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Project Report

MOMEC

Mapping of Energy Consumers

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Mapping of Energy Consumers

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ABSTRACT
Here, we present a study of the power consumption for different vessel types, and list some of the highest loaded consumers in different operations. In this brief study we are using *Electrical Power Load Analysis* (EPLA) as the data source. This also comes with a few shortcomings and the results will be influenced by design factors such as the *Utilisation Factor* (UF). On the other hand, the results will incorporate e.g. design know-how, regulations and requirements. Based on EPLA, we establish a statistical presentation of the power consumption, consisting of multiple vessels in each defined vessel group. However, we were able to only include a few fishing vessels in the study due to lacking data.

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Acronyms

AC Air Condition
AHTS Anchor Handling Tug Supply vessel
AHU Air Handling Unit

CII Carbon Intensity Index

DP Dynamic Positioning

EEDI Energy Efficiency Design Index
EEXI Energy Efficiency Index for Existing Ships
EPLA Electrical Power Load Analysis

GHG Greenhouse Gas

HPU Hydraulic Power Unit

IQR Interquartile Range

LF Load Factor
LFC Live Fish Carrier

PSV Platform Supply Vessel

ROV Remotely Operated Vehicle
RSW Refrigerated Sea Water

SLD Single Line Diagram
SOV Service Operation Vessel

UF Utilisation Factor

Summary

This report is a brief study of typical power consumption profiles for selected vessel types part of the Norwegian fleet. The results are based on *Electrical Power Load Analysis* (EPLA), and aim at providing summary profiles in terms of

- typical total power consumption,
- propulsion power in relation to total power consumption,
- distribution of power consumption between vessel systems,
- distribution of power consumption in size, i.e. power consumption of individual consumers,
- typical large individual consumers, and
- variations in vessels' power consumption in terms of the characteristics above, depending on the vessels' operational mode.

In addition to comparing different vessel groups, the report provides also information about the variability of these parameters within each vessel group.

The report shows that readily available information, namely *Electrical Power Load Analysis* (EPLA) performed by ship designers, can be used for high-level characterisation and comparison of important vessel groups. The main findings are summarised in Table 1.

This work is a stepping stone in mapping the energy footprint of the GCE Blue Maritime Cluster's fleet in light of the ambitions in the Paris agreement: to reduce *Greenhouse Gas* (GHG) emissions from maritime transport by at least 75-80 % by 2050. The reports main contribution to this overarching goal is to raise awareness of the main drivers behind the energy consumption of different vessel types. More precisely, this reports is intended for

- equipment vendors interested in how their specific product affects a vessel's power consumption profiles, and the relative importance of local power savings for their product,
- investors or developers of power saving technologies, and
- ship owners and designers interested in statistical data of energy / power characteristics in different groups of vessels.

Furthermore, the report can help the planning stage of measurement campaigns, since it provides pointers for which consumers need to be measured and logged in order to provide a good overview of a vessel's power/energy consumption. The same information may also be used when devising the vessel's logging system in the context of newbuilds.

A graphical summary of the main findings is given in Table 1. Note the reported propulsion share are EPLA-based and may be distorted due to assumptions of relatively harsh weather conditions. Please refer to Section 2 for a general discussion of applicability and limitations of the presented results and the respective subsections of Section 3.1 for a discussion of impact of these assumptions for each vessel group.

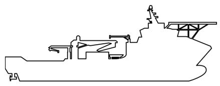
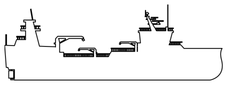
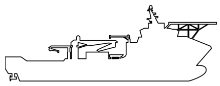
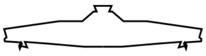
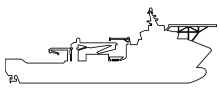
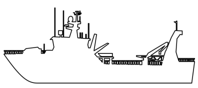
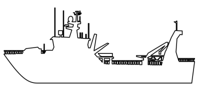
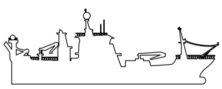
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
8	 *Platform Supply Vessel* (PSV)	79% Transit; 84% *Dynamic Positioning* (DP)	> 1000 kW: 2, 0; 100-1000 kW: 1, 5; 10-100 kW: 20, 25; 5-10 kW: 13, 13; < 5 kW: 63, 65
6	 *Live Fish Carrier* (LFC)	N/A Transit with cargo; N/A Loading	> 1000 kW: 0, 0; 100-1000 kW: 8, 6; 10-100 kW: 27, 26; 5-10 kW: 12, 14; < 5 kW: 47, 41
10	 *Service Operation Vessel* (SOV)	82% Transit; 82% DP	> 1000 kW: 1, 0; 100-1000 kW: 1, 5; 10-100 kW: 17, 18; 5-10 kW: 10, 12; < 5 kW: 67, 73
7	 Ferry	85% Transit; 88% Acceleration	> 1000 kW: 0, 0; 100-1000 kW: 2, 2; 10-100 kW: 2, 2; 5-10 kW: 1, 0; < 5 kW: 151, 148
1	 *Anchor Handling Tug Supply vessel* (AHTS)	87% Transit; 68% Towing	> 1000 kW: 2, 0; 100-1000 kW: 2, 16; 10-100 kW: 30, 49; 5-10 kW: 11, 21; < 5 kW: 192, 190
1	 Freezer trawler	85% Transit; 60% Towing	> 1000 kW: 1, 1; 100-1000 kW: 0, 4; 10-100 kW: 6, 14; 5-10 kW: 2, 3; < 5 kW: 0, 0
1	 Pelagic trawler	N/A Transit; N/A Towing	> 1000 kW: 0, 0; 100-1000 kW: 6, 7; 10-100 kW: 4, 8; 5-10 kW: 0, 0; < 5 kW: 0, 0
4	 Longline	50% Transit; 60% Recovery	> 1000 kW: 0, 0; 100-1000 kW: 1, 1; 10-100 kW: 14, 17; 5-10 kW: 4, 4; < 5 kW: 1, 1

Table 1: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2.

Chapter 1

Introduction

1.1 Background

An ever-increasing focus on man-made climate challenges has lead to stricter regulations for energy consumption, especially for carbon-based energy sources and related environmental pollution, and demands rapid readjustments and technological developments to meet tomorrow's environmental requirements.

This report is intended for equipment vendors interested in how their specific product compares with other equipment in a vessel's power consumption profile, which in turn can give an impression of how the power saving of each product affect the total power consumption of the vessel. Domestic shipping, fisheries, and leisure boats accounted for about 22 % of the *Greenhouse Gas* (GHG) emissions from the transport sector in Norway [1]. The maritime transport sector accounts for about 3 % of the global anthropogenic GHG emission, from *well to wake* [2]. In order to meet the ambitions in the Paris agreement, it is expected that the sector needs at least a reduction of 75-80 % of GHG emissions per ton mile up to 2050 in order to achieve a 50 % absolute reduction, assuming an annual sea transport growth of 3 % and 1 % annual energy efficiency improvements [2]. From and including 2023, requirements for *Energy Efficiency Index for Existing Ships* (EEXI) and *Carbon Intensity Index* (CII) is implemented for ships.

Previous investigations in the Norwegian maritime cluster have shown that there is need for increased knowledge about energy consumption for different vessel types. Moreover, it is necessary to include various operation types in different environmental conditions in order to pinpoint energy reduction- and optimisation possibilities.

This reports is intended for equipment vendors which will be interested in how their specific product comperes with other equipment in a vessel's power consumption profiles, which gives an impression of how much local power savings for their product will affect the bigger picture. The report is also intended for investors or developers of power saving technologies, and as a statistical summary of general knowledge on energy consumption from ship owners and designers. Different vessel types will most likely need various actions to significantly reduce their power demand. As an example, on a live fish carrier many of the consumers are rated to over 100 kW while on a car ferry most of the consumers are rated below 10 kW. Hopefully, the larger picture presented in this report will inspire new ideas and methodology for developing smarter, better, and less power-demanding vessels.

1.2 Task description

GCE Blue Maritime wants to develop a factual basis for improving the energy footprint for different vessel and operation types, in line with governmental requirements and regulations. In particular, such a factual basis will clarify the energy consumption related to different operations, equipment and handling for the most common vessel types in the Norwegian maritime cluster. The main objective of the work presented in this report is to provide a brief study of power usage for different vessels, operating in different modes and conditions. The study is based on *Electrical Power Load Analysis* (EPLA) as discussed in Section 2.2. The results are expected to highlight the main energy consumers for different vessels in different operations, and provide an entry point for further studies. In particular, the results are expected to establish a background for decision makers when it comes to deciding on, and prioritising, new R&D projects. Moreover, the report is expected to implicitly highlight the possibility of defining a combined survey report for the GCE Cluster's fleet, based on EEXI and CII, as a guide on reaching the cluster's goal of being climate neutral by 2030.

In this preliminary study, the vessel types are limited to the categories presented in Table 1.1.

Category	**Type**	**Operational modes**
Energy	*Platform Supply Vessel* (PSV)	Transit *Dynamic Positioning* (DP)
	Service Operation Vessel (SOV)	Transit DP
	Anchor Handling Tug Supply vessel (AHTS)*	Transit Towing
Aquaculture	Well boats	Transit with cargo Loading
Passenger	Ferries	Transit Acceleration
Fisheries	Freezer trawlers*	Transit towing
	Pelagic trawlers*	Transit towing Recovery
	Longline*	Transit Recovery

Table 1.1: Analysed vessel groups and operational modes. * denotes vessel groups where the reported figures are based on one vessel, i.e. their representativity for the group as a whole is unsure.

In addition, a set of operational modes have been defined for each of the vessel types. Some operational modes are independent of vessel types, such as *Transit*, whether others are not, e.g. DP operations for offshore vessels.

1.3 Report outline

Chapter 2 gives a short introduction to the methodology and the limitations in this brief study.

Chapter 3 presents and discusses the main findings from the study.

Chapter 4 concludes this brief study.

Chapter 2

Methodology, assumptions and limitations

Mapping the power consumption for all significant consumers onboard a vessel in different operations and conditions is a cumbersome task. Moreover, increasing the study to include multiple vessels for many vessel types, such as *Platform Supply Vessel* (PSV)s, trawlers and ferries, to obtain statistical foundation for different vessel types, significantly increases the scope of work.

Different power consumers onboard a vessel range from small electrical components such as a microwave in the galley to larger, more heavy duty consumers such as deck machinery, propulsion systems and air compressors. The switchboard and electrical power systems onboard a vessel is normally not designed to monitor each component connected to the power grid and, hence, it is challenging to pinpoint the distribution and composition of other power drawing consumers onboard a vessel. To increase the complexity, some of the consumers are also interlinked and dependent on each other in various operations.

Instead of initiating a regime of detailed monitoring of each consumer, which usually requires additional instrumentation onboard the vessels, a rougher approach more suited for a smaller and coarser study is considered. The motivation for a simplified approach is to achieve information for many vessels and vessel types instead of selecting only a few for thorough data acquisition.

The simplified methodology is based on extracting information about the consumers and their expected loading in various operations and scenarios from the vessel's electrical design and engineering information. More precisely, *Single Line Diagram* (SLD) and the electrical load balance. This load balance is mainly used to dimension the power plant onboard the vessel and for ensuring sufficient power and energy capacity and characteristics in all operations, also in critical situations. A challenge for generating such electrical load balances is the assumption given for each significant component's load in a given operational mode, and how many of the vessel's components that are running simultaneously in a given operational mode. The *Electrical Power Load Analysis* (EPLA) is reflecting the load analyses of the ship's electrical system and must cover all the relevant vessel operations and design conditions. Typically, for an offshore vessel this can be *normal sea-going* (sailing), *cargo handling*, *manoeuvring*, *station keeping* and *emergency operation*. The main task of the EPLA performed when designing the vessel is to calculate and balance the electrical power required to operate the vessel as intended and according to regulations. As a direct result of this analysis it is possible to evaluate the power production demand, which is used for designing the vessel's power plant [3, 4].

2.1 EPLA summarisation

Electric load balances are in essence a list of the nominal power consumption of equipment installed on the vessel. Each of these consumers may run at different loads (expressed as a factor between 0 and 1, the *Load Factor* (LF)), but may also be switched on and off, depending on the vessel's operation. This aspect is captured by introducing an additional factor, the *Utilisation Factor* (UF). E.g. if a specific consumer is switched on 30 % of the time, the UF is set to 0.3 . Both LF and UF depend on the operational mode of the vessel, e.g. Dynamic Positioning *(DP)* or *transit*. The typical average power consumption for a given piece of equipment is estimated by

$$p = p_n \cdot lf \cdot uf,$$

where p_n is the nominal power consumption. Deciding what operational modes to consider and setting appropriate UFs and LFs is a pivotal step in devising a vessel's electric load balance and part of the design process, i.e. an fixed input to the analyses performed within the scope of this report.

For each vessel group, two representative operational modes are chosen, and the distribution of the total power consumption as well as the propulsion share of the total consumption is reported for the two modes. To this end, we make use of the graphical representation discussed in Section 2.3.1. "Transit" is chosen as one of the two modes for all vessel groups. The other mode is selected based on two criteria: a) the mode is characteristic for the special purpose of the vessel group, and b) the mode is, with some variation, present in all electric load balances for the vessels in the group.

For each individual vessel, the consumers listed in its electric load balance are categorised according to the type of vessel subsystem to which they belong. The categories used in this report are

propulsion (p) main propulsion, bow thrusters, etc.,

accomodation (acc) consumers related to crew areas, e.g. air handling units, galley equipment, laundry, lighting, etc.,

mission (m) consumers needed to perform some operation that is connected to the specific vessel type, .e.g. trawl winches for trawlers, gangways for *Service Operation Vessel* (SOV)s, cranes for PSVs, circulation pumps for *Live Fish Carrier* (LFC), etc., and

auxiliary (aux) consumers like pumps, compressors, cooling, etc., linked to non-mission equipment.

Then, we classify each consumer according to its power consumption in the respective modes. The used categories are

category 1 consumers with power consumption below 5 kW,

category 2 consumers with power consumption between 5 kW and 10 kW,

category 3 consumers with power consumption between 10 kW and 100 kW,

category 4 consumers with power consumption between 100 kW and 1000 kW, and

category 5 consumers with power consumption above 1000 kW.

For each operational mode, the distribution of total power consumption and number of consumers in each category is reported. Again, we make use of the graphical representation discussed in Section 2.3.1.

Finally, we exemplify the largest consumers in each of the selected operational modes for a vessel group. This is done by collecting the 30 largest consumers for each mode for one vessel in a table. The vessel is chosen at random from the vessel group to which it belongs. The consumers are sorted and categorised according to their power consumption and the type of vessel subsystem to which they belong, according to the criteria detailed above. The list is deduplicated by removing equivalent consumers, e.g. "main propulsion starboard" and "main propulsion portside" will be merged into one entry "main propulsion", "circulation pump 1", "circulation pump 2", and "circulation pump 3" will be merged into "circulation pump". If these equivalent consumers do not belong to the same power consumption category, the category of the merged entry is reported as a span, i.e "category 2-3". To keep anonymity, supplier names are removed from the consumers. If need be, acronyms and the like are expanded to improve interpretability.

2.2 Limitations

While the use of electric load balances as detailed in Section 2.1 above, allows for a efficient analysis of larger numbers of vessels and hence a statistical treatment of vessel groups, compared to measurement campaigns, it also entail a number limitations of which the reader of this report should be aware.

The results is expected to be coarse and will reflect the know-how in the design offices rather than the power consumption and distribution in actual realistic operations, and might include regulatory effects such as routed power to emergency equipment, which from an EPLA indicates that these systems always are drawing power.

Hence, one of the difficult tasks at hand when using data from such electrical load balances for assessing the typical power demand and loading in a realistic operational mode is to evaluate what would be a realistic load on each key component in a given operation, what the variations in load would look like and how to avoid using loads specifically meant for dimensioning, such as the loading of the fire prevention systems.

Nevertheless, including such effects, both the know-how in the design offices and the regulatory effects, is also considered a result in it self and if the know-how varies greatly between the design offices it will be reflected in the results.

It has traditionally been customary to choose operational conditions and scenarios included in the EPLA in such a way that they represent the boundary region of the vessel's operational envelope, i.e. reported loads may be more representative of a "worst case" scenario then the typical operation in the respective mode. However, this practice has recently shifted toward using scenarios that are more representative for "normal" operation.

The traditional method to perform an EPLA is based on factors, which can partially account for the behaviour of each user in the different ship operative scenarios. The LF is the most used one in the naval domain [3].

The results from this study are intended used for indicating possible power consumption groups worth looking closer into when investigating possibilities for energy- and emission reduction measures. The list below gives a condensed representation of the main assumptions and limitations of the mythology used in this study.

- This is a brief study intended for giving a rough estimate of the main power consumers in different vessel types, for different operations.
- The study is based on EPLA, which are often use for dimensioning purposes. Hence, propulsion loads as well as emergency equipment would have higher loading than what is the case in normal operation.
- Only electrical consumers are taken into account in this study. Hence, e.g. mechanical propulsion systems and heat recovery systems are not included in the analysis.
- The number of available vessels in each studied vessel type highly affects the results.
- Most of the vessel type in the Norwegian maritime cluster are service vessels, performing various marine operations. Hence, many operational modes exist. To reduce data and to make the report readable, only two modes have been selected. This can lead to findings that are given more weight than it should be and that some findings are over-looked. However, it is seen as useful as it gives the first insight and represent the methodology and possibility to investigate several modes.
- We assume that load calculation data is sufficient for mapping the main characteristics for the power consumption.
  - If not, then also the know-how in the design offices must be challenged.

2.3 Graphical representation of results

2.3.1 Boxplots

A *boxplot* (more precisely, *box and whisker plot*) is a graphical representation used to visualise the distribution of data samples with interval or ratio scale values (i.e. "numerical" data), introduced by Tuckey [5].

It conveys the sample distribution's *location*, *variation*, and *skewness*, based on robust statistical measures, i.e. measures that are not influenced by single outliers. The measures involved are the *median*, and the *first* and *third quartile* (Q1 and Q3). The median is the mid value of the ordered samples, while the first and third quartiles are values such that one and three quarters of the ordered samples are smaller then these values, respectively. For a further information about descriptive statistics and measures we refer to Bhattacharyya and Johnson's textbook [6].

The plot is constructed by drawing a box spanning from Q1 to Q3 and a line indicating the median. Furthermore, lines starting at the edges of the box are added, so-called *whiskers*. The length of the whiskers is proportional to the length of the box, the so-called *Interquartile Range* (IQR) (i.e. Q3 - Q1), typically 1.5 times the IQR, but clamped to the smallest and largest sample point that falls within the range. Samples beyond the whiskers, if any, are considered to be outliers and either drawn as individual points or omitted. For a more detailed review on different flavors of boxplots, especially alternative definitions of the whisker lengths, we refer the reader to [7]. For the purpose of this report, the whisker length is $1.5 \cdot IQR$ and outliers are drawn. Figure 2.1 illustrated the process of drawing a boxplot based on sample data through a worked toy example.

Boxplots are useful tools for exploratory data analysis, but have a few drawbacks. First, since the distribution is, in essence, described by five values, the boxplots do not fully capture the details of complex distributions (e.g. the number of modes in a distribution obtained as a Gaussian mixtures). Second, the boxplots do not convey any information about the underlying sample size and information about individual samples is lost (except for outliers). In the context of this report, the latter may be considered an advantage, since it anonymises the underlying data.

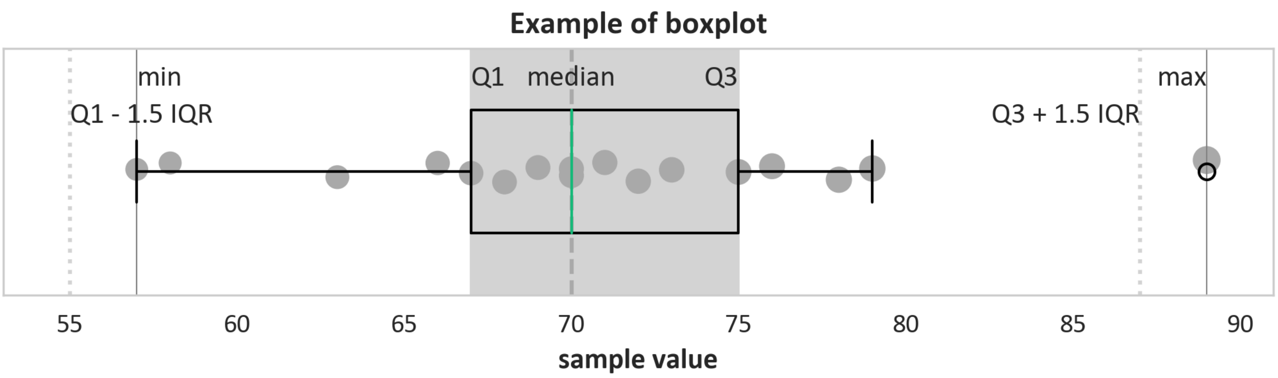


Figure 2.1: Boxplot and underlying sample data. The dark grey circles represent the example data $\{57, 58, 63, 66, 67, 68, 69, 70, 70, 71, 72, 73, 75, 76, 78, 79, 89\}$, for simplicity's sake, the samples are ordered from smallest to largest). The vertical position of the points is assigned randomly to reduce visual clutter and bears no information. Following standard definitions (c.f. e.g. [6]), it is easy to derive that 57, 67, 70, 75, 89 are the sample's minimum, first quartile ($Q1$), median, third quartile ($Q3$), and maximum, respectively. Hence, $8 = 75 - 67$ is the IQR. The values of the minimum and maximum are marked by solid grey lines, the median by a dashed grey line.
Following the definitions given in Section 2.3.1, the lower whisker extends minimally to $55 = Q1 - 1.5 \cdot IQR$ and the upper whisker to maximally $87 = Q3 + 1.5 \cdot IQR$. The most extreme possible values for start and end of the whiskers are represented by dotted grey lines.
Since the smallest sample is 57, the lower whisker is clamped to this value. The largest sample in the data smaller then 87 is 79, hence the upper whisker stops at this value. There is one data point with a larger value, namely 87. This sample is considered an outlier and drawn as an individual hollow circle.

Chapter 3

Results and discussion

3.1 Vessel group description

This section gives a detailed description of the power consumption for different vessel groups. The description focuses on the overall power consumption, the share of power consumed by the propulsion systems, and the approximate power rating of the individual consumers (i.e. few large vs. many small consumers). For a more high-level discussion on differences between vessel groups, we refer the reader to Section 3.2.

For vessel groups where only a few vessels are available, there is not enough information to discuss the distribution within the group. In this case, we restrict ourselves to report power consumptions based on individual vessels, and the reported figures are rounded to avoid identifying individual vessels.

3.1.1 *Platform Supply Vessel* (PSV)

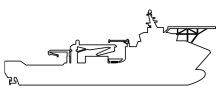
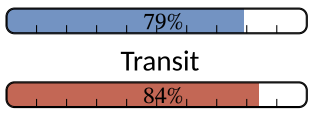
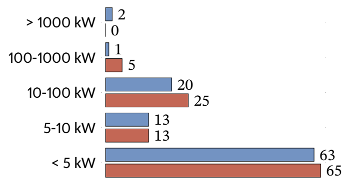
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
8	 PSV		

Table 3.1: Summary of propulsion load in operations (where available) and classification of the power consumers, based on *Electrical Power Load Analysis* (EPLA). For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

Vessel summary

The results presented in this section are based on 8 vessels with 7 distinct designs. Two of the vessels are sister ships. The main particulars of these vessels are summarised in Table 3.2, also including IQR, as explained in Section 2.3.1.

Platform Supply Vessel (PSV)s are mainly used for transporting goods, equipment, etc. to and from offshore installations. Hence, two of the most important operational modes of these vessels are transit and *Dynamic Positioning* (DP). Depending on the location of the offshore installation serviced and the type of cargo to be

	mean	median	IQR
year built	2014.6	2014	2.8
length overall [m]	87.7	86.4	5.5
beam [m]	18.8	17.5	2.1

Table 3.2: Main particulars of the eight PSVs used to derive the results presented in Section 3.1.1.

transported, each of the two modes may last for hours at a time. DP operations are typically shorter then transits.

Power consumption

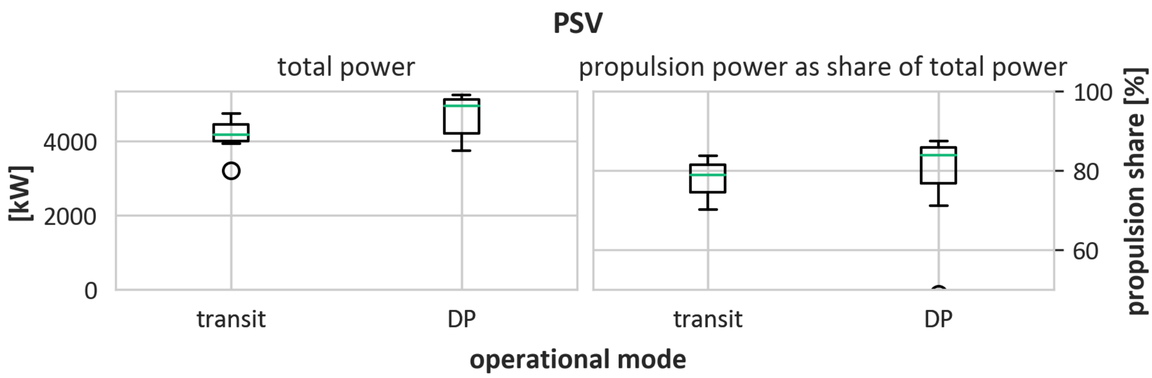


Figure 3.1: Per mode distribution of total power consumption and propulsion share for the analysed PSVs. It should be noted that transit and DP are operational modes that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in these modes.

As seen in left panel of Figure 3.1, the typical transit power demand for the analysed PSVs are just above 4000 kW and just below 5000 kW for transit and DP, respectively. There is more variability in the power consumption in DP, especially among vessels with lower DP consumption. Most of the total power, between approximately 70 and 85 %, is used for propulsion (see right panel of Figure 3.1), but the share is slightly lower for transit. Note that it is customary to assume challenging weather conditions for both operational modes for the sake of dimensioning, and especially propulsion loads may therefore be considerably higher then in real life day-to-day operation (perhaps half of the above reported figures). This effect might be more pronounced for DP then for transit, since vessels typically will slow down in harsh conditions, while the requirements for DP operations cannot be relaxed.

Figure 3.2 shows again the power consumption in the different modes, but split into different consumer categories, ranging from small (consumers rated 0-5 kW) to large (consumers rated 1000-3000 kW). The top row gives the sum of the power consumption of consumers in the respective categories, while the bottom row gives the number of consumers in each category. The most significant difference in the power consumption profile of the two analysed modes is observed for the two largest consumer categories. In transit mode, a small number of large consumers dominate the vessel's total consumption. In DP the power distribution is dominated by the group of consumers between 100-1000 kW. They are still comparable few. In addition an increased power consumption by consumers in the 10-100 kW range can be observed, both as part of the total consumption and in the number of active consumers. The contribution from the two low-power consumer categories is marginal, and does not appear to be influenced by the vessel's operational mode.

Table 3.3 gives an anonymised list of the 30 largest consumers for one of the vessels in the vessel group (chosen at random). For each operational mode, the consumers are sorted by power rating and categorised into categories 1 to 5, where 5 corresponds to consumers with power consumption between 1000 kW and 3000 kW, 4 to power consumption between 100 kW and 1000 kW, etc., following the same subdivition as in Figure 3.2.

The table shows that main propulsion is the largest power consumer in both analysed operational modes. However, the amount of power consumed by this group is slightly lower in DP (cat 5 consumers in transit vs. cat 4-5 consumer in DP). In addition, we can see that bow and retractable thrusters are also important consumers in DP. Apart from this difference, the largest consumers, their relative ordering and category are pretty similar in both modes, e.g. after propulsion, the dominant consumers for both modes are air handling and chilled water units, as well as hydraulic systems.

transit			DP		
consumer	system	p. cat.	consumers	system	p. cat.
main propulsion	p	5	main propulsion	p	4-5
air handling unit accommodation	acc	3	tunnel thruster	p	4
chilled water unit compressor cabinet	aux	3	retractable thruster	p	4
HPU pump starters	aux/m	3	air handling unit accommodation	acc	3
tank wash electric heater	m	3	HPU pump starter	aux/m	3
var. distribution panels	?	3	chilled water unit compressor cabinet	aux	3
bulk handling system compressor	m	3	tank wash electric heater	m	3
UV power	?	3	var. distribution panels	?	3
electric heater special product tank	m	3	bulk handling system compressor	m	3
tunnel thruster precharge cabinet	aux	3	electric heater special product tank	m	3
main propulsion precharge cabinet	aux	3	tunnel thruster precharge cabinet	aux	3
turning gear motor control unit	aux	3	main propulsion precharge cabinet	aux	3

Table 3.3: The 30 largest consumers for a randomly chosen PSV, sorted by power consumption, from largest to smallest, and categorised according to the vessel subsystem they belong to and their power consumption (p. cat., corresponding to the grouping in Figure 3.2), after deduplication. See Section 2.1 for the definition of the different categories. Consumers that can not be attributed to a specific subsystem area marked with "?" in the system column. Emergency systems have been removed from the list, since they are not typical consumers, but included for dimensioning. It should be noted that transit and DP are operational modes used for dimensioning, i.e. the reported figures are more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in these modes. Distribution panels usually comprise a number of small consumers (typically power category 1-2 or lower). The grouping is chosen based on location and voltage (low, medium, and high) and may or may not be tied to specific vessel subsystems. The extent of usage of this "consumer" in load balances varies greatly across design companies, projects, and personnel.

A graphical summary of the main findings is given in Table 3.1.

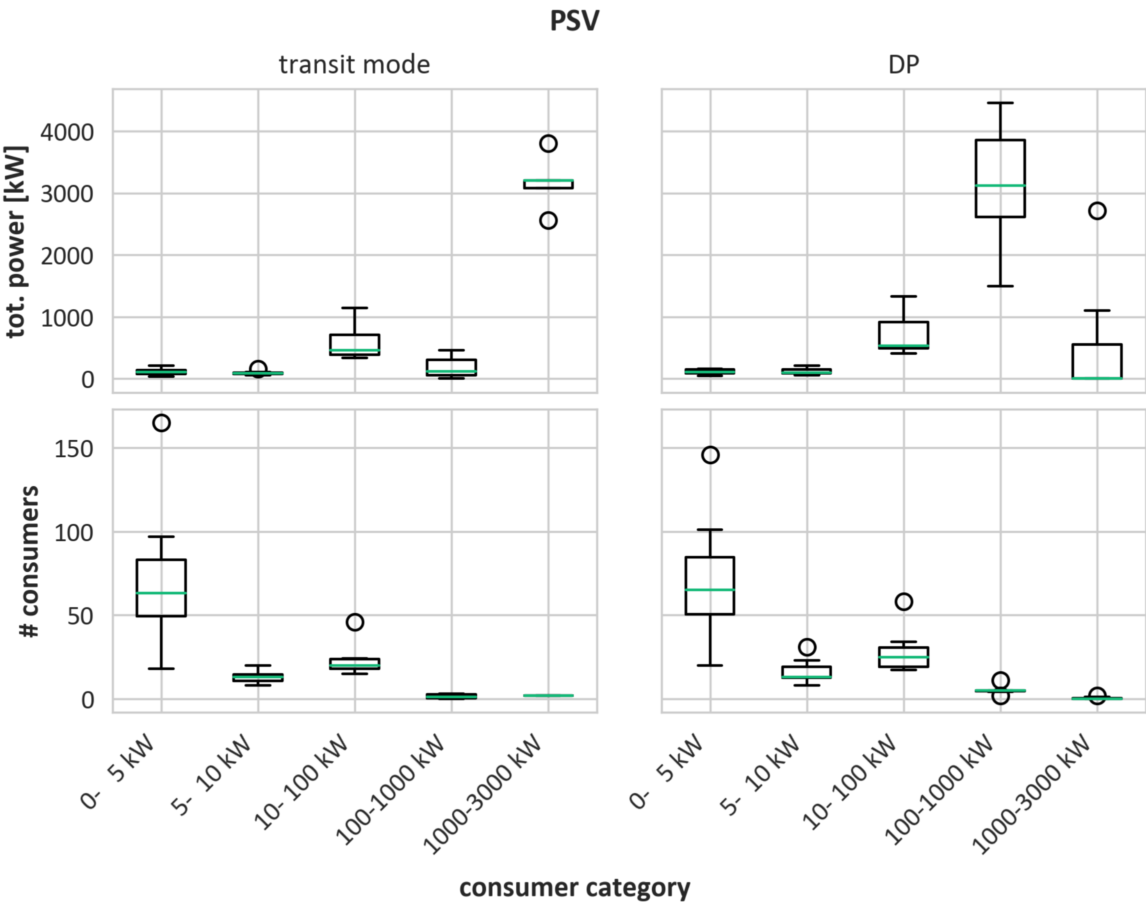


Figure 3.2: Per mode distribution of total power consumption and number of consumers, grouped by power consumption per individual consumer, for the analysed PSVs. The grouping corresponds to the power consumption categories introduced in Section 2.1, 0-5 kW corresponding to category 1, 5-10 kW to category 2, etc. It should be noted that transit and DP are operational modes that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in these modes. Consumers in the two lowest groups may be grouped together into distribution panels that will be classified as one intermediate category consumer. The use of distribution panels in electric load balances varies greatly, and may contribute significantly to the variability in number of consumers in the lowest categories.

3.1.2 *Live Fish Carrier* (LFC)

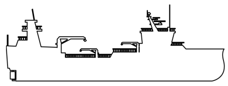
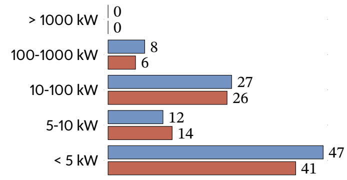
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
6	 LFC	N/A Transit with cargo N/A Loading	

Table 3.4: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

Vessel summary

The results presented in this section are based on 6 vessels. The main particulars of these vessels are summarised in 3.5.

	mean	median	IQR
year built	2018.2	2018	5
length overall [m]	94.6	84.8	20.5
beam [m]	18.3	16.9	1.6

Table 3.5: Main particulars of the 6 *Live Fish Carriers* (LFCs) used to derive the results presented in Section 3.1.2. The asterisk denotes properties that are not available for all vessels.

LFCs are used for transporting live fish to and from aquaculture sites. In contrast to other vessel types, there is a large variation in how these vessels operate also in transit. This operation mode may or may not be performed with live fish on board, entail the use of *Refrigerated Sea Water* (RSW), open or closed water circulation, and more. At the aquaculture site, the fish is typically pumped either from the net pens into the vessel's well/tank or vice versa. In addition, the vessel may perform other specialised operations at the aquaculture sites, such as delousing. Hence, two of the most important operational modes of these vessels are transit and loading. In this report we study transit with live fish and RSW. Note that the use of RSW increase the power consumption of the vessel. Likewise, transit without live fish will naturally be less power intensive.

Power consumption

The majority of the LFCs studied have no diesel-electric propulsion. Hence, the reported power consumption will only comprise non-propulsion consumers.

As seen in Figure 3.3, the typical power demand for transit with live fish and RSW for the analysed LFCs is around 2500 kW and around 2000 kW for transit with fish handling and loading, respectively. However, there is considerable variation in the power consumption during loading, especially among vessels with above-average power consumption. The number of vessels where propulsion power is available to low to derive statistics, but anecdotally we observe that propulsion share in transit lies in the 30-50 % range. For loading the, this figure appears to be in the same range, but as with DP for other vessels, this number might be influenced by the assumed weather conditions.

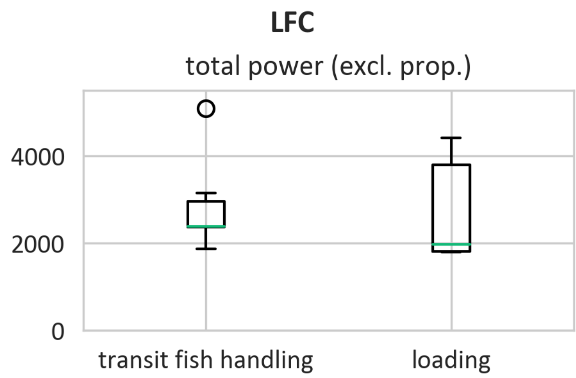


Figure 3.3: Per mode distribution of total power consumption, excluding propulsion, for the analysed LFCs. Note that transit is a operational mode that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in this mode.

Figure 3.4 shows again the power consumption in the different operational modes, but split into different consumer categories, ranging from small ("category 1", i.e. consumers in the range of 0-5 kW) to large ("category 5", i.e. consumers in the range of 1000-3000 kW). The top row shows the sum of the power consumption of consumers in the respective categories, while the bottom row shows the number of consumers in the individual categories. The main difference in the power consumption profile of the two analysed modes is found for the largest consumer categories. In transit fish handling mode, a small number of consumers in the top category accounts for a significant amount of the vessels' total power consumption. During the loading operation, these consumers are not present, but the number of "category 3" consumers and their overall power consumption can increase significantly. The power consumption associated with "category 4" consumers (i.e. 10-100 kW) decreases, while their number is unchanged or even larger.

Table 3.6 gives an anonymised list of the 30 largest non-propulsion consumers for one of the vessels in the vessel group (chosen at random). For each operational mode, the consumers are sorted by estimated power consumption by EPLA and categorised into categories 1 to 5, where 5 corresponds to consumers with power consumption between 1000 and 3000 kW, 4 to power consumption between 100 kW and 1000 kW, etc., following the same subdivision as in Figure 3.4.

The table shows that many of the largest consumers for the transit fish handling mode are related to the use of RSW. These consumers are not present during the loading operation, but the *Hydraulic Power Unit* (HPU) associated with the vessel's crane is one of the largest consumers. Both modes feature circulation pumps as important consumers. The power consumers with the largest power consumers are category 4 consumers, while the vast majority of the other top 30 consumers are category 3. Many of these are common for both operational modes analysed. The loading operations feature more distinct consumer types, most prominently systems associated with oxygen/ozone treatment of the pumped water.

A graphical summary of the main findings is given in Table 3.4.

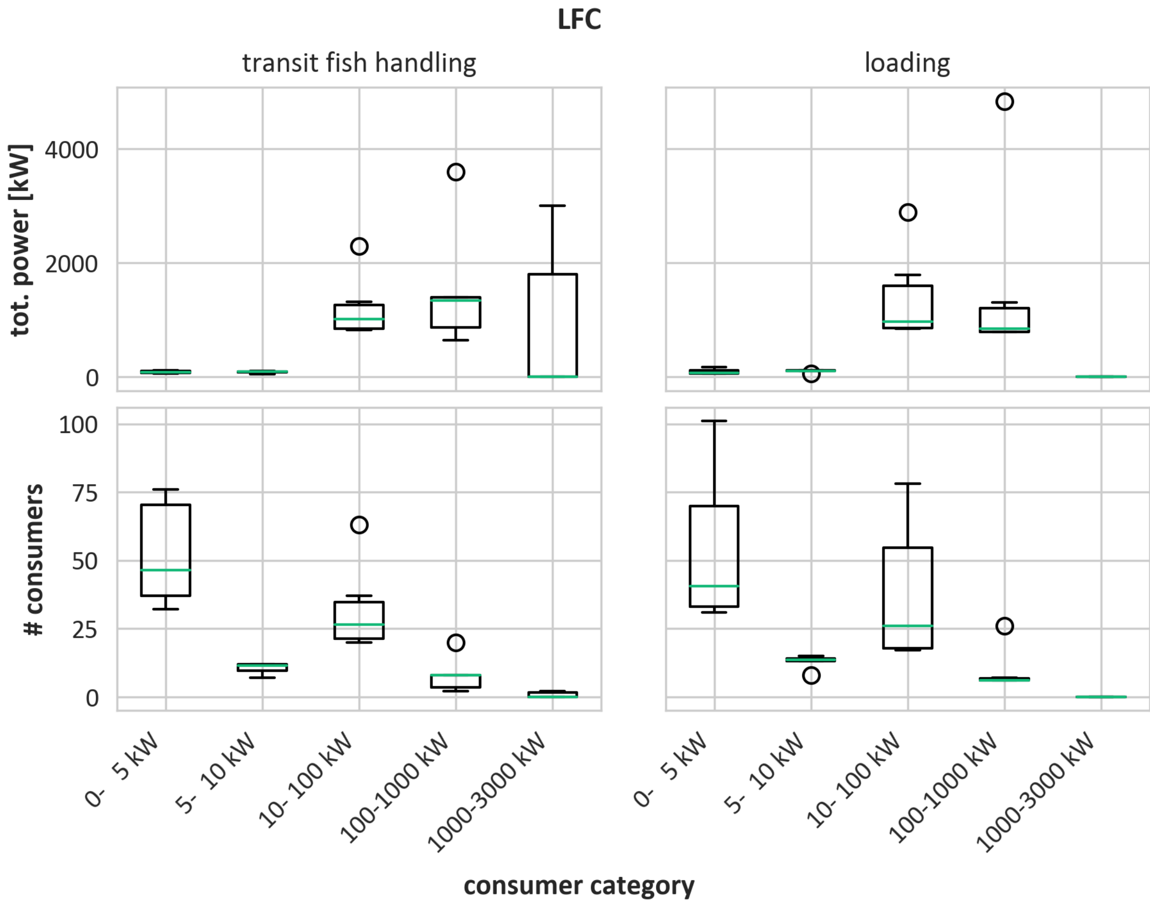


Figure 3.4: Per mode distribution of total power consumption and number of consumers, grouped by power consumption per individual consumer, for the analysed LFCs. The grouping corresponds to the power consumption categories introduced in Section 2.1, 0-5 kW corresponding to category 1, 5-10 kW to category 2, etc. Note that transit is a operational mode that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in this mode. Consumers in the two lowest groups may be grouped together into distribution panels that will be classified as one intermediate category consumer. The use of distribution panels in electric load balances varies, which may influence the number of consumers in the lowest categories.

Transit fish handling			Loading		
consumer	system	p. cat.	consumer	system	p. cat.
RSW compressor	m	4	circulation pump	m	3-4
circulation pump	m	3-4	HPU cranes	m	3
vent cabinet	aux/m	3	vent cabinet	aux/m	3
air compressor	aux	3	air compressor	aux	3
RSW circulation pump	m	3	vacuum compressor	m	3
lube oil purifier incl. pump	aux	3	lube oil purifier incl. pump	aux	3
RSW control cabinet	m	3	heating fans	acc	3
supply fan engine room	aux	3	supply fan engine room	aux	3
CO_2 stripper air fan	m	3	supply fan O_2/O_3 generator room	m	3
heating fans	acc	3	galley machinery	acc	3
			cooling unit switchboard eng. cont. room	aux	3
			ballast water management system	aux	3
			booster pump O_2/O_3	m	2

Table 3.6: The 30 largest consumers for a randomly chosen LFC, sorted by power consumption, from largest to smallest, and categorised according to the vessel subsystem they belong to and their power consumption (p. cat., corresponding to the grouping in Figure 3.4), after depuplication. See Section 2.1 for the definition of the different categories. Note that none of the LFCss in the used dataset have diesel-electric propulsion. Hence, no propulsion consumers are included in the list. Emergency systems have been removed from the list since they are not typical consumers, but included for dimensioning. Note also that transit is a operational mode often used for dimensioning, i.e. the reported figures are more indicative of a wort case scenario (high speed, adverse weather condition, etc.) then the average operation in this mode. Distribution panels usually comprise a number of small consumers (typically power category 1-2 or lower). The grouping is chosen based on location and voltage (low, medium, and high) and may or may not be tied to specific vessel subsystems. The extent of usage of this "consumer" in load balances varies greatly across design companies, projects, and personnel.

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3.1.3 *Service Operation Vessel* (SOV)

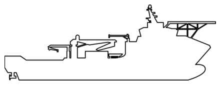
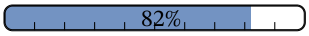
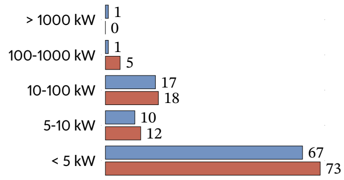
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
10	 SOV	 Transit  DP	

Table 3.7: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

Vessel summary

The results presented in this section are based on 10 vessels with 8 distinct designs. Three of the vessels are sister ships. The main particulars of these vessels are summarised in 3.8.

	mean	median	IQR
year built	2018.6	2018.5	3.5
length overall [m]	76.2	76.2	13.2
beam [m]	17.5	17.1	1.0

Table 3.8: Main particulars of the 10 *Service Operation Vessel* (SOV)s used to derive the results presented in Section 3.1.3. The asterisk denotes properties that are not available for all vessels.

SOVs are a sub-type of offshore service vessels designed to support offshore wind farm operations. Their main purposes are to provide accommodation to technical personnel working on wind turbines and facilitate the transfer of personnel and equipment between vessel and wind turbines. Hence, important operational modes are transit (to and from wind farms) and DP operation in connection with personnel transfer. Compared to PSVs, typical transit times are shorter, since wind farms usually are closer to shore than offshore platform. The vessels also spend more time in DP mode, and round trips (i.e. time between each port call) will normally last longer, since the vessels serve as accommodation for the staff throughout their shift.

Power consumption

As seen in the left panel of Figure 3.5, the typical power consumption for the vessels in this group is just below 3000 kW for transit and around 3500 kW in DP. There is considerable variation between individual vessels for both modes. The proportion of the total power used for propulsion is however more stable and for both modes approximately in the range 80 to 85% (cf. right panel of Figure 3.5). As for PSVs, it is customary to assume challenging weather conditions for both operational modes for the sake of dimensioning, and especially propulsion loads may therefore be considerably higher then in real life day-to-day operation (perhaps half of the above reported figures). This effect might be more pronounced for DP then for transit, since vessels typically will slow down in harsh conditions, while the requirements for DP operations cannot be relaxed.

Figure 3.6 shows the power consumption in the different modes, but split into different consumer categories, ranging from small (category 1 consumers, i.e. with power consumption between 0-5 kW) to large

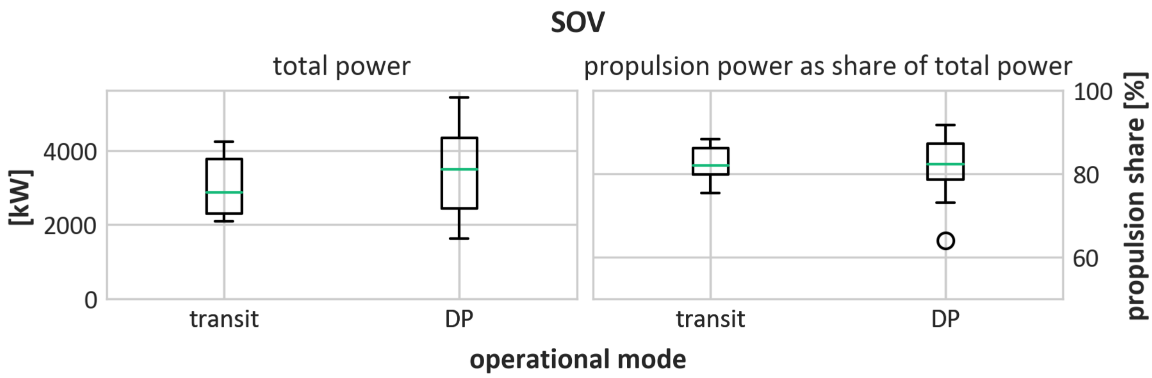


Figure 3.5: Per mode distribution of total power consumption and propulsion share for the analysed SOVs. Note that transit and DP are operational modes that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in these modes.

(category 5 consumers, i.e. with power consumption between 1000-3000 kW). The top row gives the sum of the power consumption of consumers in the respective categories, while the bottom row gives the number of consumers in each category. The main difference in the power consumption profile of the two analysed modes lies in the two largest consumer categories. In transit mode, a very restricted number of consumers in these top categories dominate the vessels' total consumption. In DP the focus lies entirely on the group of consumers between 100-1000 kW, i.e. category 4 consumers. They are still comparable few. We observe also a small increase in category 3 power consumers, i.e. consumers in the 10-100 kW range, but this is not reflected in their total power consumption. The contribution from the two lowest consumers categories is marginal, and does not appear to be influence by the vessels' operational mode.

Table 3.9 shows an anonymised list of the 30 largest consumer for one of the vessels in the vessel group (chosen at random). For each operational mode, the consumers are sorted by power rating into categories 1 to 5, where 5 corresponds to consumers with power consumption between 1000 and 3000 kW, 4 to power consumption between 100 and 1000 kW, etc., following the same subdivision as in Figure 3.6.

The table shows that main propulsion is the largest power consumer in transit and the only category 4 consumer. This is not the case for DP, where the bow thruster is the largest consumer, together with the main propulsion and the vessel's retractable thruster. These three consumers are the vessel's category 4 consumers. The DP mode features also several larger consumer (category 3) related to the vessels gangway. Apart from these differences, the list of 30 largest consumer for the two analysed operational modes are similar, both in content, relative order, and categories of the consumers. Note that the lists contain a significant amount of consumers that can be linked to accommodations, e.g. chilled water, AC fans, heating cables, fresh water circulation pump, etc.

A graphical summary of the main findings is given in Table 3.7.

transit			DP		
consumers	system	p. cat.	consumers	system	p. cat.
main propulsion	p	4	bow thruster tunnel	p	4
chilled water	acc/aux	3	main propulsion	p	4
var. distribution panels	?	1-3	retractable azimuth thruster	p	4
AC supply fans	acc/m	2	gangway HPU (m)	m	3
sockets for general use	?	2	gangway pump (m)	m	3
AC exhaust fans	acc/m	2	chilled water	acc/aux	3
gangway lift*	m	2	var. distribution panels	?	1-3
main prop aux supply	aux	2	AC supply fans	acc/m	2
humidifier	acc/m	1	sockets for general use	?	2
heating cables	acc/m	1	bow thruster tunnel drive (aux)	aux	2
provision plant condensing unit	acc/m	1	retractable azimuth thruster aux supply	aux	1-2
fresh water circulation pump	acc/m	1	gangway lift	m	2
			main prop aux supply	aux	1
			humidifier	acc/m	1
			heating cables	acc/m	1
			AC exhaust fans	acc/m	1
			provision plant unit	acc/m	1
			fresh water circulation pump	acc/m	1

Table 3.9: The 30 largest consumers for a randomly chosen SOV, sorted by power consumption, form largest to smallest, and categorised according to the vessel subsystem they belong to and their power consumption (p. cat., corresponding to the grouping in Figure 3.6), after deduplication. See Section 2.1 for the definition of the different categories. Consumers that can not be attributed to a specific subsystem area marked with "?" in the system column. Emergency systems have been removed from the list since they are not typical consumer, but included for dimensioning. Note that transit and DP are operational modes used for dimension, i.e. the reported figures are more indicative of a wort case scenario (high speed, adverse weather condition, etc.) then the average operation in these modes. Distribution panels usually comprise a number of small consumers (typically power category 1-2 or lower). The grouping is chosen based on location and voltage (low, medium, and high) and may or may not be tied to specific vessel subsystems. The extent of usage of this "consumer" in load balances varies greatly across design companies, projects, and personnel.

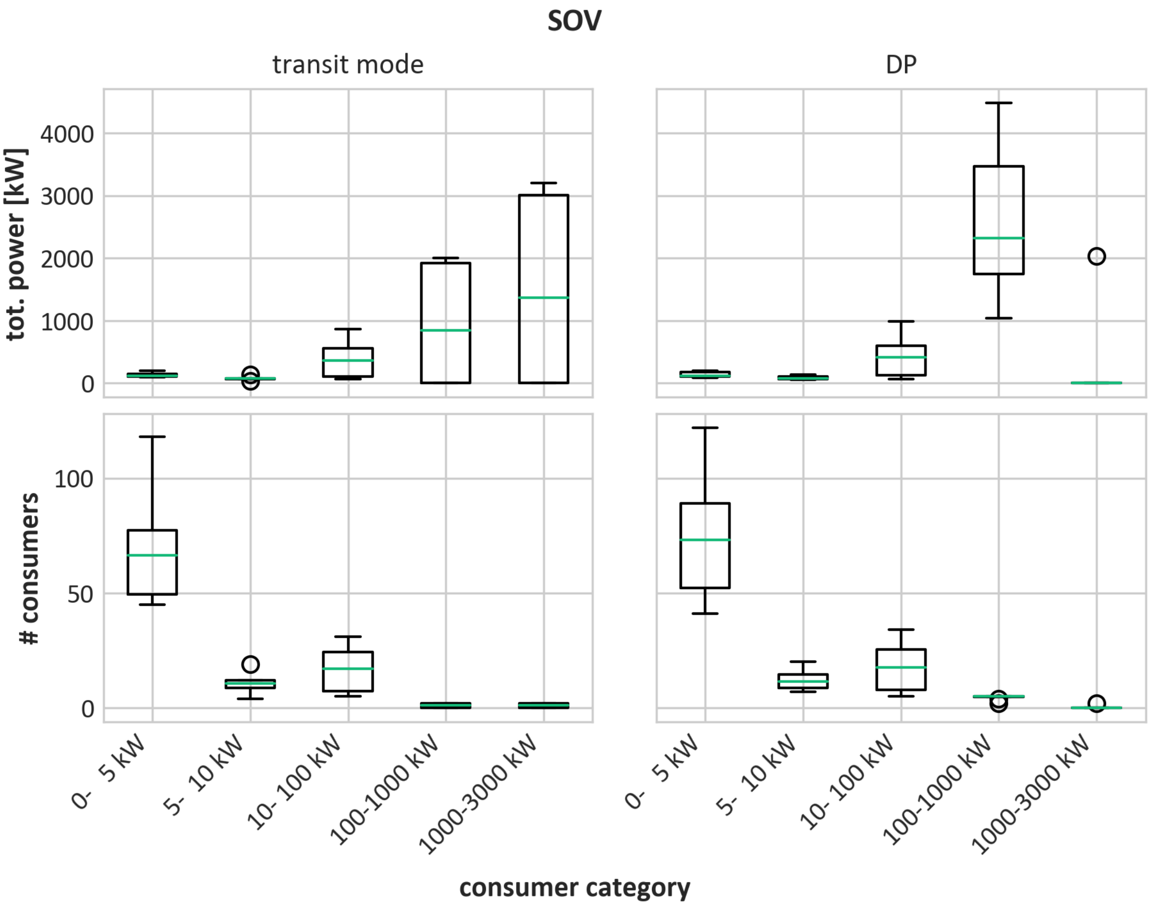


Figure 3.6: Per mode distribution of total power consumption and number of consumers, grouped by power consumption per individual consumer, for the analysed SOVs. The grouping corresponds to the power consumption categories introduced in Section 2.1, 0-5 kW corresponding to category 1, 5-10 kW to category 2, etc. Note that transit and DP operational modes that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in these modes. Consumers in the two lowest groups may be grouped together into distribution panels that will be classified as one intermediate category consumer. The use of distribution panels in electric load balances varies greatly, and may contribute significantly to the variability in number of consumers in the lowest categories.

3.1.4 Ferry

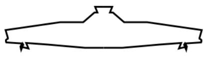
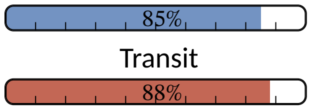
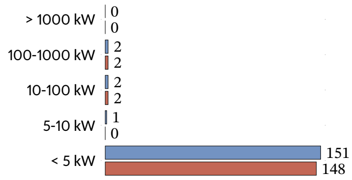
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
7	 Ferry		

Table 3.10: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

Vessel summary

The vessels in this groups are all double-ended car and passenger ferries, as typically encountered as a part of the Norwegian road network.

The results presented in this section are based on 7 vessels with 3 distinct designs. All vessels in the group have at least one sister ship. The main particulars of these vessels are summarised in 3.11.

This vessel group have operational modes that are virtually identical for all vessels. Besides transit, they mainly consist of acceleration, retardation, and manoeuvring to and from quay. The share of time spent in each mode will depend on the ferry connection serviced, but it can be assumed that transit will account for most of the individual vessel's energy consumption, while acceleration is the most power demanding operational mode. Hence, these two modes are selected for further analysis.

	mean	median	IQR
year built	2020.1	2019	2.5
length overall [m]	90.8	84	35.4
beam [m]	16.3	16.3	1.3

Table 3.11: Main particulars of the seven ferries used to derive the results presented in Section 3.1.4.

Power consumption

As seen in the left panel of Figure 3.7, the typical power demand for the vessels in this group is just above 750 kW in transit and around 1000 kW during acceleration. There is some variability for vessels with larger overall consumption. The proportion of the total power used for propulsion is around 85% for transit and 90% for acceleration (cf. right panel of Figure 3.7). As for other vessels (cf. e.g. respective discussions for PSVs and SOV), the EPLA may assume unfavourable weather conditions for the sake of dimensioning, but it is save to assume propulsion loads are closer to day-to-day encountered values for ferries then for other types of vessels. Firstly, weather conditions encountered by ferries are in general less extreme since they at large operate in fairly sheltered. Secondly, it is save to assume that the propulsion load during acceleration is at large independent of weather conditions since it is favourable form an energy point of view to accelerate at fast as possible.

Figure 3.8 shows again the power consumption in the different modes, but split into different consumer categories, ranging from small (category 1 consumers, i.e. with power consumption between 0-5 kW) to large

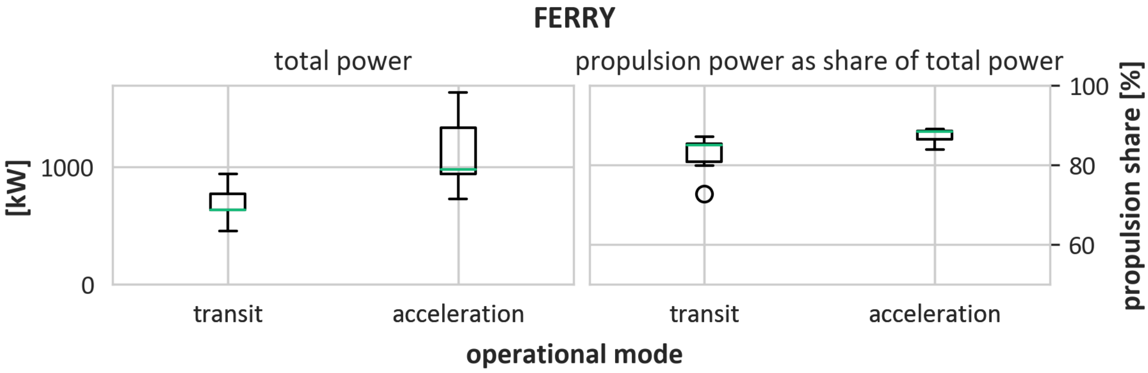


Figure 3.7: Per mode distribution of total power consumption and and propulsion share for the analysed ferries. It should be noted that transit is a operational mode that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in this mode.

(category 5 consumers, i.e. with power consumption between 1000-3000 kW). The top row shows the sum of the power consumption of consumers in the respective categories, while the bottom row shows the number of consumers in each category.

It can be seen that there are no category 5 consumers, i.e. consumers with power consumption above 1000 kW and the only category containing a significant number of consumers is category 1, i.e. consumers below 5 kW. In contrast to the other vessels groups, this consumer category is the second or third largest in terms of total power consumption. Still, its contribution to the overall power consumption of the vessels is marginal.

Table 3.12 gives an anonymised list of the 30 largest consumer for one of the vessels in the vessel group (chosen at random). For each operational mode, the consumers are sorted by estimated power consumption according to EPLA and categorised into categories 1 to 5, where 5 corresponds to consumers with power consumption between 1000 and 3000 kW, 4 to power consumption between 100 and 1000 kW, etc., following the same subdivision as in Figure 3.8.

The table shows that main propulsion is the largest power consumer for both transit acceleration and the only category 4 consumer. The next largest consumer (category 3, between 10-100 kW) is indeed losses between propulsion and batteries. Next on the lists are air handling units for the passenger areas (category 2 consumers, i.e. between 5-10 kW). All remaining consumers are smaller than 5 kW.

A graphical summary of the main findings is given in Table 3.10.

transit			acceleration		
consumers	system	p. cat.	consumers	system	p. cat.
main propulsion	p	4	main propulsion	p	4
AHU passenger areas	m	2	dirst. panel engine room	aux	2
dirst. panel engine room	aux	1	AHU passenger areas	m	2
dirst. panel pump room	aux	1	dirst. panel engine room	aux	1
hot water pump	acc/m	1	dirst. panel pump room	aux	1
dirst. panel navigation system	aux	1	hot water pump	acc/m	1
dirst. panel wheelhouse window heater	aux	1	prop. system steering gear pump	aux	1
battery room fan coil	aux	1	dirst. panel navigation system	aux	1
switchboard room fan coil	aux	1	distr. panel wheelhouse window heater	aux	1
distr. panel main deck	aux	1	dirst. panel main deck	aux	1
dirst. panel pump room	aux	1	dirst. panel pump room	aux	1
AHU crew areas/wheelhouse	acc	1	AHU crew areas/wheelhouse	acc	1
prop. system steering gear pump	aux	1	battery room fan coil	aux	1
engine room fan	aux	1	switchboard room fan coil	aux	1
battery room fan	aux	1	coil battery room fan coil	aux	1
			engine room fan	aux	1
			HPU motor	aux	1

Table 3.12: The 30 largest consumers for a randomly chosen ferry, sorted by power consumption, from largest to smallest, and categorised according to the vessel subsystem they belong to and their power consumption (p. cat., corresponding to the grouping in Figure 3.8), after deduplication. See Section 2.1 for the definition of the different categories. Emergency systems have been removed from the list since they are not typical consumer, but included for dimensioning. It should be noted that transit is a operational mode used for dimension, i.e. the reported figures are more indicative of a wort case scenario (high speed, adverse weather condition, etc.) then the average operation in this mode. Distribution panels usually comprise a number of small consumers (typically power category 1-2 or lower). The grouping is chosen based on location and voltage (low, medium, and high) and may or may not be tied to specific vessel subsystems. The extent of usage of this “consumer” in load balances varies greatly across design companies, projects, and personnel.

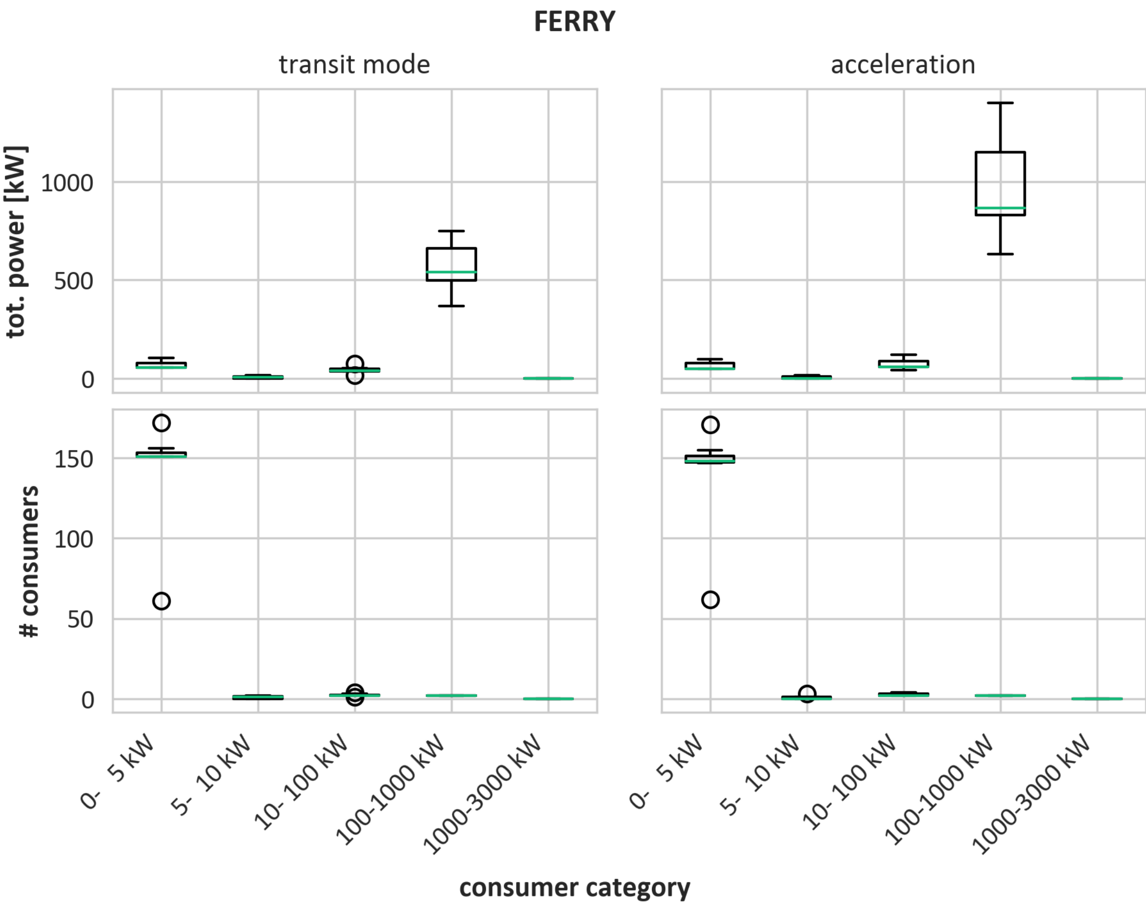


Figure 3.8: Per mode distribution of total power consumption and number of consumers, grouped by power consumption per individual consumer, for the analysed ferries. The grouping corresponds to the power consumption categories introduced in Section 2.1, 0-5 kW corresponding to category 1, 5-10 kW to category 2, etc. Note that transit is an operational mode that may be used for dimensioning, i.e. some of the reported figures could be more indicative of a worst case scenario (high speed, adverse weather condition, etc.) then the average operation in this mode. Consumers in the two lowest groups may be grouped together into distribution panels that will be classified as one intermediate category consumer. The use of distribution panels in electric load balances varies greatly, and may contribute significantly to the variability in number of consumers in the lowest categories.

3.1.5 Other vessels

In addition to the vessel groups treated so far, there are also other vessel types in the Norwegian maritime cluster, e.g. fishing vessels of various types. There is not sufficient data gathered in this project to make statistical statements on the typical power consumption profiles of these groups of vessels. However, we include anecdotal information for individual vessels of various types, but do not report on the distribution of these figures (e.g. mean, *Interquartile Ranges* (IQRs), etc.), since the low number of samples for each of the groups does not warrant a statistical treatment from a theoretical standpoint. The information contained in the remainder of this section is therefore only indicative, and must be treated accordingly. All figures are rounded to avoid that the used vessel can be identified.

Anchor Handling Tug Supply vessel (AHTS)

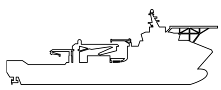
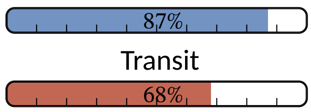
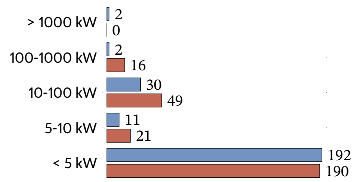
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
1	 AHTS		

Table 3.13: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

Anchor Handling Tug Supply vessels (AHTSs) are a sub-type of offshore vessels that are mainly used for deployment, retrieval, and relocation of anchors, mainly in the context of offshore oil and gas installations. Additionally, they are used to tow oil rigs.

The analysed AHTS is representative of a vessel of length between 100-120 m, and beam between 22-27 m. Typical consumption is similar to a typical PSV. Still, according to the EPLA for this specific vessel 10000 kW is listed for transit, and close to 15000 kW for towing operations. The propulsion share of the total power consumption is 85 % for both operational modes. As already mentioned for other vessel groups, it should be noted it is likely that the estimates for power consumption in these mode are devised with the purpose of dimensioning the vessels power system and may be significantly lower then consumption encountered during typical operation.

However, during towing the propulsion power includes additional thrusters to the main propulsion. The most important single consumer for this specific vessel is not related to propulsion. Cranes and launch-and-recovery systems for *Remotely Operated Vehicle* (ROV)s are equally or more power-intensive (category 3, in total there are 10-20 consumers in this category).

A graphical summary of the main findings is given in Table 3.13.

Freezer trawlers

Freezer trawler are trawlers with onboard processing plants that allow for freezing the processed catch at sea. This allows for longer fishing periods at sea between port calls. Besides transit to and from fishing grounds, important operational modes are trawling, i.e. towing the trawl at low speed (2-4 knots). Howling is also an important operational mode that is normally power intensive, but the shorter duration does not affect the overall energy footprint of the vessels as much as the two previous modes.

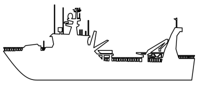
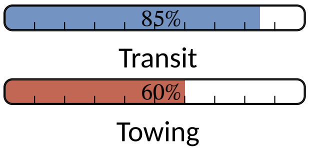
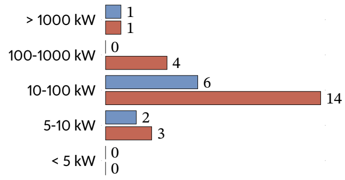
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
1	 Freezer trawler		

Table 3.14: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

The analysed freezer trawler is representative for a vessel 85-95 m length and 15-20 m beam. The typical consumption is around 2500 kW in transit, while the consumption during the trawling operation with simultaneous fish processing is around 3000kW. The share of total power consumption related to propulsion differs in the two modes. During transit, the share is around 85 %, while it drops to 60 % during trawling with simultaneous fish processing.

The main propulsion is in both modes the main power consumer (category 5 consumer), but in transit all remaining consumers are category 3 or lower (i.e. below 100 kW), with lighting and heating/ventilation being the next largest consumers. During towing with simultaneous production the largest non-propulsion consumers are related to freezing and factory equipment (category 4 consumers, i.e. 100-1000 kW). Consumers related to the handling of the fishing gear, e.g. trawl winches, are category 3 consumers or lower (i.e. below 100 kW).

A graphical summary of the main findings is given in Table 3.14.

Pelagic trawlers

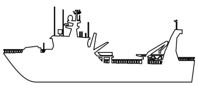
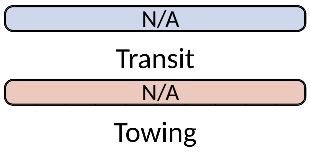
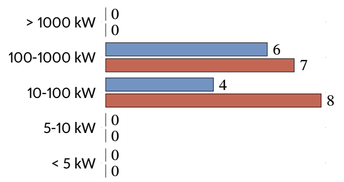
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
1	 Pelagic trawler		

Table 3.15: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

A pelagic trawler operates in the open water column (in contrast to bottom trawling, which targets demersal fish). While the focus on pelagic fish does not preclude processing and freezing at sea, the catch is often only chilled (e.g. through RSW) and first processed after landing. The important operational modes are the same as for freezer trawlers.

The analysed pelagic trawler is representative for a vessel 75-85 m in length and 15-20 m in beam and has no onboard processing plant. The propulsion power consumption is not available for this vessel, so only electrical consumers are reported. The typical power consumption is 1200 kW in transit and 1700 kW during towing.

The main electrical power consumer in transit is related to the use of RSW (category 4 consumer, i.e. in the range 100-1000 kW). This consumer is not directly linked to transit or remains a prominent contributor to the overall power consumption during trawling. It is, however, not the most power intensive electric consumer any more, since the vessel uses additional thrusters (category 4 as well). The second and third most power intensive consumers during transit are the vessels machinery and hotel, respectively. These consumer are not affected by the trawling operation, i.e. virtually equal for both modes. Consumers directly connected to the handling for the fishing gear are of category 3 or lower (i.e. below 100 kW), as for the freeze trawler.

A graphical summary of the main findings is given in Table 3.15.

Longline fishing vessel

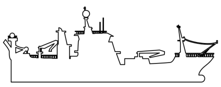
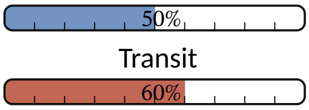
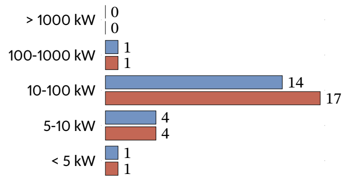
#	Vessel type	EPLA design prop. load (%) of total	Classification of consumers
4	 Longline		

Table 3.16: Summary of propulsion load in operations (where available) and classification of the power consumers, based on EPLA. For a description of the used methodology and its limitations, please confer Section 2. Note that the number of consumers below 10 kW may be artificially low because a number of them might be grouped into one consumer, typically distribution panels.

Longline fishing vessels operate fishing gear with a long line with attached hooks. This line is deployed by the vessel and retrieved after some time. Longline fishing vessels are typically equipped with processing and freezing facilities. Besides transit to and from fishing ground, other important operational modes are deployment (setting) and retrieval (hauling) of the fishing gear. Each of these modes might be performed with running processing and freezing plant or not.

The analysed longline fishing vessels are representative for a vessel of approximately 55-65 m length and 12-15 m beam. The typical total consumption in transit ranges from 500-1000 kW and 1000-1500 kW during the setting operation. Both operations are assumed to be performed with simultaneous processing and freezing/refrigeration. The propulsion systems account for roughly 50 % and 60 % of the total power consumption, respectively. Some of the analysed vessels have a conventional propulsion system.

The main propulsion is the largest consumer for both analysed modes (category 4, i.e. 100-1000 kW). Additional thrusters used during the setting operation are also category 4 consumers. The second largest consumer is linked to freezing/refrigeration (category 3-4, i.e. around 100 kW). All remaining consumer are category 3 or smaller (i.e. under 100 kW). Their relative ranking and categories are approximately equal for the two modes.

A graphical summary of the main findings is given in Table 3.16.

3.2 Comparison across vessel group

This section summarises and compares the different vessel group. For a detailed discussion of each individual group, we refer the reader to Section 3.1.

3.2.1 Main particulars

Figure 3.9 summarises the characteristics of vessels analysed within the scope of this report in term of selected main particulars. Based on these data we can make the following general observations.

PSVs represent the oldest vessel group in the dataset, and are typically almost 10 years old. They are normally 85-90 m long and 17.5-19.5 m wide.

The year of construction of the LFCs contained in the dataset spans from 2014 to 2023 (i.e. newbuilds), with a median of 2018. They are usually comparably large vessels, with typical length overall between 85-105 m and beams in the range of 17-18 m.

SOVs belong as PSVs the the broad category of offshore vessels, but are usually shorter and narrower (typical length overall in the range of 70-85 m and beam in the range of 16.5 to 17.5 m). The vessel group's age is consistently lower than for PSV, typically 5 years, with a median year of build of 2019.

Ferries represent the youngest vessel group in the dataset, with all vessels built after 2018 and 50 % after 2019. The typical length of the ferries in the dataset is approximately 85 m, but the variation in the group is significant, ranging from 67 to 111 m. This is in sharp contrast to their beam, usually in the range of 16-17 m, which is more consistent and the smallest of all vessel groups.

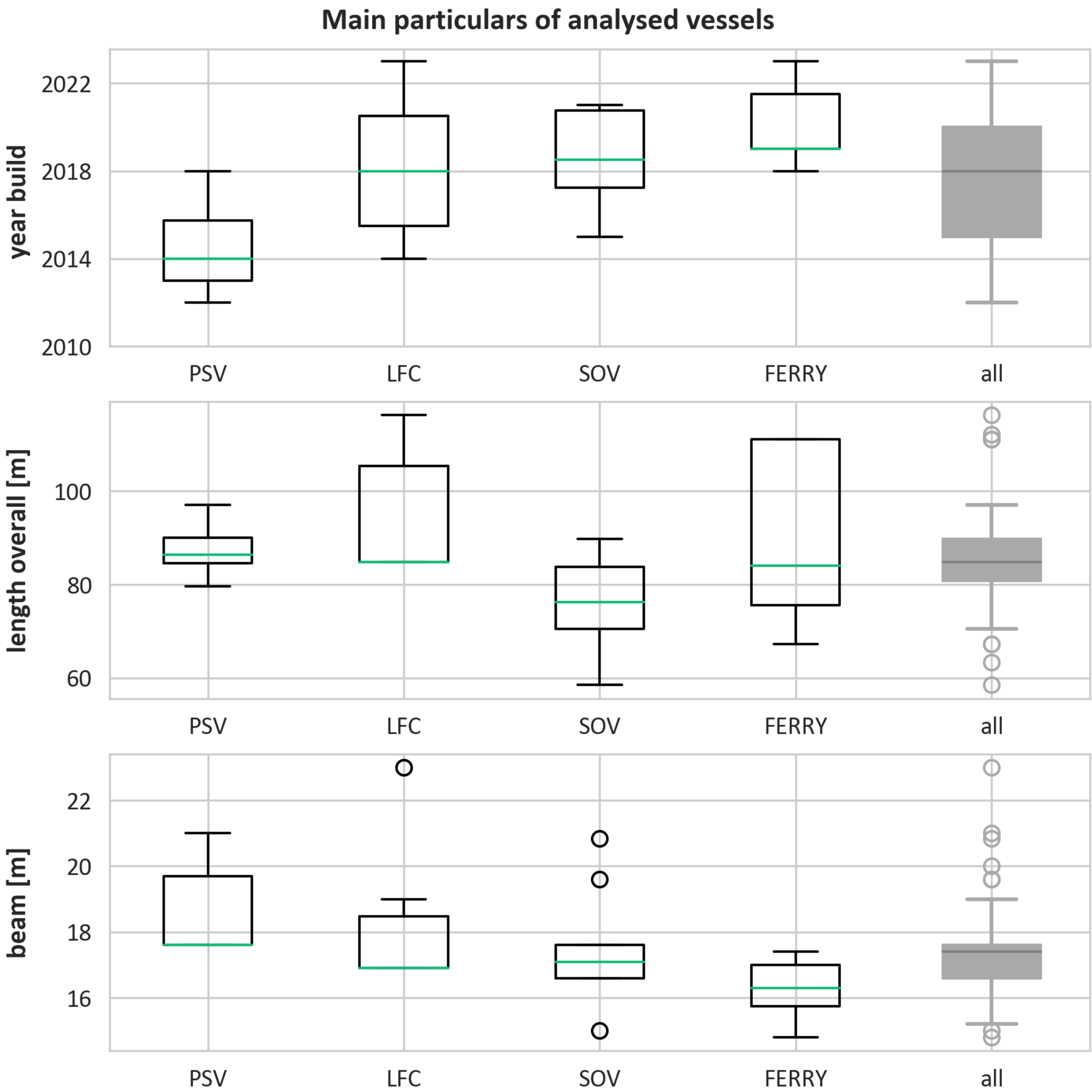


Figure 3.9: Boxplots of main particulars distribution for vessels analysed within the scope of this report, grouped by vessel type. The rightmost box in each row shows the distribution of the respective property for all vessels, irrespective of type. For a charaterisation of the different vessel groups, please confer Section 3.2.1, for a comprehensive discussion of the interpretation of this plot type, please cf. Section 2.3.1.

3.2.2 Power consumption

PSVs is the vessel group with highest typical total power consumption, usually around 4000 kW for transit and slightly higher in DP. Around 80 % of the power consumption is related to propulsion.

SOVs, the vessel group with the second largest typical total power consumption, have a similar profile, but on lower absolute level, with around 3000 kW total power consumption in transit and slightly higher in DP. The variation within the group is, however, considerably larger. A major distinguishing factor is the role of mission equipment during transit. While this type of equipment group plays a minor role for PSVs, they comprise a large part of the 30 largest consumers in this mode for SOVs.

Ferries are the vessel group with the lowest typical power consumption, with around 750 kW in transit and 1000 kW during acceleration. This is a large relative difference between two modes, compared to the other analysed vessel groups. This group stands also out when it comes to the individual power consumption of the components that comprise the 30 largest consumers. Except for propulsion, all consumers are 10 kW or smaller, and the vast majority are even smaller then 5 kW.

Since the majority of vessels in the LFC group are equipped with purely mechanical propulsion systems, the electric load balance will in most cases not provide the total power consumption, but only the power consumption for other consumers. Hence, it is more difficult to directly compare this group with the other groups of vessels. Based on the load balances from the vessels with diesel-eclectic propulsion, the propulsion load may be in the range 30-50 %. It should however be noted that this figure is derived from few vessels, and its validitiy for the group as a whole is hence rather uncertain. The total consumption from other consumers for LFCs is around 2000 kW, but can be significantly larger during loading. Based on the power intensity of the consumers in the list of the 30 largest consumers and the vessel subsystems, mission equipment probably plays an important role in the vessels' total power consumption, also during transit.

The analysed AHTS vessel stands out in terms of total power consumption and relative difference between the two analysed modes with 10000 kW in transit and 15000 kW during towing.

The analysed fishing vessels represent each one distinct subgroup with specific operations and equipment. Still, one may assume that the total power consumption of fishing vessel is typically roughly in the range 1500 kW to 3000 kW, i.e. larger then for ferries and reaching up to typical levels for SOVs. Among the fishing vessels, the freezer trawler has the largest total power consumption and it is reasonable to assume that this relationship holds in general. The conservation of the catch, be it through freezing or refrigerating, contributes significantly to the overall power consumption of the vessels. In addition, there is onboard catch processing in the case of the freezer trawler and the longline fishing vessel. Hence, the propulsion share can be assumed to be relatively low compared to other vessel groups. This is especially true for the transit mode.

For a graphical summary of the main findings, please confer Table 1.

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Chapter 4

Concluding remarks and suggested further work

In this report we have performed a preliminary study of typical power consumption profiles for selected vessel types. The analysis is based on *Electrical Power Load Analysis* (EPLA), and not operational data. This allowed us to analyse a large amount of different vessel and hence (a) produce more robust results, (b) report statistical properties and not anecdotal values, and (c) make statements about group homogeneity.

The main drawback of this approach is that the original purpose of performing EPLA is dimensioning of the vessel's power system. Hence, there is a tendency to include loads that are meant to represent the border region of the vessel's operational envelope. In other words, the reported power consumption is not necessarily a good representation of the typical loads during operation. E.g. a *Dynamic Positioning* (DP) operation analysis may assume rather adverse weather conditions, while such conditions are only encountered occasionally in day-to-day operation. It is, however, fair to assume that the assumption of adverse weather conditions first and foremost influence the power consumption of the propulsion system. Hence, if a more realistic estimate for this figure is available (e.g. through operational data or theoretical considerations), if is relatively straight forward to "calibrate" the numbers contained in this report.

It needs to be stressed that power consumption profiles for different operational modes are only one step in mapping the energy footprint of different vessel groups, since the power profiles do not contain information on how much time is spent in the individual operational modes.

It is also worthwhile noting that current indices used for quantifying energy efficiency, such as *Energy Efficiency Index for Existing Ships* (EEXI), *Energy Efficiency Design Index* (EEDI), *Carbon Intensity Index* (CII), etc., focus on energy consumption in transit, i.e. one of many operational modes relevant to the GCE Blue Maritime Cluster's fleet. The results discussed in Section3 show that these other modes can by as power intensive and, depending on the operational of a vessel, impact its energy footprint significantly.

Accordingly, further steps are necessary to gain a more complete picture of the Norwegian fleet. Possible future work can grouped into 4 different thematic areas:

Extension of current report

The current report could be extended to increase it representativeness of the Norwegian fleet. More precisely, it would be beneficial to

- validate the here presented methodology through measurement campaigns,
- extend the number of vessel groups analysed,
- include a larger number of vessels for each group, especially for the vessel groups where only a few or a single vessel has been available within the scope of this report, and

- include consumers that are not accounted for in EPLA, such as mechanical direct shaft propulsion and heat recovery systems.

Digitalisation

The here presented work can serve as a starting point for further digitalisation of the Norwegian fleet, both for sailing vessels and in the design phase. E.g. it can be used to

- develop a road-map and a specification for a measurement campaign for sailing vessels (retrofit), and
- develop a recommendation for component instrumentation for data acquisition purposes (design).

Potential energy savings

Operational data can be used to derive typical operational profiles for different vessel groups. Combining these operational profiles with the here presented information, it is then possible to derive typical total energy consumption and pinpoint large consumers/consumer groups. Hence, it is possible to asses the overall impact of different types of energy saving measures for different vessel groups.

Benchmarking of service vessels

While energy consumption over time for individual vessels (or within a group of sister ships) is common, it is harder to assess a vessel's performance within it whole group. The presented work can be use in a twofold manner to help

- calculate EEXI, EEDI, CII, etc., for different vessel groups (collect representative power plant data), and
- serve as a basis for developing new indices for service vessels that take multiple operational modes into account and are hence more suited to this vessel types.

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