.0%
Motorvessel liquid cargo 80-109m length	8	MTS 86m	11.7	€ 684	€ 23,719	2.9%
Motorvessels <80 m. length	9a	MVS 67m	12.0	€ 757	€ 12,199	6.2%
	9b	MVS 55m	12.9	€ 612	€ 8,903	6.9%
	9c	MVS 50m	13.4	€ 591	€ 8,081	7.3%
	9d	MVS 38,5m	11.8	€ 665	€ 7,822	8.5%
Coupled convoys (mainly class Va + Europe II lighter)	10	C3L/B	3.5	€ 3,235	€ 91,903	3.5%
Push Barge, 4 units, Danube			3.3	€ 3,145	€ 120,686	2.6%
Push Barge, 8/9 units, Danube			4.6	€ 2,621	€ 102,267	2.6%

5. Costs of independent in service monitoring

It is suggested that an independent in service monitoring is organised by EC or member states in order to ensure that the real sailing emissions are low and compliant with the Stage V emission limits. This shall be checked by means of measurements for a sample of vessels.

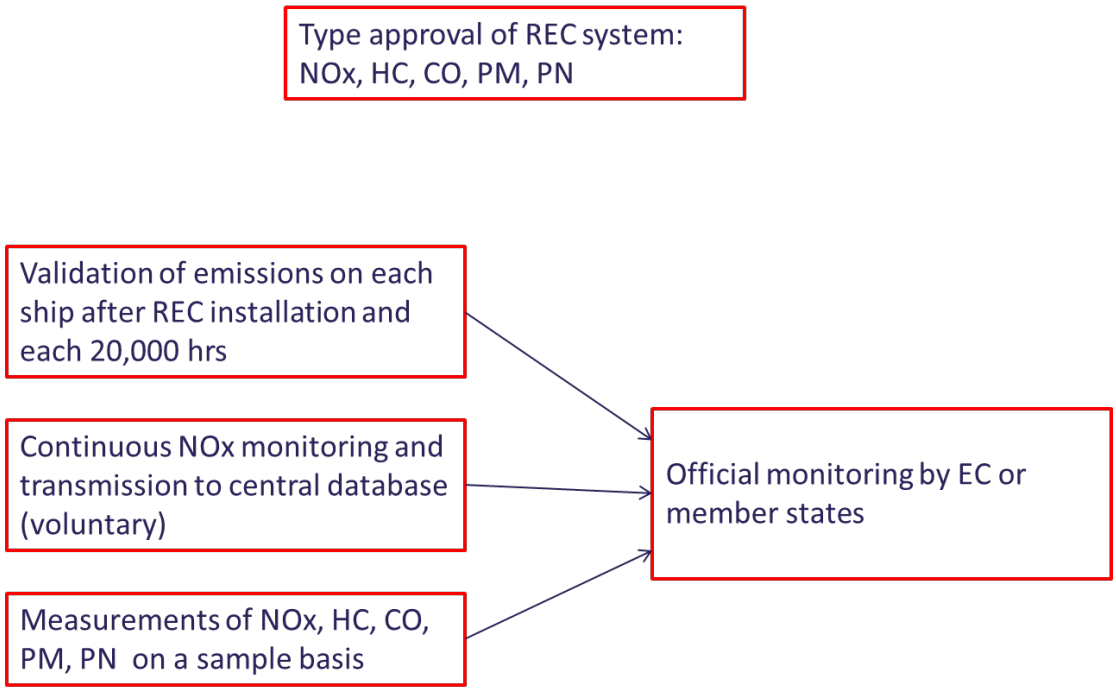
The desired sample size is to be determined in future by a working group, possibly hosted under CESNI, or by individual Member States. In the REC certification process already it shall be foreseen to include on board diagnostics and procedures to prevent malfunctioning or tampering with the REC devices. Therefore, already low real sailing emissions shall normally be reached through the requirements for the REC devices and the internal monitoring system to make sure that the system is functioning properly.

The In service monitoring can consist primarily of a number of periodic measurements and possibly be combined with measurements from continuous monitoring from the voluntary EPM system.

For example in case of subsidies granted by member states or EC for greening technologies to reach stage V (such as SCR, DPF, LNG for instance), it may be considered to have as a condition the continuous (EPM) or periodic in service monitoring (ISM) as part of the funding agreement. Subsidy schemes could be linked to the condition that the ship-owner agrees to share the NOx measurement data with the authorities.

The following scheme presents the approach that could be followed.

Figure 5.1 Proposed components for monitoring to ensure compliance with the Stage V limits.



The costs for the In Service Monitoring will subsequently depend on the number of vessels to be monitored and, of course, the number of retrofit systems implemented in the IWT sector. The latter will mainly depend on the availability of grants from public authorities on short term since there is no business case for the sip-owner/operator to invest in after-treatment systems.

6. Conclusions and recommendations

6.1 Certification and monitoring of Retrofit Emission Control devices

The proposed procedure to meet Stage V emission limits consists of a laboratory type approval of the REC (similar to UNECE 132) plus an on-board validation for each vessel. The price of the laboratory type approval is estimated to be in the range of 160,000 to 260,000 euro (including on-board durability test). Based on 100 REC units per REC manufacturer, the costs would be around 2,000 euro per REC device (the SCR-DPF system per engine).

On top of that comes the on-board validation with an estimated price range of 6,000 to 12,000 euro per vessel depending on the number of engines and precise validation procedure. The total certification costs (laboratory + on-board) are consequently estimated in the range of 8,000 to 20,000 euro per vessel, depending on the number of propulsion engines. For a vessel with one engine it is estimated at 8,000 euro and for a vessel with 4 engines the costs are estimated at 20,000 euro.

Within the total yearly operational costs of these REC systems, the certification and periodic monitoring costs are consequently in the range of 2% to 9% of the total emission control costs, depending on: the type and number of engines and the engine hours per year.

Since the certification process of Retrofit Emission Control devices is a critical element for the implementation of after-treatment systems in the IWT market is it highly recommended to set-up a working group, most likely under the umbrella of CESNI, to develop in more detail the procedures and requirements for certification and to determine the process for the In Service Monitoring (e.g. desired sample size).

6.2 In-Service Conformity testing

It is recommended that authorities organise independent SRM/PEMS measurements on a sample basis. These measurements are recommended for ships with retrofit Stage V system or OEM Stage V engines. The costs of these measurements range from 6,000 to 20,000 euro per ship, depending on the extensiveness of the test procedure .

These measurements are complementary to the Environmental Performance Monitoring (EPM) and the on board validation when the systems are newly installed (and after each 20,000 engine hours). The SRM/PEMS should focus on systems which have been in use for some time and include particulate mass and/or particle number emissions.

6.3 Environmental Performance Monitoring (EPM)

EPM includes the continuous monitoring of NOx, fuel consumption, CO2, location and distance. This will then be used for various purposes such as the official reporting of NOx to authorities (e.g. in relation to grants for retrofitting SCR-DPF systems), fuel consumption to the ship owners and CO2 and NOx to (clients of) ship owners.

EPM is recommended as a voluntary option for both engines with Retrofit Stage V emission control system as well as ships with OEM Stage V engines. It is suggested by PROMINENT to make EPM mandatory in the context of to be developed financial incentive programs in order to have a close control on the NOx levels. NOx is mainly sensitive to malfunctioning or tampering with systems while it is an emission that has a severe impact on air quality (high external costs are involved for society).

The annual costs of this voluntary system are within a range between 3,400 and 8,200 euro per year. This is relatively limited compared to the total annual running cost of the vessel. In particular if this also leads to more awareness of the crew and management to reduce fuel consumption and related CO2 emissions, the fuel savings may already offset the additional costs. Furthermore, EPM can be used in the marketing, in order to allow clients (e.g. shippers) to choose for transport solutions with low CO2 and pollutant emissions which shippers can integrate in their Corporate Social Responsibility programmes. Therefore, ships equipped with EPM may have a better position on the market and may get better contracts.

Annex 1: Recommendations monitoring and Enforcement (D3.2/D3.3)

Monitoring in the context of the Non Road Mobile Machinery Directive, 97/68/EC, means that the EC or EC member states evaluate whether the emissions in practice correspond to those during the Type Approval of engine. This can also be referred to as **'In-Service Conformity'**. In the proposal for Regulation 7795/16 article 18, 14 April 2016, monitoring is included as follows:
"the Commission will conduct monitoring programs to determine to what extent for every engine category, the emission from the test cycle corresponds to the emissions measured in actual operation. Those programmes and their results shall annually be the subject of a presentation to the Member States and subsequently of a communication to the public".
In this report the emission in actual operation are referred to as **'Real Sailing Emissions, RSE'** in line with 'Real Driving Emissions, RDE' the official term used for road vehicles.

Enforcement needs to be carried out by Type Approval authorities, if for a certain engine type the emissions in actual operations deviated too much from the emissions during the type approval. The manufacturer of the engine or the Retrofit Emission Control system should be liable for these deviations. The regulation should describe in sufficient detail how the tests in actual operation can be carried out.

Monitoring and Enforcement test procedure

It is recommended to give the RSE test an official status for both OEM engines as well as for engines with REC. The test does not have to be carried out during the Type Approval of the engine, but should be carried out during the validation with the engine or REC installation in a vessel.

In particular the In Service Conformity / RSE test procedure should include:

- The **engine control area**, in the past also referred to as **Not To Exceed area, NTE**. For inland navigation vessels, the initial proposal is included in the proposal for Regulation 7795/16. In this proposal, the area is defined as a band width around the propeller curve in the engine map. Also the power range is limited from about 25% to 100% of maximum power. It should be noted that this may lead to relatively high NOx emissions at idle and low load operation. This may be high total NOx emissions for applications with a high share of idle and low load operations. For example for vessels such as ferries and work ships which may have a very low average load.

- Emission components and limit value:
  The relevant emission components are currently limited to NOx and NH3. It can be considered to add particulate mass (PM) or Particulate Number (PN) at some point in the future.
  The limit value for the NOx emissions, which is currently used can be defined as follows:

  NOx_{RSE} **<** RSE factor **x** Limit value Type approval (dimension g/kWh)

  RSE factor could vary from about 1.2 to 2. This includes than an allowance for measurement accuracy (on board) and ambient conditions. Recommended is an RSE factor of 1.5. Possibly with an initial value of 2.0 to build up experience with variations in practice.
  For NH3 the same RSE factor is recommended (but then based on a ppm limit value).

- The ambient conditions:
  NRMM regulation requires NOx control at ambient conditions between -7° and +35°C.

- Possible allowance for averaging (if any):

According to the current proposal (proposal for regulation 7795/16??), every single point with the engine control area should comply with the RSE limit value. So no averaging across several points within the engine map. Averaging would be limited to several minutes.

Measurement equipment

It is recommend to allow a range of measurement options, as long as the labs are accredited for the particular measurement. In that way, volume of data can be collected in a costs effective manner.

Therefore, the options described above are all recommended for monitoring:

- SRM / PEMS: Standard Reference Material, which includes PEMS kind of systems currently used for road transport
- SEMS: Smart Emissions Measurement System. A general correlation should be available of SEMS with SRM or lab equipment, including the calculation procedure.
- EPM: the continuous sensor based monitoring could provide massive input for the understanding of Real Sailing Emissions. Proper working of each EPM system should be verified after the installation by an accredited organisation.

Annex 2: Recommendations Environmental Performance Monitoring (D3.2/D3.3)

Environmental Performance Monitoring - EPM, is defined as a voluntary continuous monitoring of environmental parameters on board of a vessel with a daily wireless (GPRS) data transmission to a central database. Originally EPM was referred to as On Board Monitoring (OBM), but this name would give the impression of obligatory monitoring of pollutant emissions in line with OBD (On Board Diagnostics).
EPM is wider, apart from NOx, it also includes fuel consumption, CO_2 emissions, engine load pattern and vessel parameters like location, route and speed.

EPM can be used for several purposes:

- Evaluate the performance of emission control systems
- Report NOx in g/kWh to regional or national authorities (if part of an incentive program or a voluntary program investigating In Service Conformity).
- Report NOx and CO_2 performance in g/km, g/ton.km or g/trip to clients
- Evaluate engine size, driveline configuration and efficiency of the overall energy system.
- Get insight and optimise the sailing pattern (efficient navigation)

Recommended parameters

It is recommended to monitor the following parameters with EPM.

One hour (average) values for propulsion engine(s):

- Average power (excluding idle)
- g/kWh NOx emissions (Power > 10%)
- g/kWh NOx emissions in accordance to 'In Service Conformity' ISC, emissions in Engine Control Area (probably only power larger than about 20-25%)
- l/h fuel consumption
- DTC: Diagnostic Trouble Codes

Cumulative per trip or during a longer period:

- Propulsion engine(s) idle time
- g/km NOx emission (including idle)
- litre/km fuel consumption
- kg/km CO2 emissions (based on fuel consumption)
- NOx and CO2 per ton.km emissions, based on nominal or actual cargo load
- Binned data: running time per power bin (10 power bins for 0-100%). Refer to example in the figure below.
- Binned data: average NOx in g/kWh per power bin (9 power bins 10% - 100%)

Axillary engines / generator sets per trip or during a longer period:

- running time for each generator set
- average (electric) power while running
- Calculation g/km emissions based on standard specific fuel consumption and emission factors (dependent on engine CCNR or EU Stage class)

Alternatively, for simplicity, for the auxiliary engines a default energy consumption and NOx emission can be taken into account. Default values are for example available from national emission factors for Non Road mobile machinery (including inland navigation vessels).

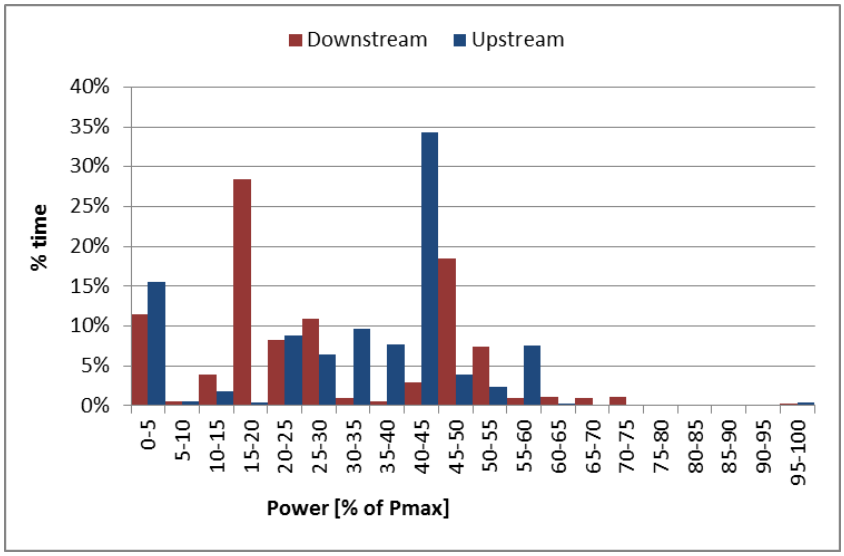


Figure: Engine power distribution for a container vessel, Rotterdam-Duisburg

Equipment

Currently, within PROMINENT, on-board data is recorded on a per second basis. Also experience is built up with transmissions of per second data to a central database. The load patterns of vessels are however fairly stationary. Engine speed and power can remain constant for hours. So in a later phase it can be decided to average data per minute, before sending it to the central database. From that further averaging can take place to parameters per hour and per trip.

Equipment for EPM monitoring is basically very compact digital equipment which fits in a shoe box. It uses an automotive NOx/O_2 sensor and a digital connection to the Engine Control Unit (ECU). Fuel consumption is obtained from the engine management or from a separate fuel consumption meter. A GPRS unit is used to transmit the data to a central database.

Annex 3: Conclusions made in D3.2/D3.3

In D3.2/D3.3 an assessment of certification procedures has been performed for new engines and retrofit solutions for compliance with strict air pollutant emission limits (Stage V). This included certification and monitoring options to secure low Real Sailing Emission (RSE). This lead to the following conclusions:

1. Measuring methods

The laboratory and on-board measurement methods were evaluated based on criteria. The summary is provided in the table below. Main conclusions of this evaluation are: the lab based measurement excel in accuracy and are therefore very suitable for certification. The on-board measuring methods score better for representativeness of Real Sailing Emissions and are very suitable for on board validation of compliance with stringent standards (Stage V) and for In Service Conformity measurements.

Criteria	Laboratory tests		On-board tests with SRM or PEMS	On-board sensor based measurement
	Original ISO cycle	ISO cycle + additional test points		
Representativeness of real-world emissions or Real Sailing Emissions	poor / average	average / good	good (with additional points)	good (NOx) (with additional points or if continuous)
Accuracy / Reproducibility	good	good	good / average	average
Cost of certification to end-user or manufacturer	average	average	average	average / good
Independent testing and quality check	poor	poor	good	good
Suitability for Certification	good	good	average / good for on board validation	average /good for on board validation
Suitability for Monitoring & Enforcement	poor	poor	good	good

2. Retrofit Emission Control devices (REC)

A type approval of REC for vessels is recommended in line with UNECE R132[6], but with a validation of the emissions performance on board of each vessel. In order to be able to act quickly, a procedure under the umbrella of EC or interested member states is recommended (rather than a formal UNECE procedure).

The current practice regarding Retrofit Emission Control deals with a single engine test report which can be used as an incentive at national level due to the fact that the current practice has a few shortcomings such as quality variation, no check of OBD/NCD system, etc..

[6] UNECE R132 was specially developed for road vehicles and land based NRMM.

3. Real Sailing Emissions (RSE)

In terms of Real Sailing Emissions a very similar procedure for both engines with REC and OEM engines is recommended.

The proposed procedure consists of a set of measurements in random points in a laboratory (type approval, as to be implemented with stage V) and on-board measurements within the NTE area (validation). The on-board test procedure can be performed with laboratory quality equipment (SRM, e.g. PEMS), or with sensor based equipment (such as SEMS or EPM). For each test point within the NTE area the limit should be below the In Service Conformity (ISC) value in g/kWh or g/kg CO_2. The ISC value is defined as the RSE-factor times the Stage V limit value.

4. In terms of **monitoring and enforcement,** the same procedures for engines with REC and OEM engines should be applied. The ISC monitoring should be in line with land based NRMM. An independent testing with Real Sailing Emissions RSE test procedure on-board of vessels can be performed with the following recommended options:

- PEMS - similar to road vehicles;
- SEMS - as an economic option;
- EPM – as an option for continuous monitoring on board of vessels, which includes energy consumption and CO_2 emissions.
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5. The main contributions of **PROMINENT** is related to the evaluation of:

- the load patterns of different types of vessels and different routes;
- the on-board measurement options SRM/PEMS – SEMS – EPM;
- EPM options for broad environmental performance.

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