START Thinking and KEEP Thinking

A CEDA Information Paper

ENERGY EFFICIENCY CONSIDERATIONS FOR DREDGING PROJECTS AND EQUIPMENT

Central Dredging Association

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Contents

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Introduction

The Central Dredging Association (CEDA) is committed to environmentally responsible management of dredging activities. This paper has been produced by the CEDA Working Group Energy Efficiency. It seeks to raise awareness, and to help structured decision making, in support of energy efficiency in line with sustainability and cost reduction.

In dredging, as with many other activities, the driver to improve energy efficiency traditionally was, and is, the continuous quest to reduce costs. Today, it is widely accepted that emissions related to fossil fuels contribute to climate change and global warming. Given this context, there is a growing interest in energy efficiency in relation to dredging projects and equipment.

This CEDA paper aims to provide information on the topic. Section 1 defines the drivers behind our quest for energy efficiency, and benchmarks the CO_2 emissions of the dredging industry. Section 2 summarises actual global, interregional and national policies, and legislation with a focus on Greenhouse Gas (GHG) emissions. Section 3 considers the topic from the perspective of a dredging project. Section 4 considers it with a focus on the dredging equipment.

1 Energy Efficiency Drivers and Benchmarks

1.1 Drivers

In dredging, as with many other activities, the driver to improve energy efficiency traditionally is the continuous quest to reduce costs. An additional contemporary driver for improving energy efficiency, is the growing public awareness regarding the adverse effects of fuel-related emissions.

Fuel-related emissions affect air quality at a local- and global level. At a local level, air pollutants like sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter, can have a negative impact on public health amongst other things. On a global level, Greenhouse Gases (GHG) like carbon dioxide (CO_2) and methane (CH_4), contribute to global warming.

Table 1-1 gives a brief summary of the two emissions categories that relate to onboard combustion processes.

EMSA
European Maritime Safety Agency

Air Emissions – Air Pollution and GHG Emissions

	Air Pollution	Greenhouse Gas Emissions
Emitted substances	Sulphur Oxides (SOx), Nitrogen Oxides (NOx), Particulate Matter	Carbon Dioxide (CO_2), Methane (CH_4).
Origin of Emissions	Combustion processes, either in Internal Combustion engines on-board, boilers, incinerators, gas turbines. **SOx** – emitted when fuels containing sulphur are consumed. **NOx** – Result of endothermic reaction between Nitrogen and Oxygen during combustion processes, at high temperatures. **PM** - Sum of all solid and liquid particles suspended in air many of which are hazardous. Combustion of fossil fuels such as coal, oil, and petrol can produce: • **coarse particles** from the release of non-combustible materials such as fly ash, • **fine particles** from the condensation of materials vaporized during combustion, and • **Secondary particles** through the atmospheric reactions of sulphur oxides and nitrogen oxides initially released as gases.	**CO_2** - Result from combustion processes where oxidation of carbon occurs. Carbon dioxide and water is the results of complete combustion of fossil fuels where carbon molecules undergo an oxidation process. Carbon Monoxide (CO), a toxic poisonous gas, is the result of incomplete combustion processes where full oxidation of carbon molecules did not occur. **CH_4** – potential emissions of methane resulting from the use of natural gas as fuel in dual-fuel engines. Methane can be emitted through methane leakage during fuel production, storage, transportation and bunkering and through methane slip, unburned methane emissions released during vessel operation due to incomplete fuel combustion in the engine.
Environmental Impact	**SOx** - Local/regional impact. SO_2 contributes to acid deposition which, in turn, affects the quality of soils and water. SOx are known as precursors for Particulate Matter formation. **NOx** – reacts with ammonia to form nitric acid vapour and related particles that can penetrate deeply into sensitive lung tissue and damage it, causing premature death in extreme cases. From the reaction with Volatile Organic Compounds (VOC), in the presence of sunlight, Ozone can cause adverse effects such as damage to lung tissue and reduction in lung function mostly in susceptible populations (children, elderly, and asthmatics). Ozone can be transported by wind currents and cause health impacts far from the original sources.	**CO_2** – increase of anthropogenic CO2 to the atmosphere with consequential contribution to Greenhouse Gas effect and Global Warming. Climate Change, amongst other direct effects of global temperature increase. **CH_4** – the same effects of CO2, but with a Greenhouse Gas Potential 25 time higher than CO2 over 100 yrs.

Table 1-1: Fuel-related emissions: Air pollution and GHG emissions (source: emsa.europa.eu).

1.2 Benchmarks

On 4th August 2020, the International Maritime Organization (IMO) released the final report of the Fourth IMO Greenhouse Gas Study. Key findings include:

- The total GHG emissions from shipping (including CO_2, CH_4 and N_2O, expressed in CO_2 equivalents) increased by 9.6%, from 977 million tonnes, in 2012, to 1,076 million tonnes in 2018;
- In 2012, CO_2 emissions were 962 million tonnes. This increased by 9.3%, in the period to 2018, to 1,056 millon tonnes;
- The share of shipping emissions, as a percentage of global anthropogenic GHG emissions, increased from 2.76%, in 2012, to 2.89% in 2018.

In the IMO's reference year 2008 (see Section 2.1), the global CO_2 emissions were estimated to be 32,204 million tonnes. Of that figure, 921 million tonnes (2.9%) is CO_2 emissions related to international shipping. (Source: Third IMO GHG Study, 2014)

The CO_2 emissions of the World Dredging Fleet was estimated to be 6.3 million tonnes for 2008. This represents about 0.6% of the CO_2 emission for international shipping (see Figure 1-1). (Source: EuDA position paper on Decarbonisation of Dredging Projects).

The World Dredging Fleet's contribution to the global and international shipping CO_2 emissions is therefore relatively small. However, for fleet owners in the transport and construction sector (e.g. a trucking or construction company, an aviation company, a shipping company or a fleet owner of dredging vessels), typically the fuel consumption of their fleet can significantly contribute to the total CO_2 footprint of these companies.

As a result, energy efficiency is often a prime objective within the sustainability strategy of fleet owners.

CEDA WGEE - Benchmarks

Some numbers from a Global Perspective

CO_2 Emissions in Absolute Numbers:

The **World Dredging Fleet** was estimated to have produced:
6.3 Mton of CO_2 in **2008** (=IMO 'reference year').

The emissions of the **European Dredging Industry** (EuDA members) was:
3.6 Mton of CO_2 in **2008.**

CO_2 Emissions in Relative Numbers:

The emissions of the **World Dredging Fleet** is:
ca. 0.6% of the total CO_2 emissions of **Global Shipping.**

The emissions of **Global Shipping** is:
ca. 2% of the **Global total CO_2** emissions.

Figure 1-1: Benchmarks.

2 Policies and Legislation on GHG emissions

A contemporary driver for improving energy efficiency is the growing awareness of the adverse effects of fuel-related emissions. This awareness has resulted in regulations for the prevention of air pollution, which seek to minimise airborne emissions of gases including SO_x and NO_x. It has also led to mandatory technical and operational energy efficiency measures, and regulation for the reduction of GHG emissions from ships. The prime focus of this section is the policies and legislation related to GHG emissions.

2.1 Global regulations for shipping emissions

International shipping travels through marine areas that are not under the jurisdiction of any country. This makes the allocation and control of GHG emissions from international shipping a challenge.

The United Nations Framework Convention on Climate Change (UNFCCC, 17) reporting guidelines on annual inventories, outline that emissions from international shipping should be calculated as part of the national GHG inventories, excluded from national totals, and reported separately. However, under the Kyoto Protocol, GHG emissions from international shipping are not part of the national inventories and therefore not subject to the agreed binding targets. Instead, the International Maritime Organization (IMO) is delegated to regulate the GHG emissions from international shipping.

According to the Third IMO GHG Study (IMO, 2014), shipping emissions could increase by 50%, in a business-as-usual scenario, to 250% by 2050 (see Figure 2-1). This scenario is obviously not in line with central aim of the Paris Agreement: to strengthen the global response to the threat of climate change, by keeping a global temperature rise, this century, below 2°C above pre-industrial levels and further limiting the temperature increase to 1.5°C.

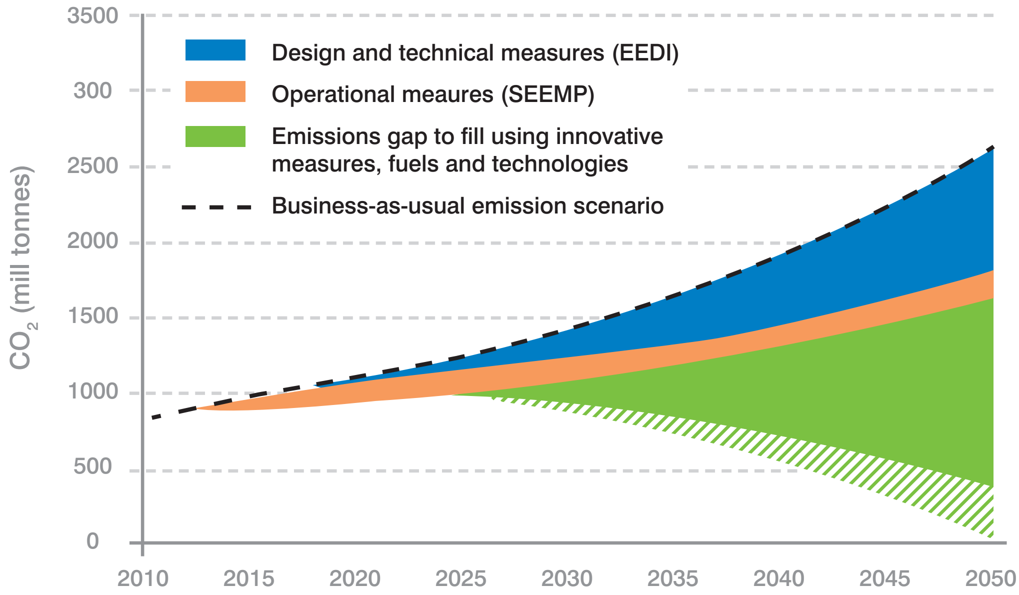

Figure 2-1: IMO GHG reduction targets and pathway (Source: Third IMO GHG Study (IMO, 2014)).

At the 72nd meeting of the IMO's Marine Environment Protection Committee (MEPC72), in 2018, the initial IMO strategy to reduce GHG emissions from international shipping was accepted as a resolution. This IMO strategy, which will be revised in 2023 and reviewed in 2028, includes an overall vision for decarbonisation; GHG reduction targets through 2050; a list of short-, mid-, and long-term measures to meet these targets; barriers to achieving the targets and supportive measures to achieve them; and criteria for future review.

The initial IMO strategy includes quantitative targets such as:

- At least 40% reduction in carbon intensity by 2030 and pursuing efforts towards a 70% reduction by 2050, both compared to 2008 levels;
- Reduce GHG emissions by at least 50% by 2050, compared to 2008 levels, while pursuing efforts to phase them out, as with the Paris Agreement temperature goals.

The IMO envisages that a revised strategy will be adopted in 2023. Feeding the process of adoption will be the IMO Data Collection System (IMO DCS) on fuel oil consumption of ships over 5,000 gross tonnes, including dredging vessels. The IMO DCS started on 1 January 2019.

The IMO's MEPC recognises that technical and operational measures, such as IMO's Energy Efficiency Design Index (EEDI) and Ship Energy Efficiency Management Plan (SEEMP), would not be enough to reduce GHG emissions from international shipping satisfactorily (MEPC 59, 2009 and IMO, 10).

In addition, global Market Based Measures (MBMs) are proposed. MBMs put a price on GHG emissions and are cost-effective policy instruments. They provide economic incentives for the maritime industry to use up-to-date technological, operational and managerial practices to reduce emissions. Also, they can create funds that can be used for different purposes, such as adaptation and transfer of technologies. IMO's MEPC considered various MBM proposals from governments, and observer organisations, but, at the time of writing, the IMO had not put any global MBM into effect.

2.2 Interregional and national regulations for shipping emissions

Despite the fact that the EU considers the IMO to be the most appropriate international forum, for regulation and emissions from shipping, the EU unrolled its own climate and shipping policy (IMO, 11). The first step was the implementation on 1 January 2018 of the Monitoring, Reporting and Verification (EU MRV) of CO_2 emissions from ships using EU ports. However, the EU MRV only applies to self-propelled ships, bigger than 5,000 gross tonnes, that transport cargo for commercial purposes at ports within the European Economic Zone. Presently vessels used for activities including dredging, ice breaking, pipe laying and offshore installation activities, are exempted from EU MRV.

On 14 July 2021 the European Commission adopted the 'Fit for 55' package of proposals. It aims to make the EU's climate, energy, land use, transport and taxation policies fit for reducing GHG emissions by at least 55%, by 2030, compared to 1990 levels.

The 'Fit for 55' package includes implementation of the maritime transport sector in the European Union Emissions Trading System (EU ETS). The EU ETS is a cap-and-trade system. It aims to meet GHG emission reduction targets at the lowest overall cost to the participants and the economy as a whole. The European Commission, among others, argue a cap-and-trade system is preferable to other forms of pricing, such as carbon taxes, which do not guarantee any particular level of reduction. With a tax the price is known, but the resulting emission level is not known in advance, resulting in uncertainty regarding the environmental outcome. In addition, taxes are considered politically difficult to implement.

In contrast to a traditional command-and-control regulation, polluting entities are given a cap-and-trade system able to choose if, when and how, they will reduce their emissions. Whenever an emitter has insufficient allowances, it must either take measures to reduce its emissions or buy more allowances on the market. This ensures that emissions are cut where it costs least to do so.

For the time being the EU ETS only applies to the EU MRV targeted vessels, which implies that dredging vessels, amongst others, are exempted.

In parallel, a number of governments in Asia and North America are also setting up emission trading systems such as the carbon tax on purchased fuel imposed by Canada as of 2019. Also, in Europe, the Dutch Ministry of Infrastructure and Water aims to become completely climate and energy neutral in 2030. As non-aligned regional and/or national MBMs are potentially disruptive on a global level, there is pressure on the IMO to address the issue on a global level (IMO, 12).

2.3 Emissions from international shipping vs emissions from national projects

The IMO DCS captures the fuel oil consumption of ships over 5,000 gross tonnes, including dredging vessels. The emissions of these dredging vessels is administrated by their flag states as part of the emissions from international shipping. In parallel, project owners are required to account for GHG emissions related to dredging projects within the applicable national state boundaries. Obviously, alignment is needed to avoid 'double accounting' on a global scale (see Figure 2-2).

National states have diverse GHG emissions policies to meet the agreed emission targets. Equally, dredging projects are expected to have ambitions ranging from a low to a high level of decarbonisation.

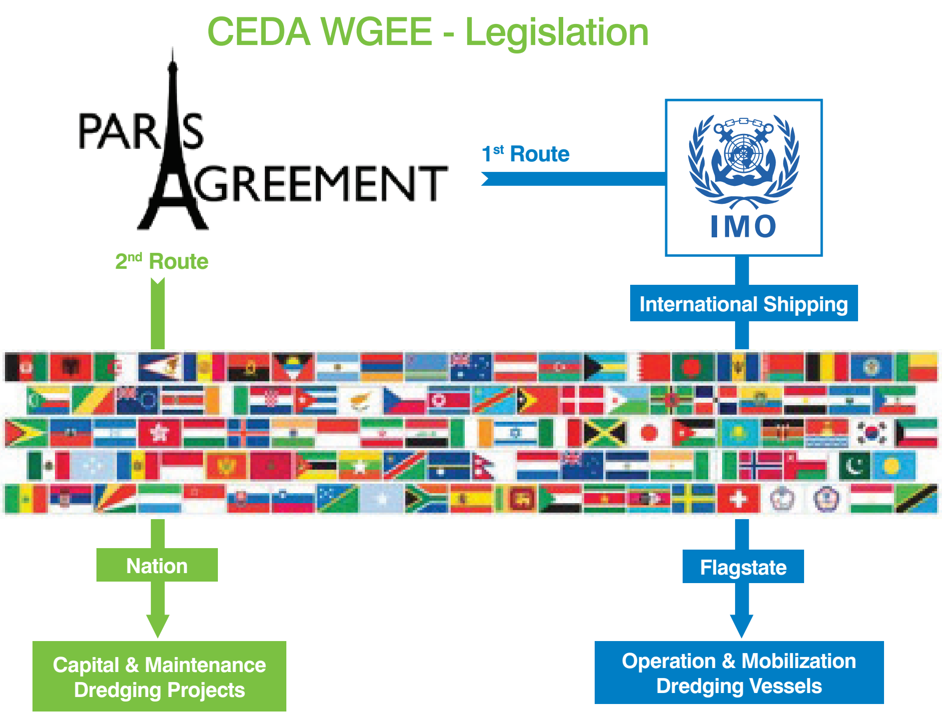

Figure 2-2: Reporting emissions.

3 Energy Efficiency of Dredging Projects

3.1 A dredging project as part of the life-cycle of infrastructure projects

The life-cycle of infrastructure projects is generally divided into phases (see Figure 3-1). To properly address the energy efficiency of dredging projects, the life-cycle phases need to be split into different sub-elements. For illustration:

- **Energy efficiency and the life-cycle of offshore windfarms.**
  Obviously the environmental and economic benefit of a windfarm is established during the operational lifetime phase. However, these benefits only follow after energy consuming preparation and installation works, by dredging and other equipment, during the construction phase of the windfarm;
- **Energy efficiency and the life-cycle of port and navigation infrastructure.**
  During the construction, maintenance and potential rebuilding of port and navigation infrastructure, dredging activities can consume a significant amount of energy. However, the port and navigation infrastructure can last many decades. The operational lifetime phase is very long and the energy consumption during this period will typically represent the main element over the lifespan of the infrastructure. Operational energy consumption of port and navigation infrastructure principally result, for example, from the consumption of electricity, fuels and heat/steam by buildings, vehicles, equipment, harbor craft and transport vessels. (PIANC, 2019).

From these 'project life-cycle' perspectives, it is possible that more energy consumed in the construction lifetime phase will lead to an overall energy saving when considering the overall lifetime of the project. For example, the construction of a windfarm with large turbines requires more energy than the construction of a windfarm with smaller turbines. However, the extra energy consumption will be outweighed by that produced by the larger turbines. As another example, deepening waterways to accommodate larger transport vessels requires energy, but this will be outweighed by the energy efficiency of the larger vessels.

Naturally, less energy consumption for the same outcome is preferable. However, the significance of the saving might differ greatly depending on the specific project and lifetime phase(s) of the project considered.

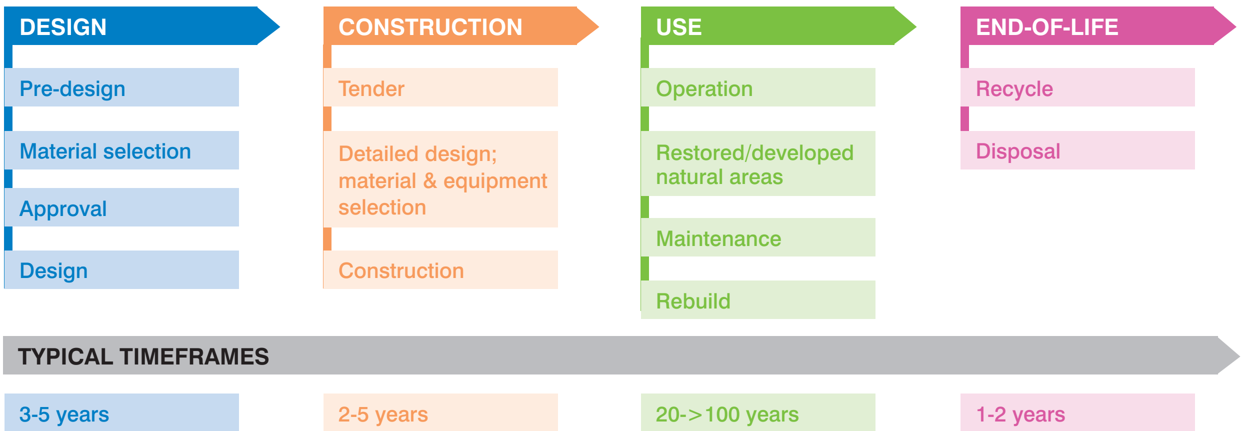

Figure 3-1: Activity phases related to the life-cycle of an infrastructure project (PIANC, 2019).

3.2 Dredging project: Scope, definition and choices

The scope of work for dredging projects is typically decided by the owner of a construction, maintenance or rebuilding project, during the definition stages. To a large extent, it is this scope of work that defines the total energy consumption of the dredging equipment and therefore the energy efficiency, in terms of kWh/m^3, with key components being:

- Volume;
- Type of soil;
- Transport distance (horizontal);
- Deposition method (reclaim, re-use, or dispose).

Boundary conditions, and constraints to the execution, influence the amount of energy consumed on the project as well, for instance:

- Boundary conditions (e.g. wave climate, water depths, tidal currents);
- Specifications (e.g. strict tolerances, thin layers to be dredged or reclaimed, or an implicit need to mobilise/demobilise multiple times);
- Environmental constraints may also have a significant bearing on the use of energy on the project if, for example, the dredger has to take a longer route to avoid nesting birds.

Some of these aspects play a role in all dredging projects while others are only important in specific cases. There is also a large variation in the degree to which aspects can be influenced or managed. For natural circumstances, like weather and sea state, the conditions are beyond control. However seasonal variation may give options to choose a more favourable window to schedule works. In turn, such a choice may be against preferences resulting from environmental considerations. This shows the balancing act for project owners.

Optimisation of the scope of work traditionally takes place as part of the preparation by the owner, commonly advised by a dredging consultant. Environmental constraints are likely to be set after consent by relevant authorities. One has to be wary of relevant legislation and its interpretation. In this decision-making process, early consultation with legislators about the interpretation of rules and laws, is advised, to avoid strict requirements and to ensure sufficient operational freedom for project optimisation.

It is becoming more common for project owners to involve contractors, who are already part of the decision-making process, to achieve best-for-project optimisation. This helps to avoid the situation where choices in the licensing and design stages, although smart in themselves, turn out to be constraints for the most energy efficient execution of the project. Different options exist for the involvement of contractors in the preparation stages of a project prior to, or during, a tender process.

3.3 Dredging project: procurement and criteria

Owners of dredging projects commonly procure the realisation of the works through tendering. There are many possible options for this process including: combining design and construction works, combining capital and maintenance work, pre-selecting contractors for a competitive dialogue, etc.. See *CEDA Information Paper on Effective Contract/Procurement Type Selection* (2019) for details of this procurement process.

Having decided the scope of the project, and agreed specifications and/or constraints for the execution, which impact on the energy consumption of the project, the owner can make further choices in the procurement stage. Performance criteria can be applied to the use of energy and/or GHG emissions resulting from the realisation of the works. Such criteria can either be of the ‘knock-out’ or ‘relative scoring’ type. However, the owner must ensure that:

- The procurement rules, set by the applicable jurisdiction, are adhered to;
- Performance criteria are non-subjective (for scoring during evaluation of tenders and for verification during execution);
- Weighting of performance criteria, in relation to price, is clear and unambiguously made known to tenderers;
- The contractor winning the tender, and performing the works, complies with the contractually agreed performance criteria;
- There is an effective penalty system in case the contractor does not comply with the criteria.

Budget must be allocated, early in the definition stages of the project, in order to compensate for additional costs that may result from the application of performance criteria to the project.

Possible goals with respect to energy efficiency

In view of energy efficiency for a given scope of work, project owners can aim for reduction of impacts on:

- Air quality (short term impact). Typical emissions considered are:
  - Sulphur dioxide (SO_2)
  - Nitrogen oxides (NO_x)
  - Particulate matter (PM)
- Climate (long term impact). The GHGs considered are primarily:
  - Carbon dioxide (CO_2)
  - Methane (CH_4)
  - Nitrous oxide (N_2O)

Combinations of impact on air quality and climate are also possible. In these cases the various emissions are converted into an equivalent unit by using weighting factors. For GHG emissions the most common unit is CO_2-equivalents.

Relation with laws and regulations

The number of applicable laws and regulations regarding energy use, fuel and emissions, is increasing. That may increase further in the challenge to achieve the main aim of the Paris Agreement (UNFCC, 2015): keeping the global temperature rise, this century, below 2˚C above pre-industrial levels.

Owners must ensure that up-to-date laws and regulations are used as a baseline when applying performance criteria. No gains must be sought from improvements which are already enforced by law. When regulations come into effect during the execution of a project, the owner must address specifically how this is covered in the scoring system used for tender evaluations.

For energy efficiency, defined as the total use of energy to execute the pre-defined scope of the dredging/reclamation work, no generally applicable baseline can exist. Therefore, the owner must define the project-specific baseline when energy efficiency is included in the performance criteria.

4 Energy Efficiency of Dredging Equipment

An example of energy efficiency from an equipment perspective is Life Cycle Analysis (LCA) covering the construction, operational, maintenance and end-of-life phases of trailing suction hopper dredgers and cutter suction dredgers (see Castro et al. (2011)). The LCA clearly shows that it is fossil fuel consumption during the operational lifetime phase, together with the emissions related to this fuel consumption, that dominates the environmental impact of dredging equipment over its entire life-cycle. In this case, the relevance of energy efficiency of dredging equipment is substantiated within an 'equipment perspective'.

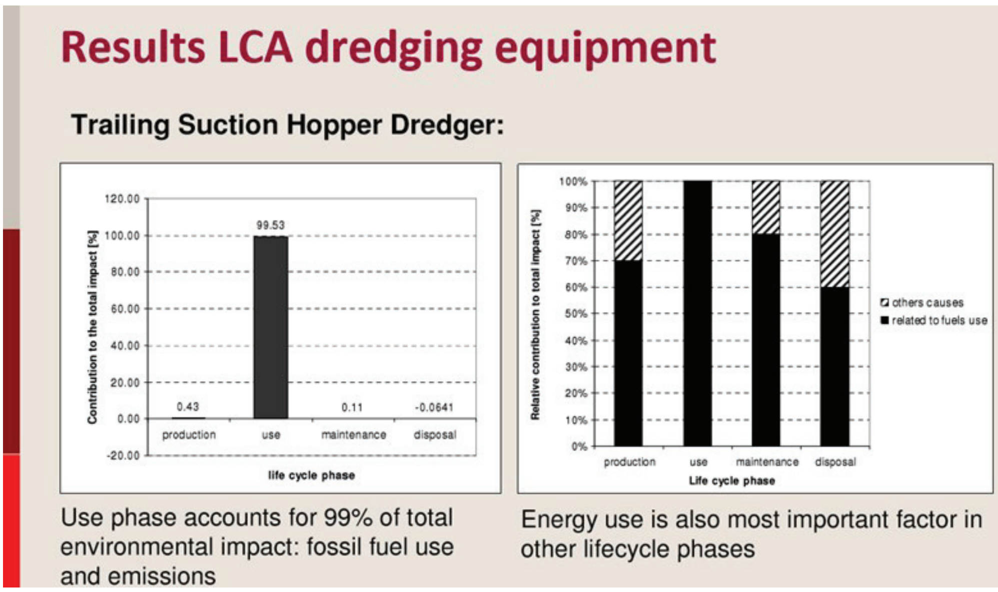

Figure 4-1: Life-cycle analysis of a trailing suction hopper dredger. (Castro et al., 2011)

To be successful, dredging equipment owners must adapt their fleet and technology to keep pace with, or stay ahead of, trends in the market. Given their existing fleet, and market vision, fleet owners may define an operational mix for their new equipment. In this context, 'operational mix' refers to the distribution of time spent on the different expected maintenance or capital dredging projects. Operations are further typified by factors including the volumes and characteristics of the soil to be dredged, the various discharge methods and transporting distances. It is this operational mix that forms the basis for the design. Therefore, a dredger designed for maintenance work in a specific port area will differ greatly from a general purpose dredger designed as a result of a much wider operational mix.

A well-defined operational profile is critical for the successful design of equipment and minimisation of the fuel-related emissions of the equipment during its operational lifetime.

4.1 Alternative fuels

Currently diesel (mainly Heavy Fuel Oil (HFO) and Marine Gas Oil (MGO)) is mostly used as an energy carrier. Of all fossil fuels, Liquefied Natural Gas (LNG) offers the benefit by significantly reducing the emission of air pollutants and producing the lowest CO_2 emissions. However, the release of unburned methane (or 'methane slip') reduces part of the benefit over HFO and MGO. The result is a CO_2-equivalent reduction of just 20% compared to traditional diesel fuels (see Table 4-1 and Figure 4-2).

For stationary equipment like cutter suction dredgers, plain suction dredgers and backhoes, an electric shore supply, with land-based power generation, is a potential alternative. The shore supply can have generators running on any fuel, and fuel supply, and related regulations, are easier on land than offshore. Alternatively, the shore supply can be the local power grid. However, for now, this alternative is limited to relatively small-scale equipment as the power requirements of larger equipment is a major challenge for any local power grid.

Potential decarbonising energy carriers for all types of equipment, in the future, are biodiesel, methanol (from black liquor), hydrogen, hydrogen carriers (such as methanol and ammonia) and batteries (see Table 4-1). These energy carriers can have a biological source (bio-fuel) or a green electricity source (e-fuel).

The relatively poor energy density of batteries makes them unsuitable as a main source of power for dredging equipment. Batteries can however be used for peak shaving and optimise energy efficiency.

The future availability for many alternative fuels is limited by the availability of the source. For example, the availability of hydrogen (or a hydrogen carrier) is currently limited, but there is no limit on the scalability. For biodiesel and methanol, from black liquor, the opposite applies. For crop-based biodiesel the available agricultural land is limited and for waste-based biodiesel and methanol, from black liquor, there is not enough waste available.

The availability of the 'energy dense' alternatives is compromised further as the dredging industry is competing with others for the alternatives. The maritime industry, and other transport sectors such as aviation, as well as non-transport sectors, are all facing similar challenges. (Source: Transport and Environment, 2018).

Given their scalability, hydrogen and hydrogen carriers are a prime alternative for the fossil fuels currently used. However, the technology needs further development to become mature.

Table 4-1: Assessment of alternative fuels and technologies.

	Source	CO_2 eq. reduction*	Energy density	Scalability*	Technology readiness
Diesel	Fossil	0%	++	++	++
LNG	Fossil	20%	+	++	+
Biodiesel (crop-based)	Bio	20%	++	-	+
Biodiesel (waste-based)	Bio	80%	++	-	+
Methanol (from black liquor)	Bio	90%	+	-	o
Hydrogen (or hydrogen carriers (e.g. methanol and ammonia))	Green electricity (e-fuel)	95%	o	++	o
Battery	Green electricity (e-fuel)	95%	--	o	+

*Source (DNV GL, June 2018)

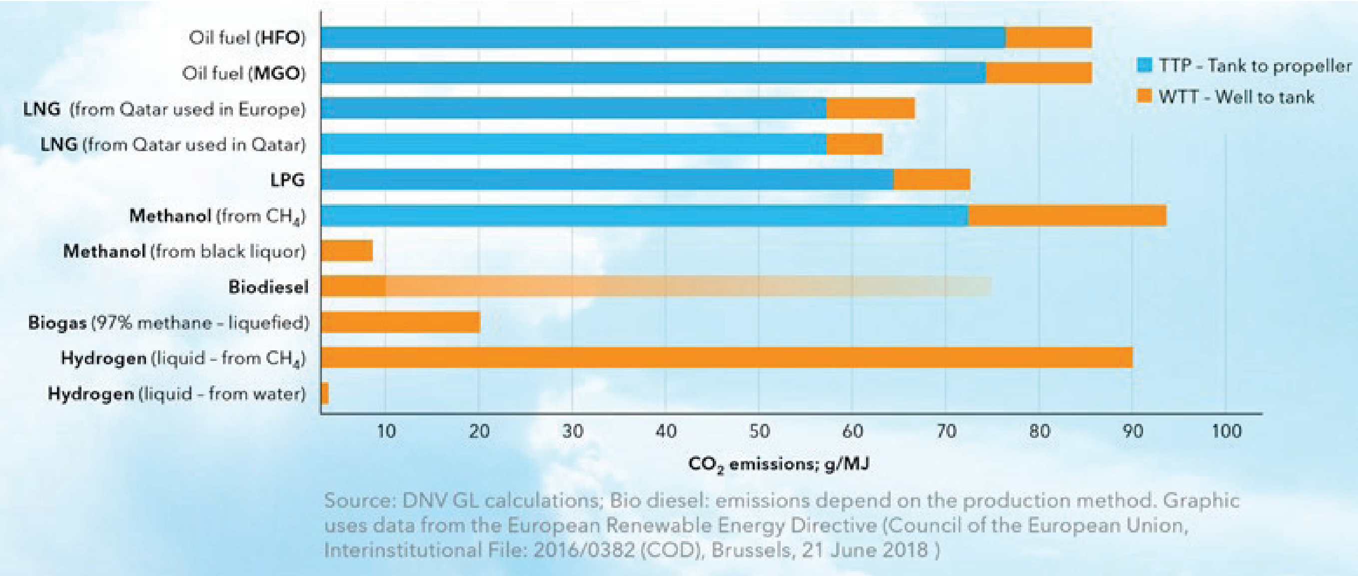

Figure 4-2: Assessment of alternative fuels and technologies, (DNV GL, 2018).

4.2 Technical improvements

It is clear that the IMO and EU ambitions, regarding the reduction of GHG by 2050, cannot be met by technical improvements alone. However, technical improvements to optimise the energy efficiency of dredging equipment is more important than ever, because the best fuel is the one that is saved.

Potential technical improvements

- Power generation today is mainly by diesel engines. Major improvements of their energy efficiency is unlikely. In the future, diesel engines may be replaced by zero emission fuel cells. For local operating small-scale equipment, exchangeable battery packs and power supply from shore may be applicable.
- Constant speed, controllable pitch propellers are inefficient. The application of two-speed gearboxes, or fixed pitch propellers, could produce improvements of 5-10%.
- Sails are beneficial on long transport distances. These distances exceed the typical sailing distances on a dredging project.
- With further Computational Fluid Dynamics (CFD) optimisation of the hull and its appendages, an improvement of around 5% is possible.
- The optimisation of a drive train, based on an envisaged operational profile, offers opportunities to improve the energy efficiency up to 10%. However, any envisaged operational profile will include assumptions and uncertainties.
- For dredging installations, no major innovations are expected. A maximum reduction of 5% may be achieved.
- For automatisation and artificial intelligence a 5% reduction can be expected. With autonomous sailing the whole-ship concept can be adopted, resulting in an additional 5% gain.
- With waste heat recovery a 10% reduction is possible. This, by reducing the energy consumption of heating, ventilation and air conditioning systems and/or the heating of steam turbines. The latter is economically feasible for large vessels only.
- By reducing sailing speed significant reductions are achievable. However, this is an operational choice not a technical development. The disadvantage of a reduced sailing speed is that, in general, the resulting reduction in capacity will outweigh the reduced fuel cost.
- In general, larger dredgers have a lower fuel consumption (e.g. a large hopper volume and a large dredge pipe diameter gives a lower fuel consumption). In some specific situations this is not the case, for example when used for shallow dredging works, small dredgers can have a lower fuel consumption.

Given the various technical improvements, an overall reduction of 10-30% can be expected within a time period of around 15 years. This 10-30% is less than the total of the various individual improvements because the gain of one improvement can reduce the improvement of another technology. This means that technical improvements are not enough to achieve large reductions and future additional energy carriers will be needed.

A cumulative challenge is the timeline set by the IMO targets. Figure 4-3 illustrates that, given an average life of 30 years, new-build vessels (blue line) will have to achieve the 50% GHG reduction target, by 2032, to achieve IMO's target of 70% reduction for the entire fleet (orange line), by 2050.

Technical improvements are generally more cost-effective than a change of energy carrier. As a result, they are likely to be the preferred solution in the early stages of the transition to zero emissions. Combined with the use of biodiesel, the technical solutions can follow the required trend for new-build vessels up to circa 2035. Thereafter, the availability of alternative energy carriers is a necessity to keep up with the trend. Given this timeline, pilot projects to improve the technology readiness of alternative energy carriers are needed now.

The IMO targets are from 2018. Meanwhile, the EU and other nations have set more demanding targets (see Section 2.2) which imply the need to accelerate the timeline shown in Figure 4-3.

It is likely that during the (accelerated) transition towards alternative energy carriers, traditional fossil fuels will increase in costs via CO_2 taxes (or something similar), and alternative energy carriers will be costly and limited in availability. Therefore, energy costs will rise and, as costs have always been a strong motivator to improve efficiency, it is likely to lead to an intensified focus on energy efficiency.

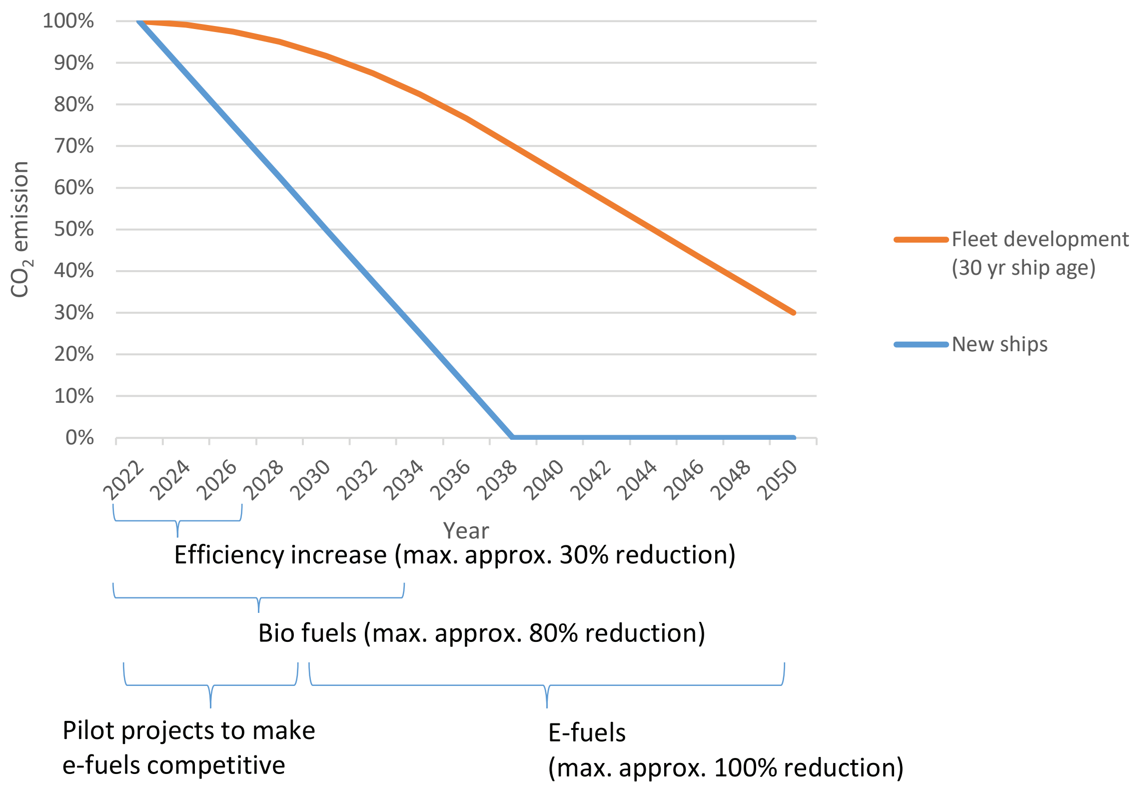

Figure 4-3: Decarbonisation of new-builds needed (Updated from source: den Boer et al., 2019)

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6 Case Studies

6.1 C1: Case study: Examples of the influence clients and contractors may have on energy efficiency on a project

Many projects offer options for clients and/or contractors to influence the energy efficiency on the project substantially. Here some practical examples are provided.

It should be noted that the amount of energy used (in terms of kWh per cubic meter of dredged material) is not a fixed value. The scope of work and the natural conditions largely determines this (see section 3.2 of the main text).

Clients

Boundary conditions have an effect on the energy efficiency of a dredging project and are, to a large extent, imposed by the client or relevant authorities.

Table C1-1 shows a few examples, and their relative effects, and whether the client can influence the choice made.

Example: Sailing distance

This example shows the effect of the sailing distance of a TSHD on the fuel consumption for the dredging and reclamation works. As part of the preparations for the Environmental Impact Assessment for the Maasvlakte 2 project (Rotterdam, The Netherlands), effects were studied including the distance from the borrow area to the reclamation works. A total volume of over 200 million m^3 was to be reclaimed, using various TSHD sizes and work methods. For a 10 km sailing distance the fuel usage (for the total cycle) was calculated at 0.78 kg fuel/m^3, and for 27 km it was 1.15 kg fuel/m^3 (almost 50% more). Other factors, like morphodynamics of the coastal zone, also played a role in the ultimate decision for the borrow area.

Contractors

A contractor, planning or executing a certain scope of work, can have a significant influence on the energy efficiency, taking into account the constraints set by the client (as well as from the law and applicable regulations). Table C1-2 shows a few examples. It should be noted that the application of such examples is project-specific.

Constraint (example)	Effect on energy efficiency (kWh/m^3)	Influence by client?
Decrease NOx	Slight increase in fuel consumption and decrease in energy efficiency	None. International regulations are the deciding factor
Reduce overflow in order to limit turbidity	Decrease in energy efficiency. When the overflow constraint is limited, the effect on energy efficiency is also limited. When overflow is completely forbidden, the effect on energy efficiency is very large	Client must ensure that the cause for, and extend of, the constraint is sound, in the sense that it is actually justified as protection for key marine habitat
Block-out periods for execution of project (e.g. spawning season (marine life) or bathing season (tourists))	If the blockage leads to additional (re)mobilisation of equipment, or to operations in less favourable weather conditions, the energy efficiency may decrease	Client to reconsider whether the constraint is unavoidable (from environmental point of view) or actually a choice to be made
Sailing distance to borrow area or disposal area	Decrease in sailing distance significantly increases energy efficiency	Client to consider sailing distance, and resulting energy consumption, early in project scoping studies (see example)

Table C1-1: Examples of constraints, their effects and client influence.

Operational choice by contractor	Effect on energy efficiency (kWh/m3)	Notes
Choice of vessel	Project size and conditions largely determine the optimal vessel (in terms of energy efficiency)	For a variety of commercial reasons non-optimal vessels are sometimes allocated to projects
Optimise dredging installation on board	Increasing dredging and/or pumping production by optimisation of the dredging process, or enhancing the dredging installation, will increase the energy efficiency	• Optimisation of dredging processes has been the industry aim for decades, based on extensive research and field experiments • Considering the often large investments, changes in the dredging installation are more likely to be feasible for new-builds or relatively young vessels, rather than those nearing end-of-lifetime
Reduce sailing speed (TSHDs, barges)	Propeller power is relative to the sailing speed, to a power of 3. Reducing speed is therefore very effective in terms of increasing energy efficiency.	Fuel prices at levels seen in the past decades have not yet caused contractors to reduce sailing speed of TSHDs significantly below the maximum speed possible given the installed propulsion power*
Cycle optimisation (when working in tandem, or sailing in strong eb/flood currents)	Optimising the energy efficiency by reducing the sailing speed may well have a zero or positive effect on cost efficiency. It is therefore an interesting option for reducing fuel consumption and emissions	

* Fuel costs are typically in the range of 20%-30% of the total direct costs of a TSHD. At such percentages, lowering the speed below the maximum (given the installed propulsion power) is not economical (hence, lowering the speed would decrease cost-efficiency).

Compare this with container vessels (with fuel cost percentages twice as high), which adopted speed reductions ('slow steaming') in periods of high fuel prices when there was also overcapacity in the market. This shows that two factors influence the choices made by vessel owners: The cost of fuel (relative to the total costs for operating the vessel) and the market circumstances (vessels in high demand or not).

The possible gain in energy efficiency, by adopting slow steaming, is significant and may be an option to reduce the fuel usage, and also the GHG-emission profile, for a given dredging/reclamation scope of work.

Table C1-2: The effect some operational choices can have on energy efficiency.

BHD and CSD operations

The above shows examples of how energy efficiency of the transportation component of the dredging works can be influenced. For the excavation component, which is the main part of the operation of a BHD or a CSD, for instance, the energy efficiency can not be influenced in a similar manner. In this case, it is only the technological gain, from prolonged research and development, that can improve the efficiency of the process and often increases the energy efficiency along the way. Such improvements have been, and will probably remain, a continuous effort by major contractors and shipbuilders in the industry.

6.2 C2: Case study: Rotterdam Maintenance Dredging

The 2019 tender for maintenance dredging in Rotterdam, The Netherlands, was a joint procedure by the Port of Rotterdam and Rijkswaterstaat (Agency of Ministry of Infrastructure and Environment). It is an example of how the impact of the energy use, that comes with dredging, is made part of the procedure, the evaluation criteria and the award.

All relevant environmental effects, including emissions of GHGs and pollutants, were combined into a single parameter: the Milieu Kosten Indicator (MKI), also known as the Environmental Cost Indicator (ECI). A study by TNO[1] provided an inventory and valuation of the environmental effects of fuels (combining production, transport and use). It also established a calculation protocol and determined the MKI rate for each fuel, expressed in euro per tonne. In the MKI, the exhaust of GHGs was valued at 103 euro per tonne CO_2-equivalent.

MKI rates for fuels not included in the TNO database could be determined using the Life Cycle Analysis calculation protocol and emission-cost values.

In the tender, the bidders were required to estimate their fuel consumption (in tonnes) for execution of the contractual dredging scope, on the basis of the equipment planned and the estimated production. The fuel consumption was to be multiplied by the MKI rate for the fuel, which resulted in a total MKI for their bid. This was set against two reference values for total MKI that were calculated in advance by the employer:

- Knock-out upper value, based on the use of MGO minus 10%.
- Lower value, based on the best score anticipated by the employer.

For bids which showed a total MKI below the upper value, a fictive discount was applied. The fictive discount reached a maximum value at, and above, the best score for total MKI as determined by the employer. The winning bids for both lots showed a reduction of environmental cost of 40% against the reference value.

During execution of the contracts the fuel type and consumption is monitored and the data is included in the trip report. The total MKI, based on the actual fuel consumption, is compared against the value included by the contractor in its bid. A penalty applies if the actual total MKI value is higher than the bid value (after correction for dredged quantities). Practical results so far show that both contractors are able to achieve and demonstrate the value they have promised.
In addition to this, if they invest in innovation, and further improvement of their equipment, reducing the environmental costs for this particular work, they will be rewarded with a contract extension.

Including the environmental effects of fuel consumption, by quantifying it into the total MKI, is regarded as a successful step towards significant reduction of emissions and ultimately the elimination of GHGs emitted as part of dredging. It has taken considerable effort, from both the employers and the contractors, to establish a structured and quantifiable methodology. A key factor is that contractors have the freedom to decide which innovations to pursue, which fuel to use, and how to achieve reduction of consumption, while knowing the MKI-scoring system that is applied. After the success of this pilot, both organisations are using this method in many other tender procedures regarding dredging works.

In line with tightening national or regional GHG reduction goals, it is expected the MKI rates for fuels will be raised and/or the reference values for total MKI will decrease.

1 TNO 2016 R10662 Environmental profiles of marine fuels for inclusion in the National (i.e. Dutch) Environmental Database.

6.3 C3: Case study: Port of Lisbon Maintenance Dredging: WID-TSHD-BHD comparison

The Port of Lisbon is situated in one of the most important estuaries of the Iberian Peninsula. Its importance stems not only from its dimensions, but also its environmental, social and demographic features. The Port of Lisbon Authority must regularly dredge its access channels and manoeuvring and anchorage basins.

Since the introduction of the Framework Water Directive into Portuguese legislation, the Port of Lisbon Authority has adopted a strategy to obtain five-year environmental licences by presenting a dredging plan that includes monitoring, the selection of the most suitable equipment for dredging in each area, and environmental procedures reports.

Regarding the types of uses in the estuary, the Port Authority included engineering techniques and projects in the choice of solutions. In this way, it aims to achieve its sector objectives by conserving the estuary´s environmental, social and economic balances to minimise the impacts. In 2014, a water injection dredger (WID) replaced the backhoe dredger which was used on previous projects.

As a result, of incorporating the WID, there was a 77% reduction in fuel consumption and a 50% reduction in work execution time (see Table C3-1).

The Port of Lisbon´s plan aimed to reduce pollution and CO_2 emissions. Now that there is a rapid increase of consumption in the international market, and decay of energy resources, it is important to control the energy that we use.

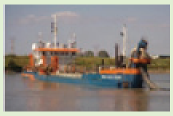
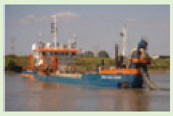
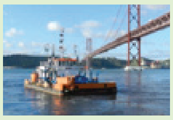
EQUIPMENT		Capacity (m^3)/Power (kW)	Campaign (year)	Dredged Volume (m^3)	Total Fuel (MGO) (litre)	Fuel consumption (litre/m^3)	Fuel Reduction (%)
	TSHD	2,500 m^3	2013	800,000	404,000	0.5	
	BH- barge	900 m^3 / 1,600 kW		200,000	198,000	1	
	TSHD	2,500 m^3	2014	200,000	98,500	0.5	77%
	WID	460 kW		800,000	38,500	0.05	

Table C3-1: Illustration of reductions in fuel consumption and work execution time for different equipment.

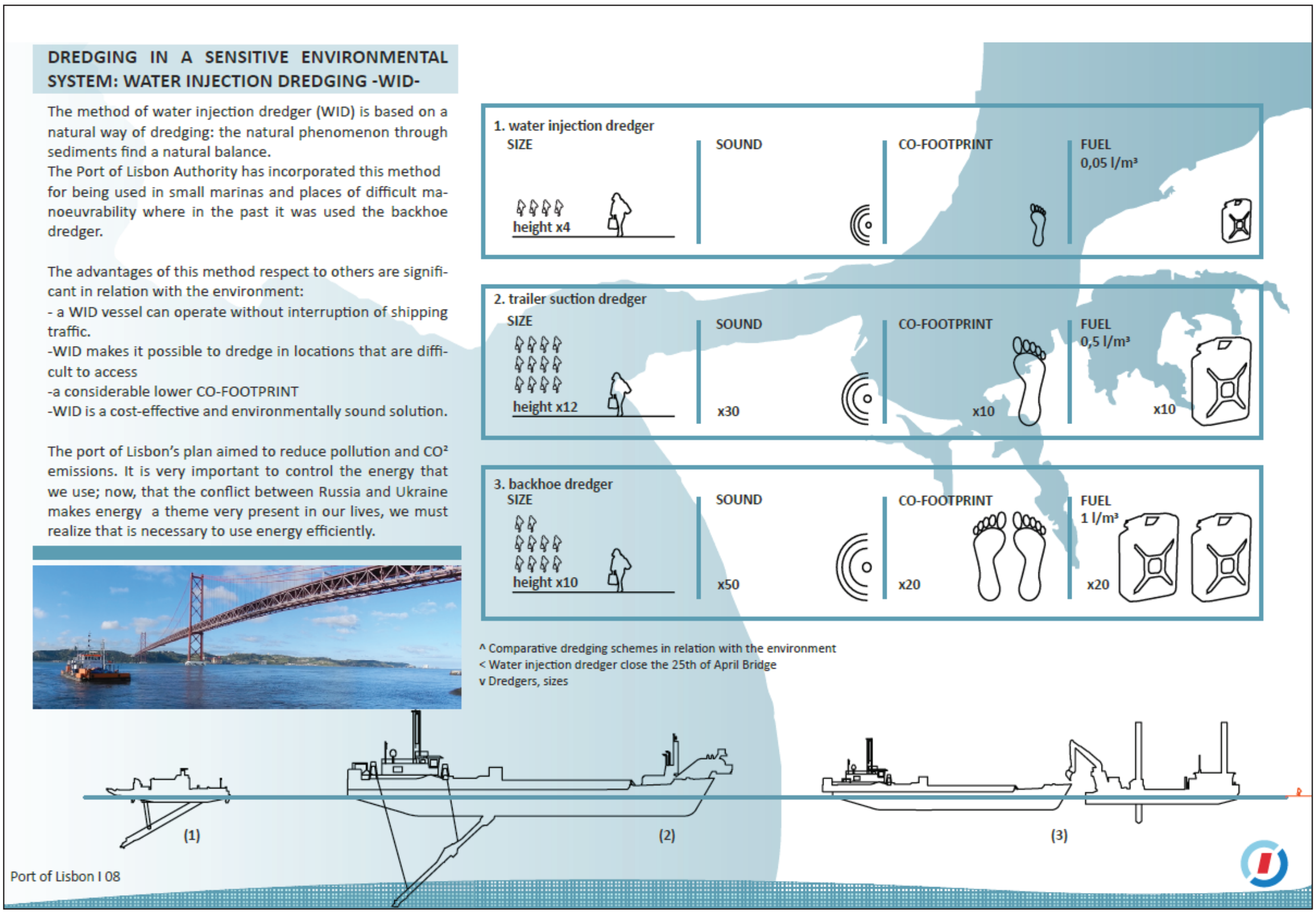


Figure C3-1: Various footprints of WID, TSHD and BHD

This initiative was recognised by the European Sea Ports Organization whose theme in 2014 was innovative environmental projects.

Ref.

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(2) Port of Lisbon Authority. Integrated Plan for the System of Support Infrastructures for Leisure Craft in the Tagus Estuary.

(3) Port of Lisbon Dredging Plan (2010-2015).

(4) Port of Lisbon Authority Strategic Development Plan.

(5) Council of Ministers resolution number 177/2008. The Tagus Estuary Nature Reserve Management Plan.

(6) ESPO Award 2014 Shortlisted Project: The Port of Lisbon: Innovative Dredging Project. https://www.espo.be/news/espo-award-2014-shortlisted-project-the-port-of-li.

Notes

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