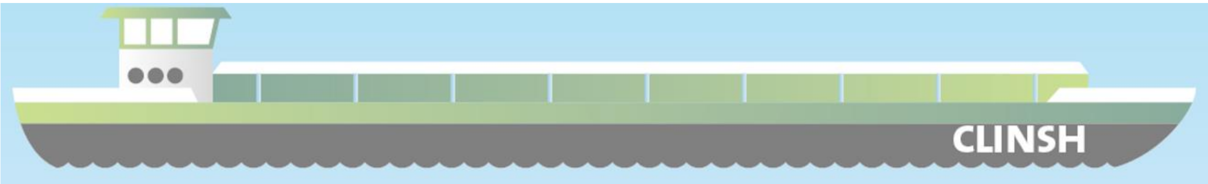
SYNTHESIS REPORT
SHORE POWER AND ENERGY SCAN PROGRAMME INLAND SCHIPPING

PORT OF ANTWERP
NORTH SEA PORT
DE VLAAMSE WATERWEG
MOW VLAANDEREN

17/08/2021



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0. EXECUTIVE SUMMARY

This synthesis report is the result of a programme of 26 energy and shore power scans of inland ships, that were performed in the first half of 2021, and can be summarized as follows:

- About 31% of the ships in this study experience technical problems when connecting to shore power.
- When the ship is conform NEN-EN 15869-3:2019 standard, no problems with using shore power are identified. This makes the standard a good tool for making ships electro technically compatible with shore power.
- Only 31% of the ships in this study are conform NEN-EN 15869-3:2019. The most common technical infringements are: (i) no isolation transformer (54% of the ships), (ii) no IP67 shore power cable/plug (42% of the ships), and (iii) no soft start switch (peak current) (15% of the ships). Mostly this doesn't mean the ship can't use shore power.
- The most common reasons why skippers don't use (often) shore power are: (i) not enough shore power cabinets (54%), (ii) the price is too high (50%), (iii) no good accessibility of the cabinets (31%), (IV) technical issues on board (31%), and (V) not sufficient power (23%).
- The average electrical power consumption of the inland vessels in this study amounts 6.33 kW. This is also the mean power consumption when berthed (*e.g.,* when using shore power).
- The average fuel cost (incl. maintenance) for generator power of all ships included in this study amounts 0.25 €/kWh. This is lower, but comparable to the standardized shore power price (0.27 €/kWh).
- When energy-saving measurements are implemented (excluding maximizing shore power use), the average load of the generator set decreases, which increases the cost of generator power. Thus, favoring the use of shore power.
- When all profitable energy saving measurements (payback time < 4 years) identified in the energy scans are implemented, the average primary energy savings per ship (only taking into account the electrical consumption on the ship) for different ship types amounts, 30% for a passenger ship, 48% for a tanker, 27% for a container ship and 19% for a dry cargo vessel.
- The most common energy saving measurements with the highest energy saving potential for the lowest investment cost are: (i) adjusting sanitary boiler control, (ii) limiting the use of electrical resistance heating, (iii) maximizing shore power use, (IV) replacing the lighting with LED, (V) residual heat recovery engines, and (VI) energy monitoring.
- The total savings of all cost-effective measures (< 4 years) identified during these 26 energy scans amounts 1,935,144 kWh/year primary energy and 499 ton CO_2-eq/year.

INHOUDSTABEL

1. INTRODUCTION

This synthesis report is the result of 26 energy and shore power scans of inland ships. A large variety of ships are included in the study in order to form a good picture of the inland shipping sector. Container ships, tanker ships, dry cargo ships and passenger ships with different sizes (27m – 135m length), capacity (77 ton – 6,287 ton) and year of construction (1949 – 2020).

The scan has 2 goals:

1. To offer a first indication of the possibilities for saving energy on your ship. It provides insight into current energy consumption (in particular at berth) and is an impetus to use energy as efficiently as possible.
2. Checking the shore power connection for technical defects and limitations.

In the energy scan, the annual energy consumption and cost is determined and an inventory of the consumers is drawn up. Depending on the availability of data and the energy-saving potential of the energy consumers, energy measures are proposed per theme.
This energy scan is not intended as a comprehensive and thorough review, but is a first step towards the implementation of energy-saving measures. Some of these measures may require further implementation advice.

The shore power scan checks whether there are restrictions on the use of the shore power connection of the ship and proposals are made to make the necessary adjustments on board.

Based on this information this synthesis report summarizes the general findings. In addition, solutions are provided to eliminate technical limitations for the use of shore power, to increase the ease of use of shore power and to improve general energy management on inland ships. In other words, the result is a best practices guideline that both port and inland ships can use.

Project:	CLINSH – Clean Inland Shipping
Goal:	The objective of LIFE CLINSH is to improve air quality in urban areas situated close to ports and inland waterways, by accelerating IWT emission reductions.
Project reference:	LIFE15 ENV/NL/000217
Duration:	2016 – 2021
Project website:	www.clinsh.eu

CLINSH is an EC LIFE+ project delivered with the contribution of the LIFE financial instrument of the European Community. Project number LIFE15 ENV/NL/000217
This deliverable is part of Enprove.

Disclaimer
This report contains information provided by skippers and observations recorded during a ship visit. Enprove cannot be held liable for any consequences caused by inaccuracy or incompleteness of the information provided, nor for the consequences of actions taken on the basis of the information contained in this report. The company information provided will be treated confidentially.

2. INVENTORY

2.1 SHIP TYPE

A variety of inland ship types are included in this study: dry cargo vessels, container ships, tankers, passenger ships and other (Figure 1).

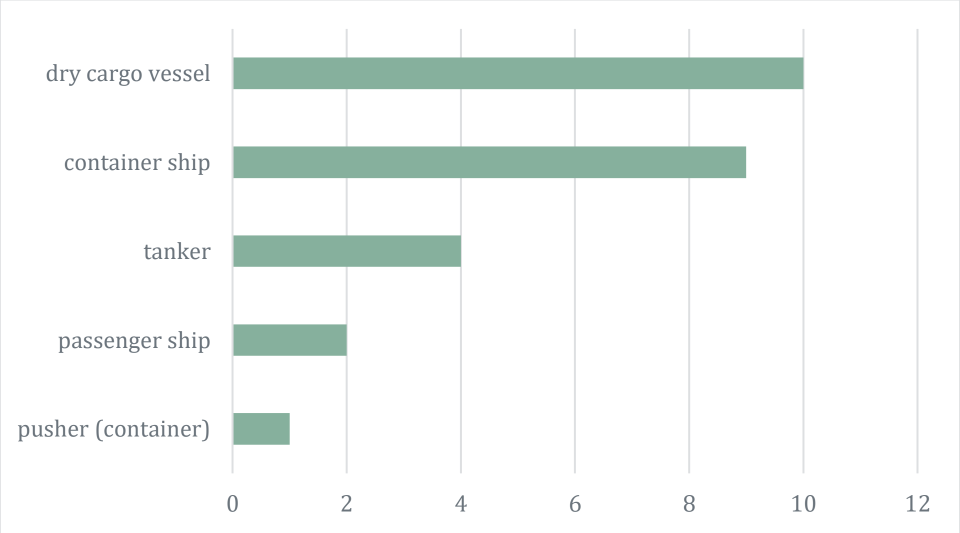

FIGURE 1: THE DIFFERENT SHIP TYPES INCLUDED IN THE STUDY

The length of the different inland ships varies from 27 meters to 135 meters. The construction year ranges from 1949 to 2020.

2.2 LOAD CAPACITY

The average load capacity per inland ship type is shown below (Figure 2). The largest ship is a container ship with a load capacity of 6,287 tons. Note that for the pusher the load capacity of the cargo bed is not taken into account.

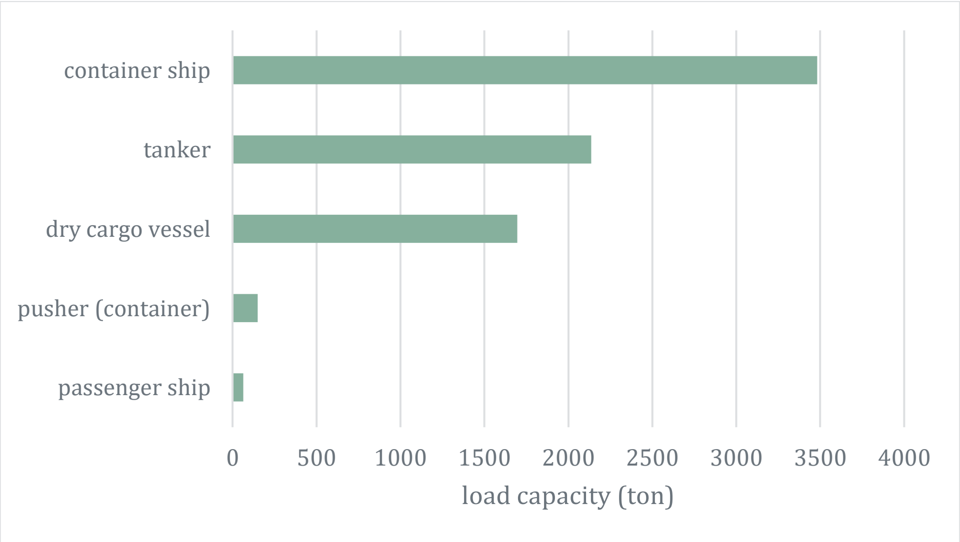

FIGURE 2: THE AVERAGE LOAD CAPACITY PER SHIP TYPE

3. SHORE POWER

3.1 USER EXPERIENCE

An important part of this study was the questioning of the skippers about shore power use. The main purpose was to find out whether the inland shipping sector is already convinced of the use of shore power and what the main arguments are why they only make limited use of shore power. The findings are summarized below.

The skippers were asked if they use shore power and if yes, only when this is mandatory (generator ban) or always if possible. When the skippers don't use shore power because of technical issues these ships were placed under a fourth category. The results are shown below (Figure 3).

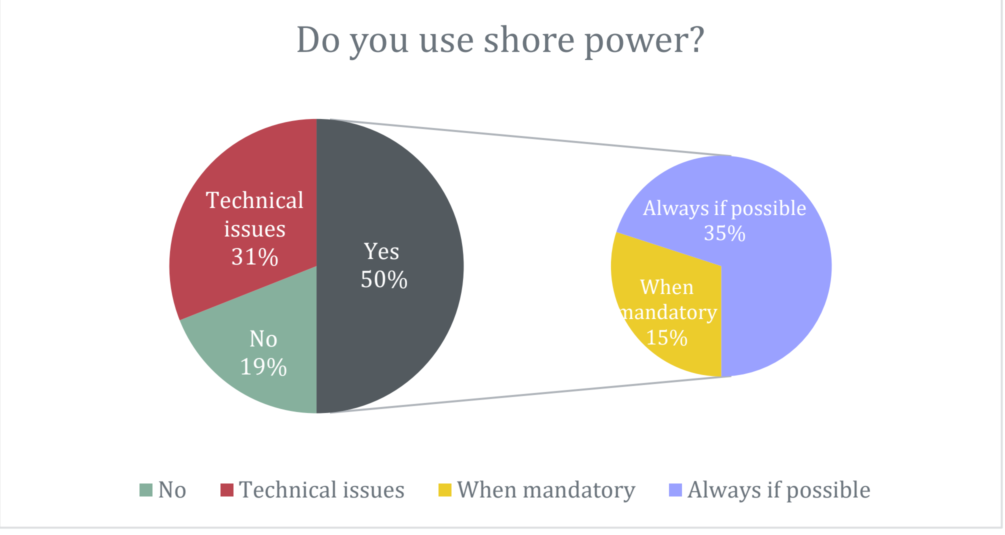

FIGURE 3: QUESTIONNAIRE: DO YOU USE SHORE POWER?

Most skippers are negative towards a generator ban (Figure 4). An important side note is that this refers to a total generator ban. However, many skippers are willing to accept a generator ban after 10 pm since most of the large power consumers on board are not active at that time. The skippers who also don't agree with the latter are usually skippers where gas oil is paid for by the shipping company but shore power is not (see below).

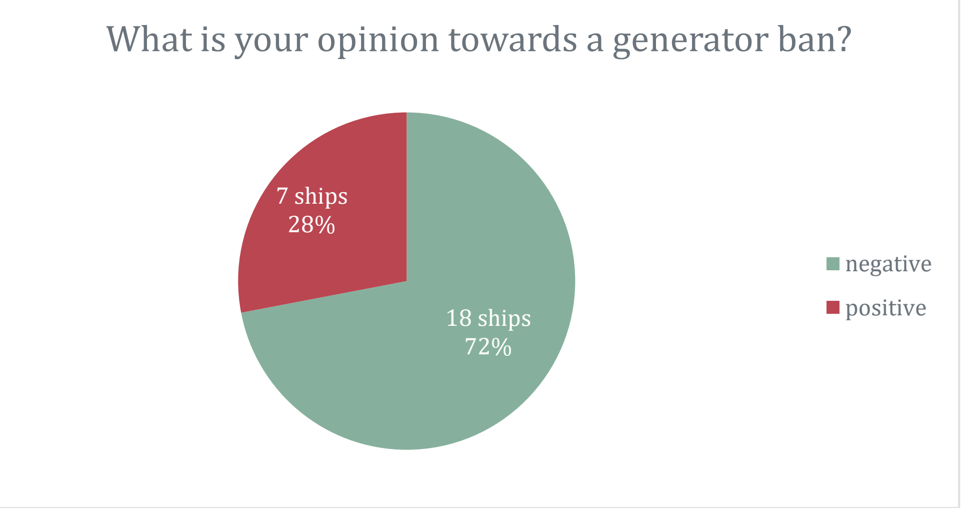

FIGURE 4: QUESTIONNAIRE: WHAT IS YOUR OPINION TOWARDS A GENERATOR BAN (NUMBER OF SHIPS; %)?

The most common arguments for making no or minimal use of shore power are the following: not enough shore power cabinets, shore power is too expensive, the shore power cabinets are not easily accessible, the ship has technical issues when connecting with shore power, the shore power cabinets don't deliver enough power for the ship or the app is not user friendly (Parkline). The arguments were sorted according to occurrence in the graph below (Figure 5).

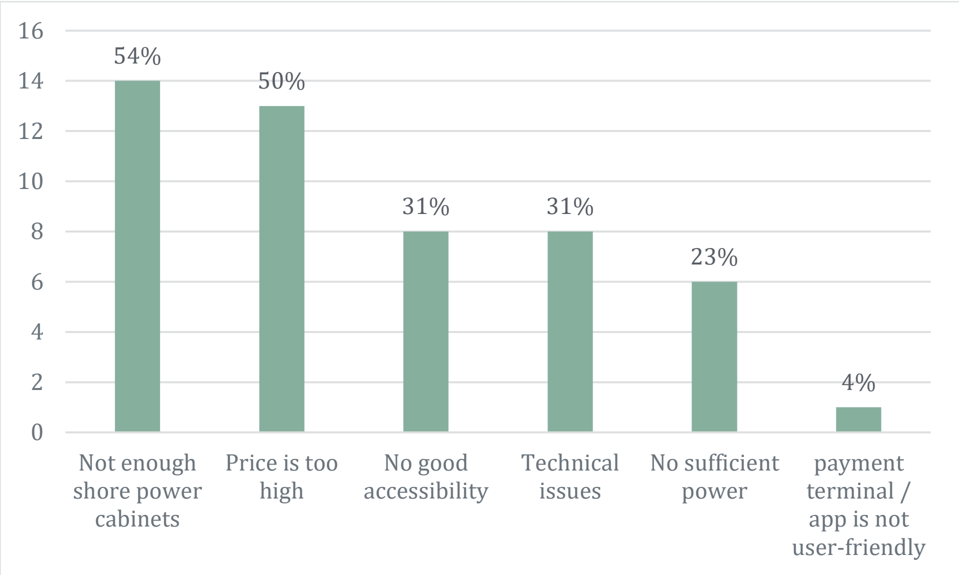

FIGURE 5: THE MOST COMMON REASONS WHY SKIPPERS DON'T USE (OFTEN) SHORE POWER. THE DATA LABELS INDICATE THE PERCENTAGE OF ALL SKIPPERS (26) ANSWERING THE ABOVE.

NUMBER OF SHORE POWER CABINETS

54% of the skippers indicated that there are not enough shore power cabinets (overall).

For many ships, the number of shore power cabinets remains the main limiting factor for (extensive) use of shore power. The tight planning of many ships does not allow the skipper to invest a lot of time in finding a location where shore power cabinets are available. Skippers who are currently already convinced of the use of shore power often still find it necessary to use generator power due to the absence of shore power cabinets at many locations.

In other words, expanding the network of shore power facilities can be seen as an important tool to further optimize the use of shore power in the inland shipping sector.

PRICE OF SHORE POWER

50% of the skippers indicated that shore power is too expensive.

The price of shore power is universally set, just as in the Netherlands, at 0.27 €/kWh. This is high in the perception of the shipper mainly because the gas oil consumption of the generator set is usually apparently negligible compared to the consumption of the propulsion engines. As a result, the use of the generators is still considered "free". Our analysis has shown that for about 31% of the ships shore power is cheaper compared to generator power (see chapter 3.3.2. Fuel cost). The larger the generator on board compared to the average consumed electrical power of the ship, the higher the fuel cost for generator power and the cheaper the use of shore power. By implementing the identified profitable (payback time < 4 years) energy-saving measures on board (energy scan), the electrical power absorbed by the ship can be further reduced. This means that the fuel cost for generator power increases in favor of the use of shore power. The total energy cost will decline. When we take this into account, the amount of ships where shore power is the cheapest option increases to 50%. By maximizing the use of shore power, the savings will increase further. Note that this analysis looks at the average absorbed electrical power of the ship. In reality, it can happen that the electrical power absorbed is temporarily considerably higher ashore due to, for example, the presence of reefers (refrigerated containers) on board, controlling unloading pumps (tanker), heating of the cargo on board (tanker), cleaning the ship, or operating the hatches. At these moments the load on the generator increases and the use of generator power for (almost) every ship becomes cheaper. The fuel cost for generator power will approach the minimum fuel cost of 0.14 €/kWh (*i.e.,* corresponding with a generator running at its optimum operating point; load of 60-85%).

An important obstacle to the use of shore power is the fact that many shipping companies pay for gas oil but not for shore power. This was confirmed by questioning the skippers. All container ships and tankers, except one, operate on this principle. For dry cargo vessels about half of the skippers sail on an independent base (pay for their own gas oil and shore power), the other half do not have to pay for gas oil, but do pay shore power themselves (contract with a shipping company). This means that the choice of using generator power is self-evident for these skipper and there is no incentive to use shore power. These skippers are therefore always negative about a generator ban. Some skippers indicate they prefers to sail a few kilometers further to find a place where they can moor without a generator ban. In other words, an awareness campaign towards the shipping companies in which the use of shore power is promoted is urgent. Especially for ships where the use of shore power is effectively cheaper, this is a win-win for the shipping company, port and skipper. If shore power were also funded by the shipping company, the skippers indicate that they would use shore power.

Some skippers argue for a system in which the cost for shore power is included in the port dues. In this case anyone can use shore power everywhere without hassle (no payment terminals, shore power always available). As a result, there would be much more use of shore power (since the use itself in this case will be regarded as "free") and therefore more money would be available for expansion of shore power infrastructure (positive feedback loop). The biggest obstacle here is potential discrimination against ships that cannot use shore power or are never docked for a long time. On the other hand, the increase in port dues will only be minimal, as the cost of shore power (facilities) is thus distributed over a considerable number of ships. This system is already being used for drinking water in some parts of the Netherlands. Another point of attention is that this system comes with no awareness creation for energy savings.

ACCESSIBILITY OF SHORE POWER CABINETS

31% of the skippers indicated that the shore power cabinets are difficult to reach.

The inland skipper is often confronted with the impossibility of mooring at locations where shore power facilities are present due to a shortage of berth locations (double ships, ships on location with shore power facilities still using the generator set, etc.). The shore power connections are difficult to reach and are very far apart. The cable length that would be needed amounts on average 50-100 meters. The use of lightweight shore power cables can greatly increase the ease of connecting, but comes with a higher price compared to traditional copper shore power cables. According to the skippers, the port infrastructure in Belgium generally takes too little account of the expansion in length of inland vessels. The average length of the ships included in this study is approximately 110 meters.

Enprove recommends analysis of GIS data for identification of the optimal locations for shore power cabinets, taking into account the average length of inland vessels. A practical example is elaborated below.

One of the ships taken up in the study was moored at Lichterweg 9 in the port of Antwerp (see figure below). The shore power cabinets are indicated in red. According to Geopunt, the quay has a length of approximately 275 meters. This is sufficient for two average inland vessels (2x110m). These ships can lie with their nose to the shore or away from the shore. In other words, to easily reach the control cabin / engine room (where the shore power connection on most ships is located) with the shore power cable, four (instead of two) shore power cabinets are required. The optimal positions according to the skipper are indicated in blue in the figure below. The number of shore power cabinets per quay, but also the position of the shore power cabinets is crucial.

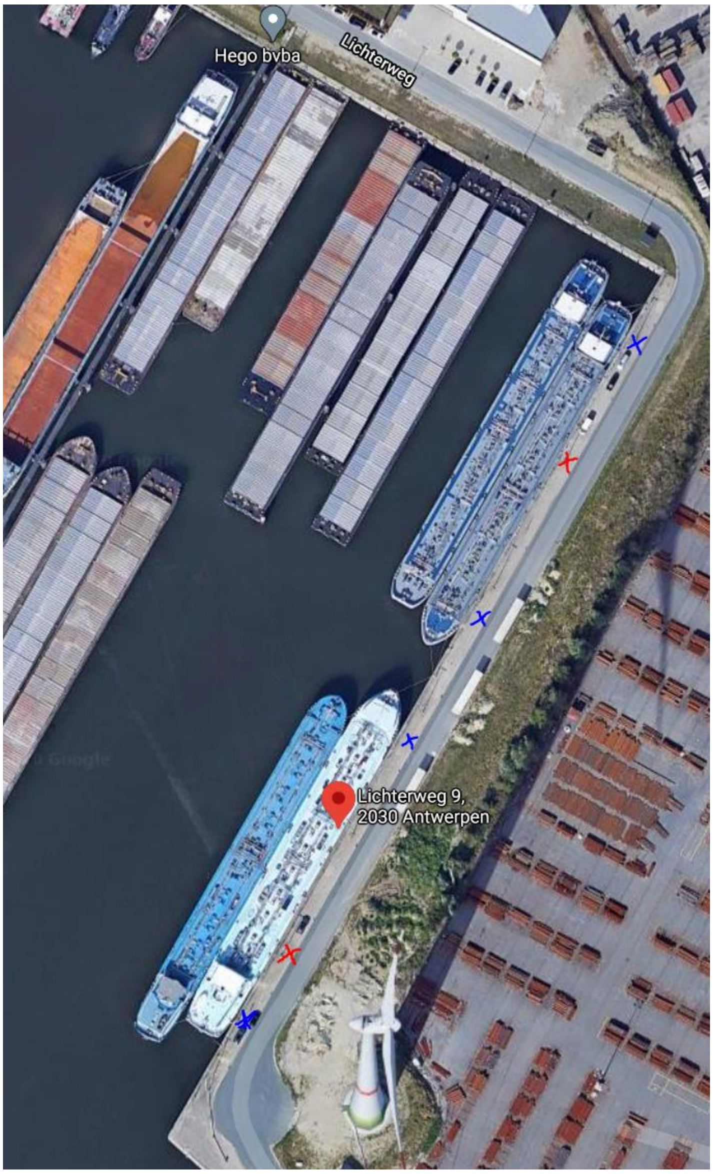

FIGURE 6: PRACTICAL EXAMPLE OF "POOR" ACCESIBILITY OF SHORE POWER CABINETS. RED CROSSES REPRESENT CURRENT SHORE POWER CABINETS, BLUE CROSSES REPRESENT SUGGESTED LOCATION OF SHORE POWER CABINETS

Ships with two shore power connections (front and back) are less susceptible to this problem.

TECHNICAL ISSUES (SHIPS) FOR CONNECTING WITH SHORE POWER

31% of the skippers indicated to experience technical issues when connecting with shore power.

These technical issues are usually the result of loss current from the ship, peak current from the ship or the lack of an isolation transformer. This manifests itself in various ways: tripping of the main fuse in the shore power box, tripping of the residual current switch in the shore power box / on the ship, corrosion of the hull of the ship, etc. The technical obstacles in the use of shore power are further substantiated in chapter 3.2.

AMOUNT OF POWER ON THE SHORE POWER CABINETS

23% of the skippers indicated that there is not enough power on the shore power cabinets for powering the entire ship.

The European Standard for shore power (NEN-EN 15869-3:2019, see further) specifies the requirements for electrical installations for the shore power supply of inland waterway vessels with electrical energy, three-phase current 400 V, 50 Hz, with a nominal current up to 125 A. In other words, the maximum power that inland vessels can use is approximately 86 kW. The connections with 125 A are reserved for tankers. More common are the 63 A (43 kW) and 32 A (22 kW) connections.

Despite the fact that, according to figure 11, the average power consumption is never higher than 23 kW, it cannot be concluded that offering a 32A (22 kW) shore power connection would suffice in almost all cases. This can be compared by analogy with an average Flemish home. The average electricity consumption equals 3600 kWh/year or thus an equivalent average power of 0.41 kW, according to the VREG (Flemish Regulator of the Electricity and Gas Market). The average peak power of a Flemish family is currently about 3.15 kW according to estimates by the VREG, or 7.68 times higher than the average power. The main connection of the house will therefore not be dimensioned on the average power, but by taking the peak power (including a margin) into account. A ship with an average power of 23 kW will therefore quickly show a peak power of > 43 kW and therefore requires a shore power connection of 125 A or 400 A.

This means that large ships (container / tanker) with a high consumption inherent to their activity (reefers on board, unloading pumps, heating of the loading on board etc.) are currently unable to use shore power. These ships usually sail continuously, which means that these cabinets must be provided at the places where the ships are temporarily ashore. For container ships these are waiting berths. Providing cabinets with a 125 A connection at these places will ensure that these ships can also use shore power. For tankers the loading and unloading quays are interesting places for shore power because of the high primary energy and CO_2 savings potential (high energy consumption of unloading pumps). Because of the high power consumption of the unloading pumps seen on the ships included in this programme (100 kW @ 50 Hz for each pomp, most ships have at least 2 pumps), shore power cabinets with a capacity of >125 A (86 kW) will be needed. The average duration of the unloading activities is 2-3 hours. This requires good cooperation between private companies (terminals) and governments. It is important here that these shore power cabinets are also built according to a well-defined standard in order to guarantee uniformity. The electricity price is also ideally agreed universally (avoiding unreasonable competition and profiteering). The minimum cost for generator power (excluding maintenance, high load: *i.e.,* when the unloading pumps are operational) is typically 0.14€/kWh. The price for shore power (high current: 400 A for tankers at loading and unloading quays) is therefore ideally set at a lower or similar price. An important note here is that for tankers the shore power cabinets must be ATEX certified because of explosion safety (see further, section 3.2).

EASE OF USE OF THE APP / PAYMENT TERMINAL

One skipper (4%) indicated that the app / payment terminal is not user friendly.

Overall, the app / payment terminal is found very user friendly. As of February 1, 2021, a universal payment system has been introduced for all ports in Belgium and the Netherlands (provider is Parkline). As a result, the skipper only needs to create one account and all shore power cabinets can be used in the same way. The service (helpdesk) has also improved considerably, according to the skippers. Problems with a shore power cabinet are almost always resolved immediately. The number of defective shore power cabinets has therefore decreased sharply.

Some skippers indicate that using a badge would be a possible improvement. Upon arrival, the badge is held against the terminal in order to obtain an automatic registration. On departure of the ship, the badge is used again to the register. The shore power cabinets could be equipped with a system that enables automatic logout (eg. power measurement, which automatically logs out when there is no power demand for x number of minutes). In this way it is not possible that another ship uses shore power at the expense of another skipper.

3.2 TECHNICAL OBSTACLES SHORE POWER USE

Inland vessels are equipped with a variety of electrical loads operating at 400 V. While underway, continuous electrical power supply is provided by the on-board system from generators driven by diesel engines. When the vessel is berthed, these generators remain in operation if there is no suitable on-shore power supply available. In some cases, this leads to intense noise pollution both for the crew on the vessel itself and on other vessels lying alongside and also for residents ashore. The exhaust fumes are an additional pollution factor.

The electrical shore connection requirements are specified in an European Standard (NEN-EN 15869-3:2019) and makes it possible to provide the vessels with an electrical power supply while berthed and to eliminate noise and exhaust pollution. This European Standard contains electrical safety requirements for the prevention of hazards in making, using and breaking the shore connection.

During the scan of the ship, any technical obstructions to the use of shore power were investigated. In general, very few major technical issues were reported. The majority of the ships (69%) are perfectly capable of using shore power. The technical installations on board were compared with the NEN-EN 15869-3:2019 standard. This standard specifies the requirements for electrical installations for the shore power supply of inland waterway vessels with electrical energy, three-phase current 400 V, 50 Hz, with a nominal current up to 125 A.

About **69%** of the ships were **not conform NEN-EN 15869-3:2019**. The most common technical infringements are:

1) No isolation transformer (54% of the ships)
2) No IP67 shore power cable/plug (42% of the ships)
3) No soft start switch (peak current) (15% of the ships)

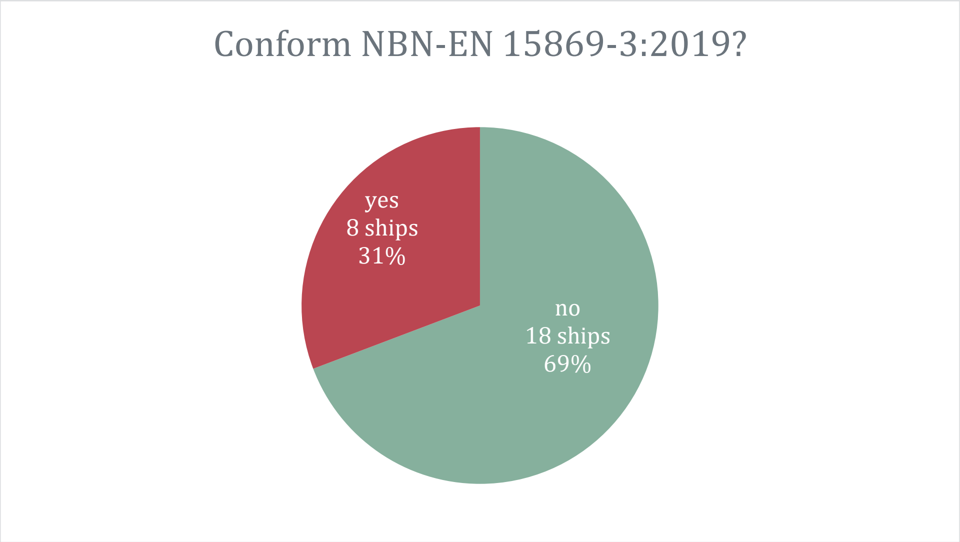

FIGURE 7: CONFORMITY OF THE SHORE POWER CONNECTION ON SHIPS ACCORDING TO NEN-EN 15869-3:2019

It is important to mention that not all the ships that not comply with the NEN-EN 15869-3:2019 standard can't effectively use shore power. As shown in the previous section, (only) about 31% of ships experience technical problems connecting to shore power. On the other hand, all the ships that are conform the standard do not experience any problems when using shore power. In other words, the standard is a good tool for making ships electro technically compatible with shore power.

ISOLATION TRANSFORMER

In the case of a shore power connection, the zero and the protective earth are connected to each other in a distribution station and connected to the groundwater via a steel pin in the ground. In the port, all earthed connections are therefore interconnected. Steel sheet piling and jetties are also connected to the earth via groundwater. If, for example, an aluminum ship is moored next to a steel ship, then different metals (steel and aluminum) are immersed in an electrolyte (water). A small potential difference then arises. If the earth connection is connected to the hull of the ship, the two metals will be connected via the earth connection and corrosion will occur (Figure 8).

The same can happen if a steel ship is moored next to a steel sheet pile. The steel of the sheet pile has a different potential than the steel of the ship. The ship and the steel sheet piling are connected to each other via the earthing system, which also causes corrosion

Protective earth plays a very important role in protecting the electrical installation and cannot be omitted. Under current regulations (NEN-EN 15869-3:2019) it is even mandatory to provide the ship with a proper earthing system.

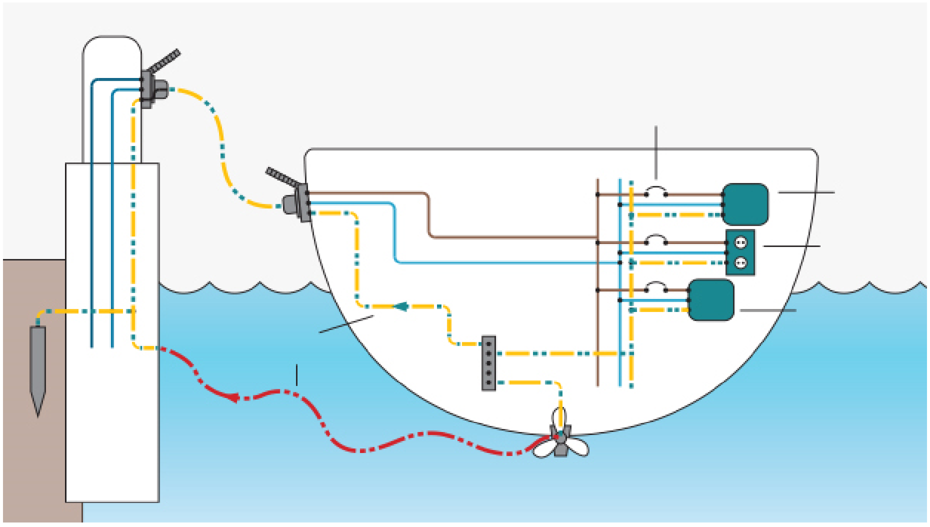

FIGURE 8: POTENTIALLY DANGEROUS SITUATION WHERE GALVANIC CORROSION CAN OCCUR

According to the standard (NEN-EN 15869-3:2019) it is mandatory to install an isolation transformer. This will also ensure that corrosion is avoided and safety is guaranteed.

When using an isolation transformer, the earth wire remains in the shore cable for safety, but it is not connected to the ship. The phase and neutral of the power connection are connected to the primary (shore) side of the transformer, which converts the voltage to the same voltage or a different voltage if necessary. On the secondary (ship) side of the transformer, a new, galvanically isolated from the shore, phase and neutral is created. The neutral is connected to the earthing system on board, which electrically has nothing to do anymore with the earthing of the shore connection. This safely breaks the connection between two different metals (or two different potentials of the same metal). There is then no longer a risk of corrosion.

You must also connect the neutral connection to the earthed system on board at the other energy suppliers on board, such as the generator and the inverter. See also the (NEN-EN 15869-3:2019) for this. The various options for earth leakage protection or insulation monitoring are subject to this standard.

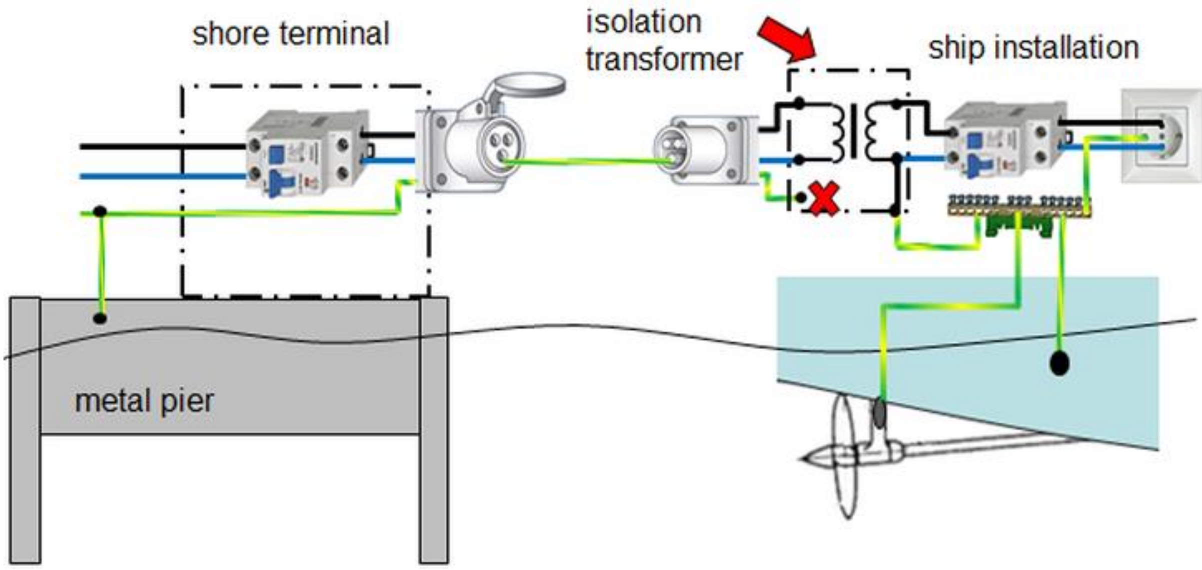

FIGURE 9: THE CORRECT USE OF AN ISOLATION TRANSFORMER PREVENTS GALVANIC CORROSION (SOURCE: VICTRON ENERGY)

SOFT STARTER

An isolation transformer is best equipped with a built-in soft start to prevent the expected short-term increase in current (up to ten times the rated current) when connecting the transformer to the mains (Figure 10). The short-term current increase would almost certainly cause the activation of overload protection devices in the terminal box on the shore. Activation of protective devices is unnecessary because it is not caused by any failure, but by normal behavior of the transformer during its connection. The unwanted activation of protection devices is prevented by connecting an isolation transformer with the help of the built-in soft start.

Stand-alone soft start devices are also available and can be an option when an isolation transformer is already in place and has no built-in soft start.

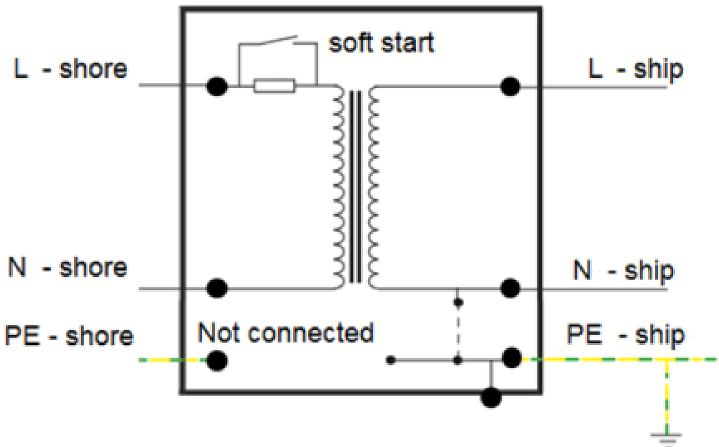

FIGURE 10: AN ISOLATION TRANSFORMER WITH BUILT-IN SOFT START (SOURCE: VICTRON ENERGY)

IP 67 SHORE POWER CABLE / PLUG

The **IP**-code (*International Protection Rating, also sometimes Ingress Protection*) on electrical equipment is an indication of the degree of protection of the structure of electrics or electronics against damage caused by their own use in "hostile environments" and against possible danger to the user.

The IP rating is internationally standardized in the IEC 60529 standard. The IP-rating has two digits: the first indicates the degree of protection against contact and ingress of objects, the second the degree of protection against moisture.

According to the NEN-EN 15869-3:2019standard the shore power cable / plug needs to have the IP 67 code. This means (i) (6) safe to touch because the housing is completely closed, complete protection against dust, and (ii) (7) no water penetration when submerged (30 minutes at 1 meter).

EXPLOSION SAFETY / ATEX AND SHORE POWER

Due to explosion safety, it is currently not allowed for ships with ATEX-cargo on board to simply connect to shore power (Directive 2014/34/EU). According to the ADN regulation it is only allowed to connect to shore power under specific circumstances (European Agreement Concerning the International Carriage of Dangerous Goods by Inland Waterways, 2021). Shore power connection points at ATEX locations are only possible if the entire installation can be carried out according to the ATEX classification applicable to that location. Plugs and sockets with ATEX classification are available.

It is physically possible to have these ships connected to shore power, but none of the ships we visited has these ATEX plugs / sockets and the terminals visited do not have a connection for this on their zoned loading and unloading installations.

Research by, among others, DNV commissioned by the Port of Rotterdam Authority into the combination of shore power and dangerous cargo on inland vessels showed that these two can go well together (“Gaan walstroom en gevaarlijke lading samen?”, Van den Berg, 2015). DNV stated in the report that sparking during the connection and disconnection of shore power must be prevented. This is possible by de-energizing the plugs before making or breaking a connection. Of course, this certainly applies in the protected zone and cargo zone of both the ship itself and an adjacent moored ship. In addition, DNV pointed out that the electricity cables can be damaged by frequent connecting, disconnecting and moving cables, which could lead to sparking. Damage can also occur because ships move under the influence of currents, suction and tidal action. By performing (periodic) tests and inspections, damage to the cables can be noticed in time.

3.3.1 POWER CONSUMPTION

The figure below shows the installed total generator power in function of the mean consumed electric power (red = dry cargo vessel; yellow = passenger ship; green = container ship; black = tanker).

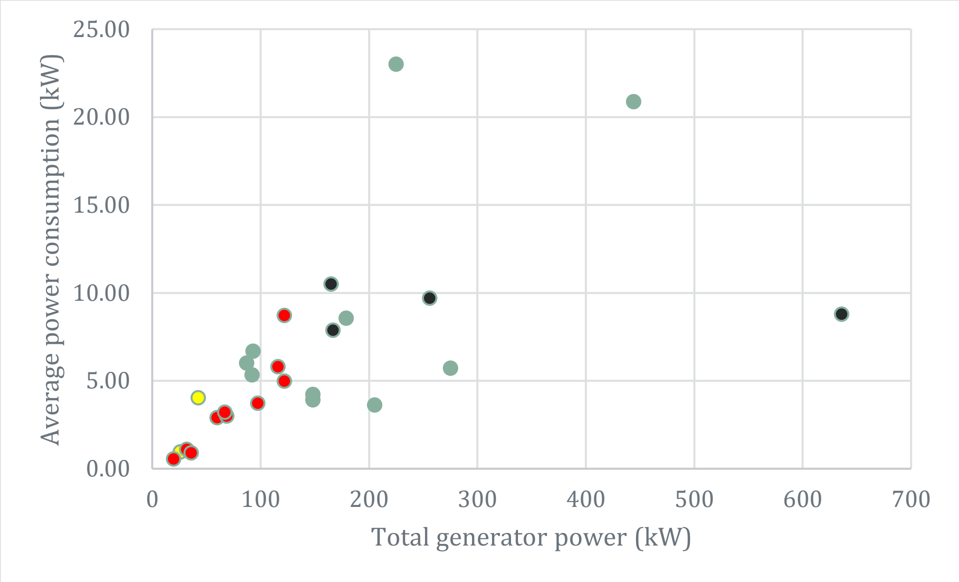

FIGURE 11: TOTAL INSTALLED GENERATOR POWER IN FUNCTION OF THE AVERAGE POWER CONSUMPTION (RED = DRY CARGO VESSEL; YELLOW = PASSENGER SHIP; GREEN = CONTAINER SHIP; BLACK = TANKER). THIS DOESN'T INCLUDE PEAK LOAD (*E.G.,* WHEN REEFERS ARE PLUGGED IN, OR UNLOADING PUMPS ARE IN OPERATION)

Using the data from this study, the average electricity power consumption for and inland vessel amounts **6.33 kW** (median of 5.15 kW). This is a factor 6 higher compared to previously reported values, *e.g.,* Rebel report 2015, 1.04 kW. This may be explained by the increased use of electrical heating / heat pump technology to heat the ships instead of the use of a fuel oil boiler. The total potential shore power consumption will thus be higher according to the results of this study.

ENERGY FOR DOMESTIC USE VERSUS ENERGY FOR SPECIFIC OPERATIONS ON BOARD A SHIP

It is common practice to instinctively overestimate the consumption (share in the annual energy balance) of large power consumers that are typically only used for a short period of time. This includes infrastructure specific to a ship, such as operating the hatches, using a high-pressure cleaner, raising and lowering the wheelhouse and operating pumps. These consumers have a small impact on the annual electricity consumption. However, these consumers are responsible for producing peak consumptions on board of a ship and, in other words, they largely determine the required power of the generator set and by extension the shore power connection.

On the other hand, consumers with a lower installed power are active for a large part of the year / a full year and mainly determine the annual electrical consumption. This mainly includes electrical heating (standard practice for new and renovated ships), cooling (air conditioning, refrigerator and freezer), domestic hot water production and ventilation.

This study therefore focused on the consumers related to "household consumption" when analyzes were performed on the (annual) energy consumption and on the consumers "for specific operations on board of a ship" when analyzes were performed on the shore power connection capacity.

Analysis of the data from the 26 ships included in this study has shown that the median percentage of installed power for domestic applications in relation to the total installed power on the ship accounts for 50% (Figure 12). The other 50% is made up of the installed capacity of electrical consumers, specifically linked to ship activities. The share of domestic energy use in the annual energy balance is on average 87%, the share of ship specific energy use is on average 13%. This corresponds to the general view that household consumers in particular determine the annual electrical consumption of a ship. The total median installed power is 89 kW and can be seen as an approximation for the peak power. This is approximately a factor of 17 greater than the median annual power consumption (5.15 kW). Note that determining the actual peak power was outside the scope of the energy scans. The peak power depends on the usage profile of the various consumers on board and can differ greatly from the total installed electrical power on board.

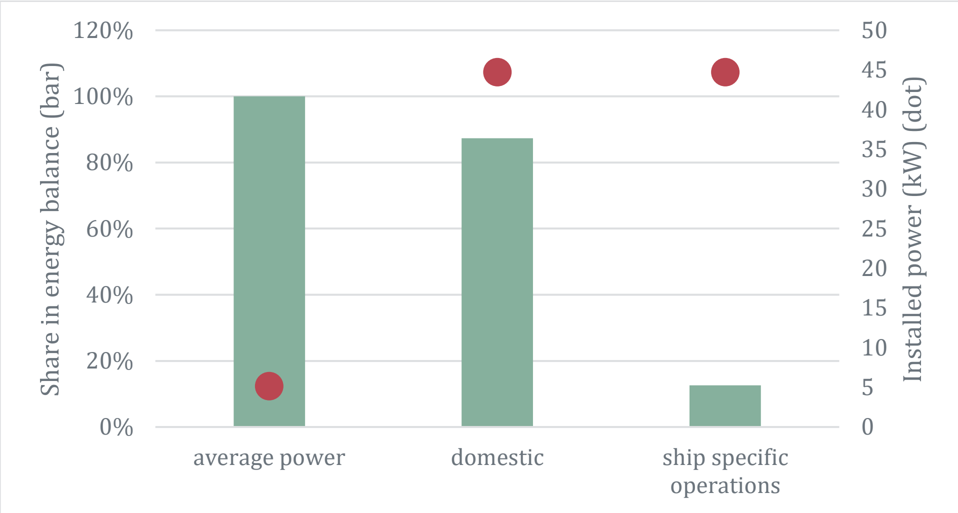

FIGURE 12: ANALYSIS OF THE MEDIAN POWER CONSUMPTION AND INSTALLED POWER FOR DOMESTIC USE AND SHIP SPECIFIC OPERATIONS (RED DOTS), AND THE COMPARISON WITH THEIR SHARE IN THE ENERGY BALANCE (ELECTRICITY) (GREEN BARS)

The share of installed power for domestic use in the total electrical power installed on the ship varies greatly from ship to ship (Figure 13). Tankers can typically be related to a low share of domestic related power (e.g. due to the large installed capacity of unloading pumps). Passenger ships and dry cargo vessels tend to have a large share of domestic related capacity. For container ships, the variation is large and no trend can be seen when analyzing the data from this study.

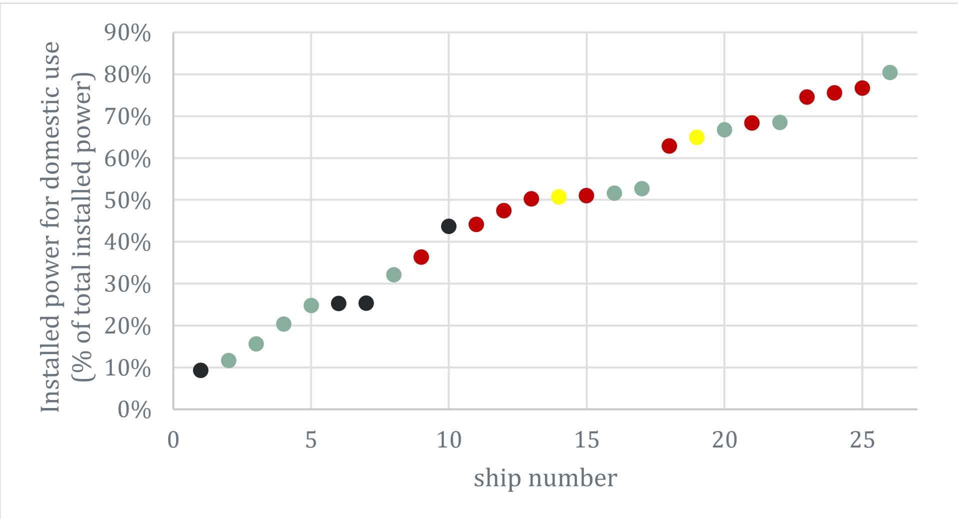

FIGURE 13: PERCENTAGE INSTALLED POWER FOR DOMESTIC USE FOR ALL SHIPS IN THIS STUDY (RED = DRY CARGO VESSEL; YELLOW = PASSENGER SHIP; GREEN = CONTAINER SHIP; BLACK = TANKER).

3.3.2 FUEL COST

BACKGROUND

In addition to the known and generally accepted advantages of using shore power instead of generator power, such as reduced emissions and the removal of noise nuisance, the perception remains that shore power is expensive (see also the user experience shore power section). It is therefore important to introduce the concept of fuel cost of generator power and to clearly communicate the difference with the fuel price for gas oil.

The efficiency of a motor depends on the load. At a low partial load (when the motor delivers much less power than the rated power), the efficiency is very low. This means that much of the energy of the supplied fuel is lost and not released as useful energy. In the case of a generator, this means that relatively little electrical energy is generated for the amount of fuel consumed. The efficiency and specific fuel consumption (number of units of fuel consumed per unit of useful energy produced) are inversely related to each other. When the efficiency is low, the specific fuel consumption is high and vice versa.

The specific consumption must be taken into account to determine the effective fuel cost of the generators and to obtain an equal basis for comparison with shore power. The effective fuel cost can be calculated using the formula below:

$$fuel\ cost\ \left(\frac{€}{kWh}\right) = \frac{fuel\ price\ (\frac{€}{L})}{density\ (\frac{g}{L})} * specific\ fuel\ consumption\ (\frac{g}{kWh})$$

Where the fuel price is known but subject to fluctuations, currently around 0.51 €/L (Statbel: “officieel tarief van de aardolieproducten”, 2021), the density of gas oil is assumed to be constant, 845 g/L, and the specific consumption must be calculated (see below).

The specific consumption can be calculated with the use of the technical specifications of the generator set on the ship, and the average consumed electrical power of the ship during standstill. The power requirement of the generator on board of inland vessels is typically designed to meet peak power demand. So most of the time the generator runs at a load below the most efficient point (far from the optimal 80% load). In reality, based on previous studies and also confirmed in this study (see section 3.3.1), the generators run most of the time at an average load of 8%. In order to determine the specific consumption at this load, the data from the technical data sheet of the manufacturers must be extrapolated (often data is only available onwards from 20-25%). The corresponding electricity generation efficiency for a recent generator set is 21% (specific fuel consumption of 377 g/kWh). This is a factor of 1.6 lower than when the motor of the power generator is running at its optimum operating point. Electrical energy taken from the electricity grid, a Belgium power plant has an average generation efficiency of 40%. This is approximately twice as high compared to using generator power (see figure below).

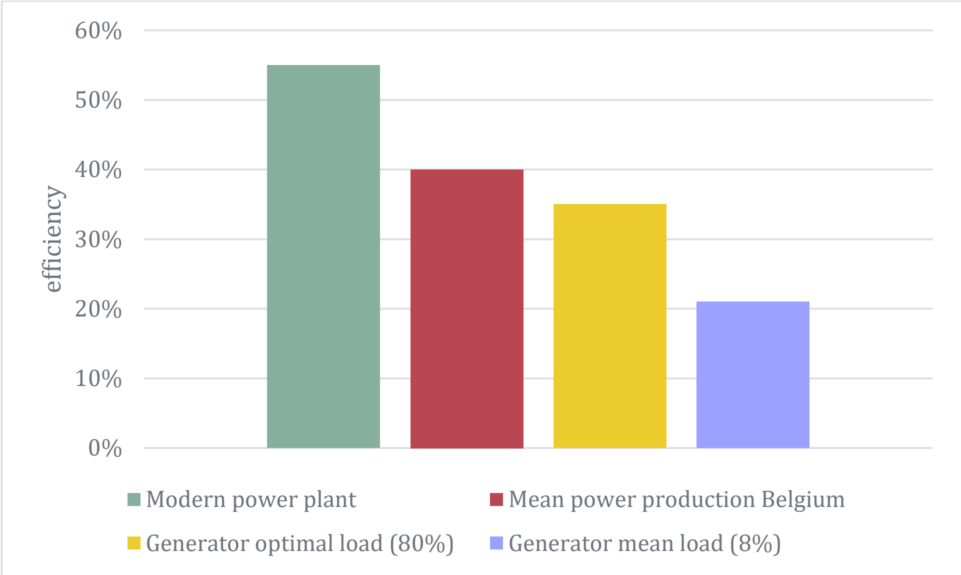

FIGURE 14: THE EFFICIENCY FOR POWER PRODUCTION USING DIFFERENT TECHNOLOGIES. SHORE POWER IN BELGIUM COMES FROM POWER STATIONS WITH AN AVERAGE EFFICIENCY EQUAL TO 40% (DATA EBO, ENERGY POLICY AGREEMENT). THE GENERATOR ON BOARD OF AN INLAND VESSEL PRODUCES ELECTRICITY WITH AN EFFICIENCY OF 21% ON AVERAGE (BASED ON 26 INLAND VESSELS).

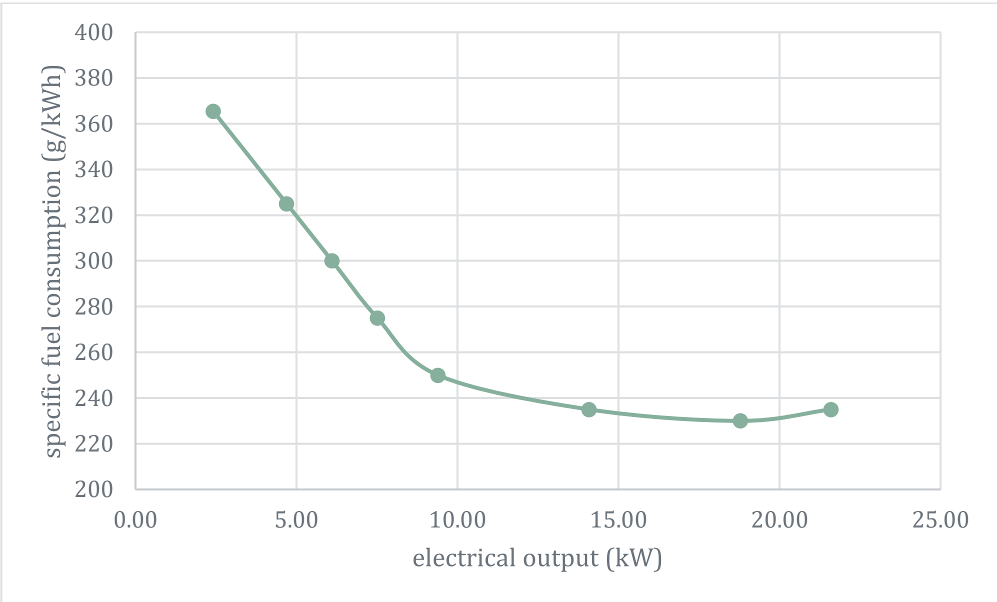

FIGURE 15: THE SPECIFIC CONSUMPTION OF A TYPICAL INLAND SHIPPING GENERATOR SET IN FUNCTION OF ITS ELECTRICAL POWER SUPPLIED (YANMAR GENERATOR SET, 4TNV84T-BGGE SPEC SHEET, @1500 RPM).

The effective fuel cost of the generator set can be determined on the basis of the above data. This amounts to 0.23 €/kWh. An important addition to this is the avoided maintenance cost of the generators when using shore power. Due to a lower number of running hours of the generators, less maintenance will be required. Typically it is assumed that the maintenance cost is 0.17 €/operating hour (Walstroom versus generatorstroom – een studie naar de kosten, 2011). When we include the maintenance cost in the fuel cost of the generator set using the average consumed power of the ship (6.33 kW in this example), the total cost of generator power is equal to 0.25 €/kWh. This is visualized in the figure below.

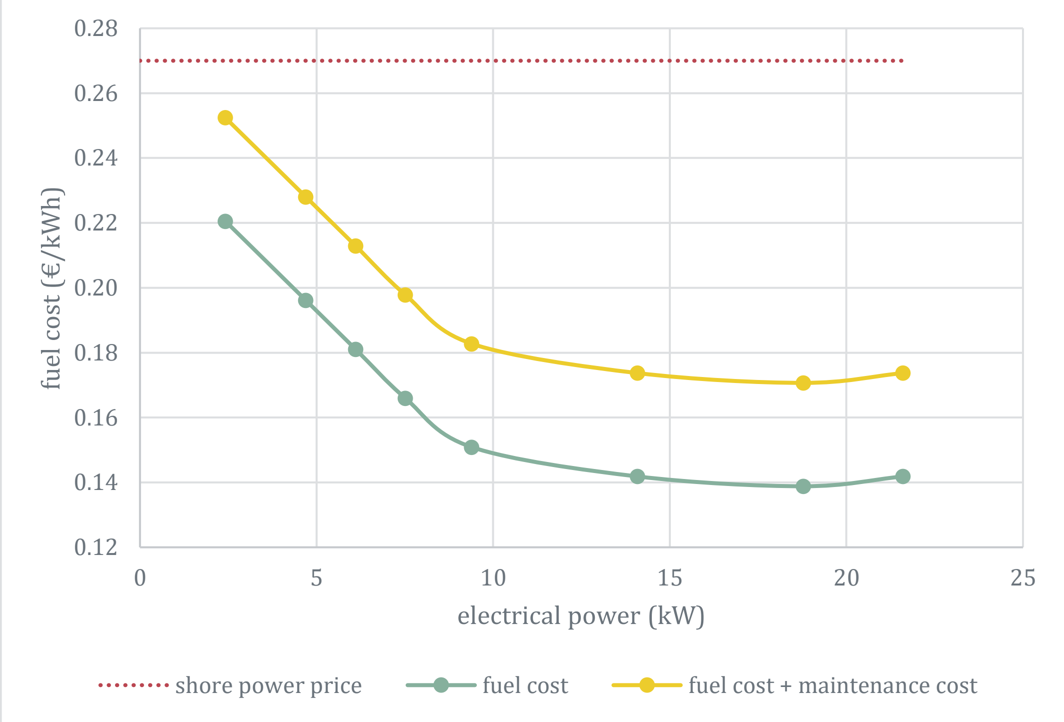

FIGURE 16: THE FUEL COST OF A TYPICAL INLAND SHIPPING GENERATOR IN FUNCTION OF ITS ELECTRICAL POWER SUPPLIED (INCLUDING MAINTENANCE COST OF THE GENERATOR SET). THE DOTTED HORIZONTAL LINE SHOWS THE AVERAGE SHORE POWER PRICE.

Furthermore, the use of shore power is future proof. With an increase in the share of renewable energy in the electricity grid, the primary energy consumption for electricity generation and the associated CO2 emissions will logically also decrease sharply. So there is still a lot of potential for improvement. On the other hand, few new innovations are possible in the field of internal combustion engines and the efficiency of electricity generation via the gas oil generators will improve little or not at all.

In the following cases, among others, the use of the generators on board has an advantage (in terms of financial efficiency): (i) electric heating: relatively high constant load during the winter; (ii) presence of large battery pack: first hours on shore power consumption from battery, then the generator can run at constant power to provide electricity and store energy in the battery.

DATA ANALYSIS

The **average fuel cost** (incl. maintenance) for generator power of all ships included in this study amounts **0.250 €/kWh.** This is comparable to the standard shore power price (0.27 €/kWh). Note that when the two outliers in the data are removed (red dots, Figure 17), the average fuel cost (incl. maintenance) amounts 0.238 €/kWh.

The figure below show the average generator load in function of the fuel cost (incl. maintenance). The fuel cost decreases with increasing generator load. Because of the low average load of the generator set for most ships the fuel cost is rather high. Note that the red dots deviates from the pattern because of the very low average consumed power of the ship (only 0.94 kW and 1.09 kW). This causes the maintenance cost per kWh produced electricity with the generator set to increase significantly. These points reflects small ships (passenger or dry cargo) with a gas oil boiler for heating and no air-conditioning.

When energy-saving measures are implemented, the average load of the generator set decreases, which increases the cost of generator power (points on the figure below are raised). This is in favor of shore power use.

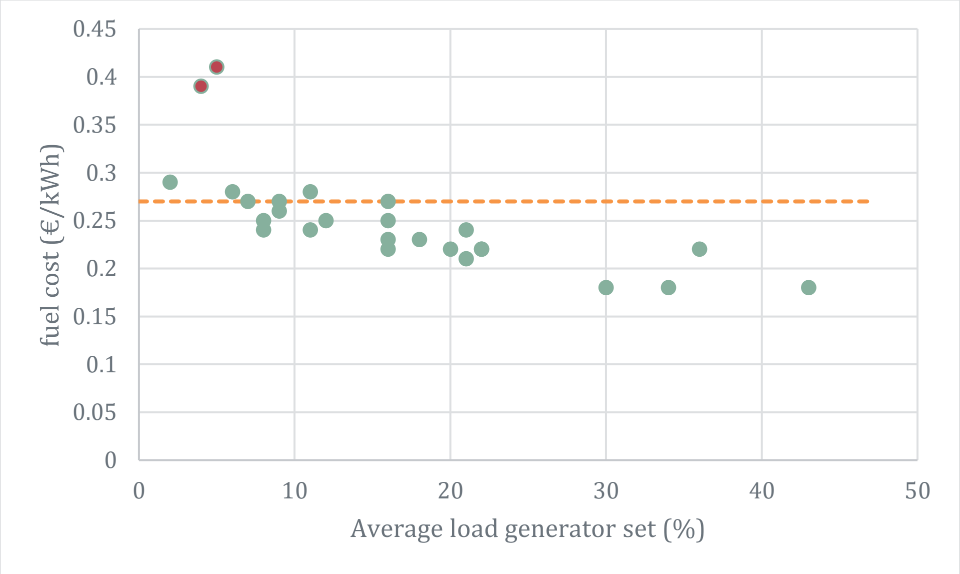

FIGURE 17: THE AVERAGE GENERATOR LOAD IN FUNCTION OF THE FUEL COST (INCL. MAINTENANCE) FOR GENERATOR POWER. THE SHORE POWER COST IS SHOWN WITH THE DOTTED LINE (0.27 €/KWH).

4. ENERGY SAVINGS ON BOARD

4.1 SUMMARY

The primary energy savings were calculated for each energy savings measurement. The figure below gives a summary of the cumulative primary energy savings per category. Quick wins have a payback time less than 1 year, certain measurements between 1 and 4 years, potentially profitable measurement between 4 and 10 years and unprofitable measurements more than 10 years. Also one safety measurement with an associated energy saving was identified.

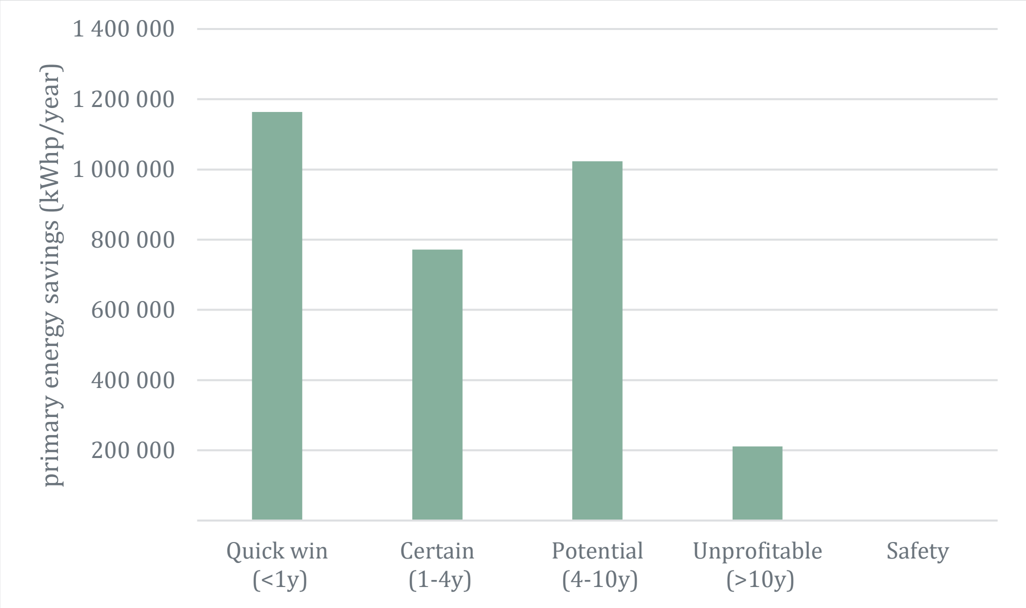

FIGURE 18: PRIMARY ENERGY SAVINGS FOR EACH MEASUREMENT CATEGORY, SUMMED FOR THE 26 INLAND VESSELS UNDER INVESTIGATION

The same summary is given below for the CO_2 savings.

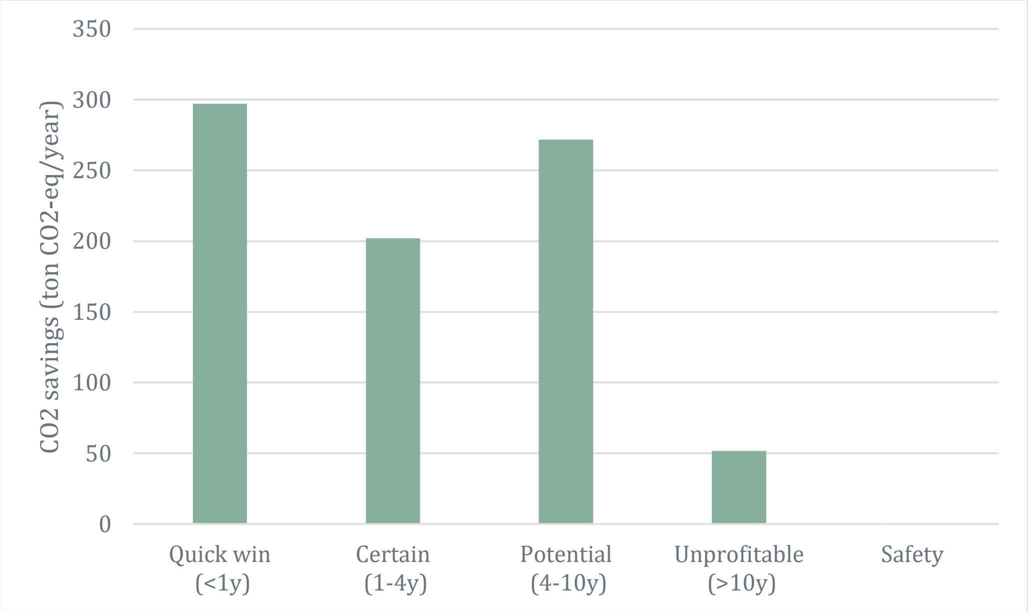

FIGURE 19: CO2 SAVINGS FOR EACH MEASUREMENT CATEGORY, SUMMED FOR THE 26 INLAND VESSELS UNDER INVESTIGATION

When all profitable measurements (payback time < 4 years) identified in the energy scans are implemented, the total primary energy savings amounts 1,935,144 kWh_p/year. This equals a total CO_2 savings of 499 ton/year or 100,162 euro/year (based on a gasoil price of 0.51 €/L and a shore power price of 0.27 €/kWh). A large proportion of the measures are potentially profitable. These require a detailed study and / or a request for quotation from a supplier before it can be said with certainty if they are profitable.

The average savings per ship for each ship type is shown in the table below.

TABLE 1: AVERAGE SAVINGS PER SHIP FOR EACH CATEGORY (SHIP TYPE) WHEN INPLEMENTING ALL PROFITABLE MEASUREMENTS (PAYBACK TIME < 4 YEAR)

	passenger ship	**tanker**	**container ship**	**dry cargo vessel**
Primary energy savings (kWhp/year)	27,065	149,565	132,494	28,775
Primary energy savings (% of total primary energy for electrical power production)	30	48	27	19
CO2 emissions savings (ton CO2-eq/year)	4.57	38.35	34.69	7.54
Financial savings (€/year)	2,704	7,507	5,670	1,613

4.2 ENERGY SAVING MEASURES

The most common energy saving measurements are shown below. The triangles show the number of occurrences of the measurement. The columns show the average primary energy saving per measurement per ship compared to the total primary energy consumption of the ship for electricity production (percentage).

FIGURE 20: MOST COMMON ENERGY SAVING MEASUREMENTS (FOR 26 INLAND VESSELS)

The average primary energy saving potential for the most common measurements (top 10) above is shown below. Energy savings due to energy monitoring is caused by, mostly, behavioural changes.

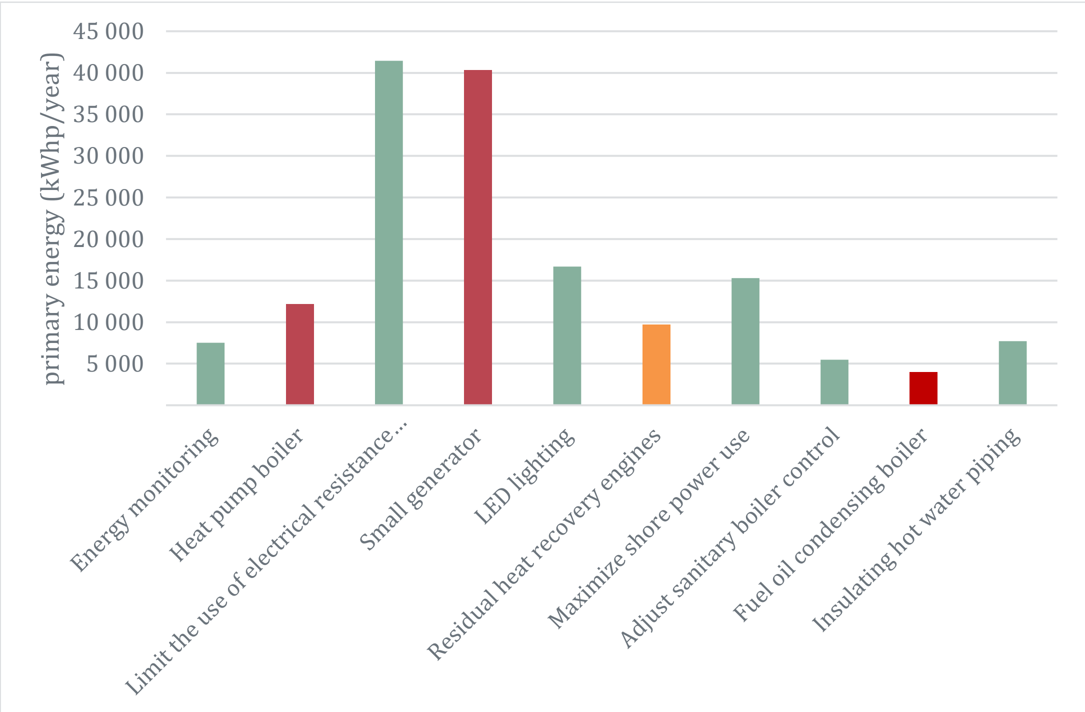

FIGURE 21: AVERAGE PRIMARY ENERGY SAVING POTENTIAL FOR THE MOST COMMON MEASUREMENTS (GREEN = PAYBACK TIME < 4 YEARS; RED = PAYBACK TIME > 4 YEARS; YELLOW = +/- 4 YEAR PAYBACK TIME)

When we sort the top 10 most common measurements according to their average investment per primary energy savings, the following figure can be constructed (Figure 22). Adjusting sanitary boiler control, limiting the use of electrical resistance heating, maximizing shore power use and replacing the lighting with LED are the most common measurements with a low investment cost but a high primary energy saving potential.

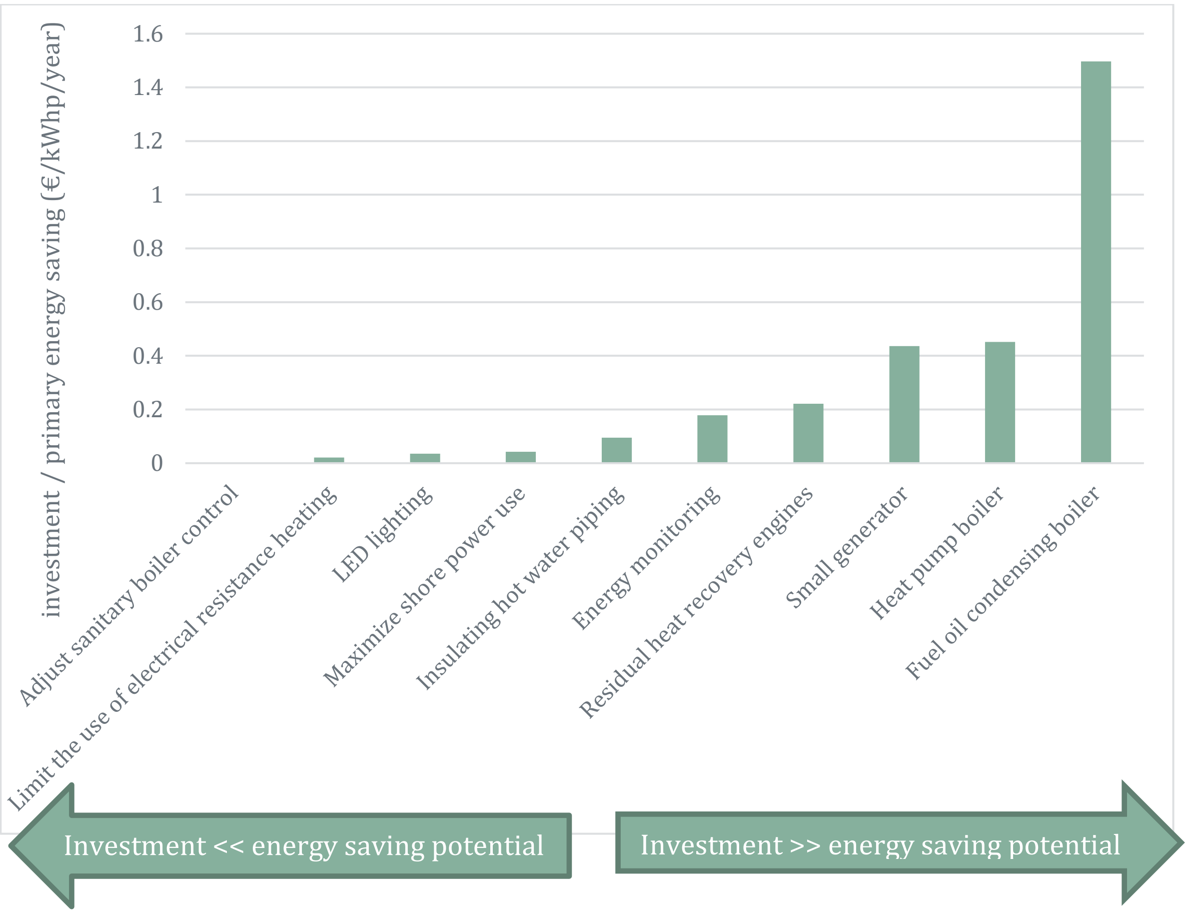

FIGURE 22: AVERAGE INVESTMENT PER PRIMARY ENERGY SAVING POTENTIAL

The top 10 **total** primary energy saving potential is shown below.

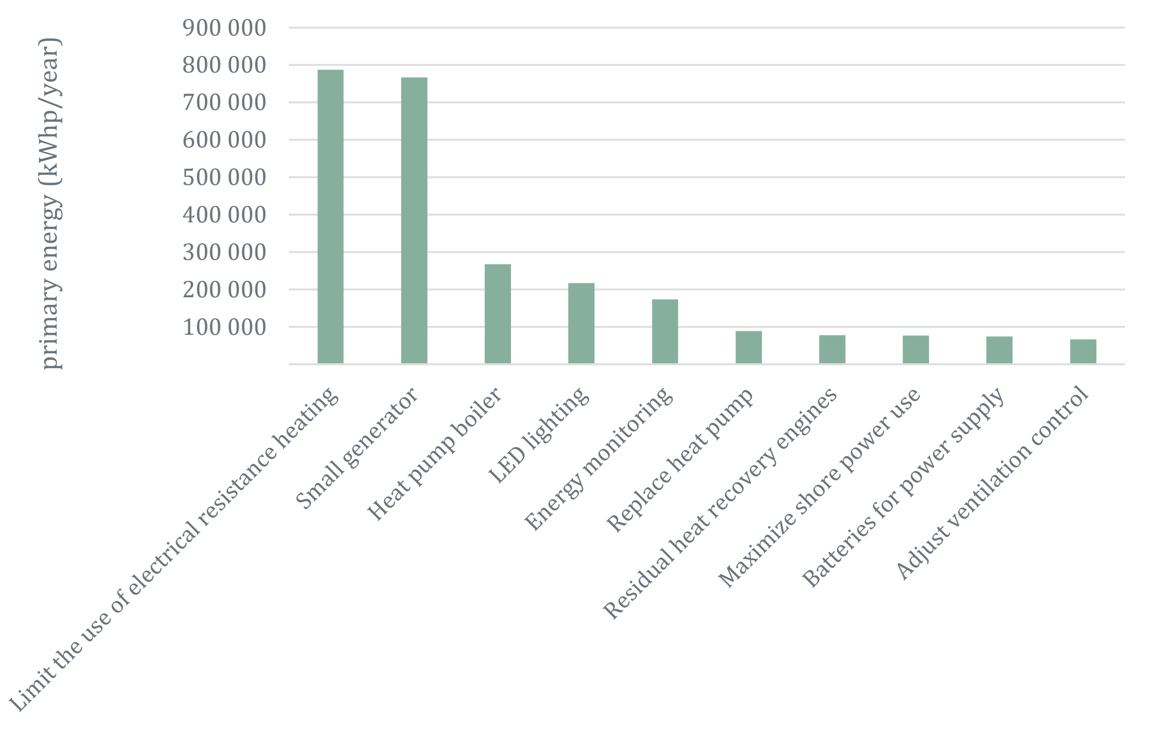

FIGURE 23: TOP 10 TOTAL PRIMARY ENERGY SAVING POTENTIAL

The top 10 **average** primary energy saving potential is shown below.

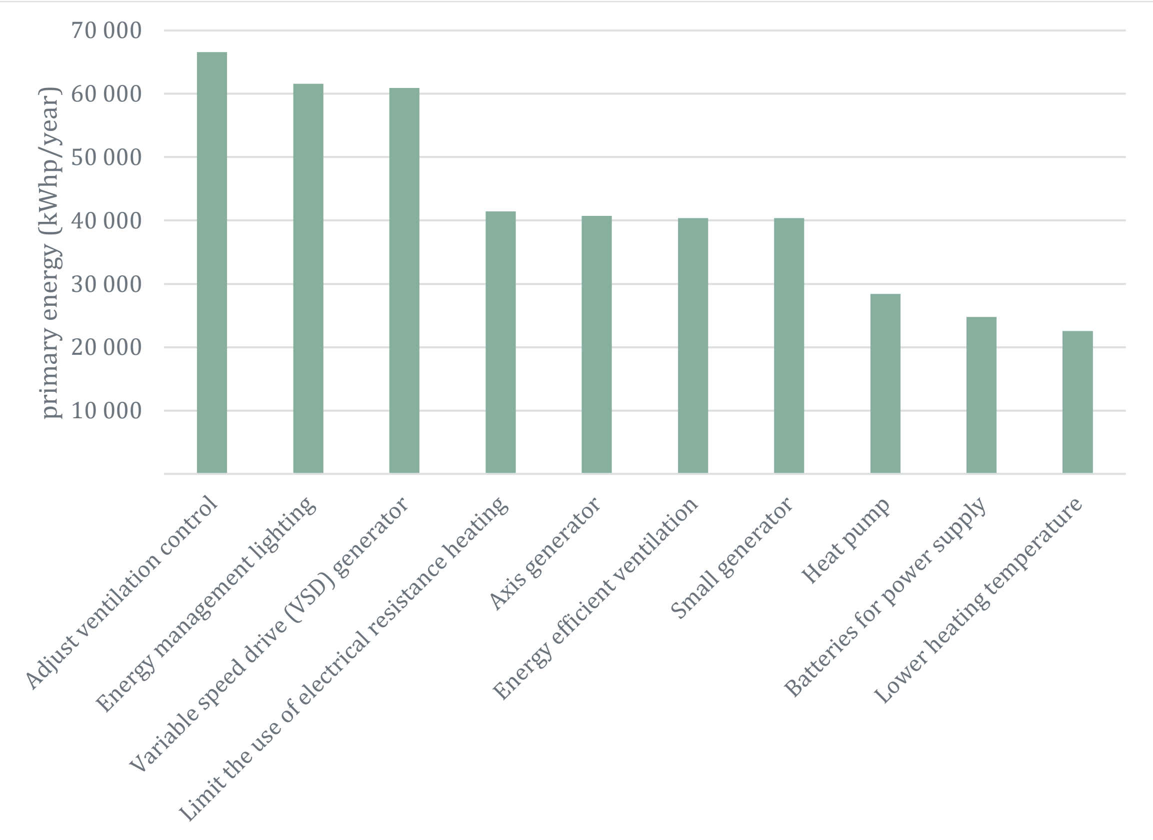

FIGURE 24: TOP 10 AVERAGE PRIMARY ENERGY SAVING POTENTIAL