KYSTVERKET

Method description MarU

Rev. 0

The Norwegian Coastal Administration's model for estimating maritime emissions

Preface

In 2011 the Norwegian Coastal Administrations (NCA) first model for estimation of maritime emissions was launched. The model was referred to as "an environmental accounting system for ships based on AIS ship movement tracking". It was shortly called *Havbase,* due to its focus on activity in the three management plan areas off the coast of Norway. The model was developed and hosted by a third-party actor, and fulfilled NCA and other governmental organisations needs for maritime emission estimates for many years.

Towards the end of the 2010's limitations in the Havbase model became more apparent. The model was based on methodology intended for the analysis of large, global fleet compositions consisting of ships with traditional propulsion systems. When you analyse a smaller population, with a somewhat different fleet composition, this method becomes inaccurate, vulnerable to errors in registers with ship data, and over-generalisation of statistical variables. Further, the fleet in Norwegian waters had developed and the model did not account for the changes, e.g., introduction of hybrid or battery vessels, and LNG as a fuel.

Based on an overall assessment, NCA decided to investigate development of its own emissions model, which could give NCA the opportunity to utilize the NCA's own data and other available data and models in the best possible way. In 2020 the prototype *Marine Emissions* was developed and made available internally in NCA as a beta version. Due to various external circumstances the development stagnated.

However, the NCA's need of a more detailed and tailored emission model persisted, and June 2023 marked the kick-off for a new effort. Throughout the autumn of 2023 and spring of 2024, *NCA's model for estimation of maritime emissions (MarU)* was developed. As Havbase, MarU is an AIS based environmental accounting system, and it has largely taken advantage of the work which was done developing Marine Emissions.

The main change in MarU from the previous models is that the data processing and calculation steps have been separated into different modules, whereas "everything" happened within the same model for Havbase and Marine Emissions. More specific: AIS processing happens in one separate module, registers with ship data are handled in another module, geographical locations and areas are handled in a third module, and the emission calculations, i.e., MarU, are the fourth and final module.

This document explains the MarU module, while touching upon the other modules when needed for obtaining the full picture. The document is intended for the users of the results, for them to understand the extent and limitations of the model and results. Further details can be obtained by examining the code.

Summary

Title:	Method description MarU	Tittel:	Metidebeskrivelse MarU
Author(s):	Lyngra, Nora Helen Lund Nordkvist, Haakon Akse Kittelsen, Jørgen	Forfattere:	
Date:	2024-11-08	Dato:	
Report No:		Rapport Nr.:	
Pages:		Sider:	
ISBN Paper:		ISBN papir:	
ISBN electronic:		ISBN elektronisk:	
ISSN:		ISSN:	
Project:	MarU	Prosjekt:	
Project manager:	Lyngra, Nora Helen Lund	Prosjektleder:	
Key words:	Emission estimates, shipping, ship traffic, AIS data	Emneord:	

English summary:

Norsk sammendrag:

Language of Report: English

List of changes

Revision	Date	Change description	Sign.
0	2024-11-08	First version.	NHLL

Contents

Preface iv
Contents 0
List of figures 6
List of tables 6
List of equations 6
List of abbreviations and definitions 7
1 Introduction 9
1.1 Differences between MarU and Havbase 9
2 Data sources 12
2.1 AIS data 12
2.1.1 AIS sources and processing steps 12
2.1.1.1 Enrichment by geographical information 13
2.1.1.2 Enrichment by operational phase 14
2.1.1.3 Establishment of voyage segments 16
2.1.1.4 Establish complete voyages port to port 17
2.1.1.5 Categorise traffic type 18
2.1.2 AIS data input to MarU 19
2.2 Geographical information 19
2.3 Ship data 22
2.3.1 Ship data sources 22
2.3.2 Imputation of missing ship data 22
2.4 Emission specific input variables 24
3 Estimation of ship air emissions 25
3.1 Methodology 25
3.2 Calculation of energy demand 26
3.3 Calculation of fuel oil consumption 26
3.4 Calculation of emissions 27
3.5 Results 28
4 Assumptions and adjustments 29
4.1 Reduced auxiliary engine and boiler energy demand during prolonged port stays 29
4.2 Battery electric vessels 29
4.3 On-shore power and charging facilities 29
4.4 Dynamic positioning 30
4.5 Energy demand adjustments for aquaculture service vessels and fishing vessels 30

5 Data Use Policy 31
6 Further work 32
6.1 From global to local emission model 32
6.2 Shore power and charging facilities 32
6.3 Fishing vessels 32
6.4 Offshore vessels 32
6.5 Rigs and other mobile facilities 32
6.6 Layup/switched off engine 32
6.7 Changes in ship register data and emission factors 32
6.8 Resistance-based model 32
6.9 Inclusion of other types of estimates 33
7 References 34
8 Appendix A – S&P Global StatCode5 to MarU mapping 35
9 Appendix B – Share of vessels needing imputed values. 42
9.1 All vessels 42
9.2 Vessels over 2000 GT 43
10 Appendix C – Fitness of Neural network model 44
10.1 Predicted speed service, mean absolute error. 44
10.2 Predicted correct diesel engine type by rpm [SSD,MSD,HSD] 44
10.3 Predict correct stroke type 45
11 Appendix D – Output columns from MarU 47

List of figures

Figure 1 Simplified overview of the MarU model and associated input, modules, and output. 9
Figure 2 The MarTraf steps for processing and enriching AIS data. 12
Figure 3 An example of using H3 indexing. 14
Figure 4 Example of voyage segments..16
Figure 5 Example of a complete voyage..17
Figure 6 Examples of traffic types. Map from www.kartverket.no...18
Figure 7 Sources of geographical data utilised in MarTraf. 19
Figure 8 Sources of geographical data utilised in MarU..20
Figure 9 The Norwegian maritime borders. Source: https://www.kartverket.no/til-lands/fakta-om-norge/maritime-grenser 21
Figure 10 Simplified overview of MarU emission estimation steps.......................................25
Figure 11 Detailed MarU emission estimation steps. 25

List of tables

Table 1 Comparison of MarU and Havbase features. 10
Table 2 Comparison of MarU and Havbase ship types. 10
Table 3 Comparison of MarU and Havbase ship size categories. 11
Table 4 Values to be imputed. 23

List of equations

Equation 1 Load factor. 26
Equation 2 Main engine energy demand. 26
Equation 3 Specific fuel oil consumption. 26
Equation 4 Main engine fuel consumption. 26
Equation 5 Auxiliary engine and boiler energy consumption. 26
Equation 6 Auxiliary engine and boiler fuel consumption. 27
Equation 7 Calculation of CO2 equivalents..27

List of abbreviations and definitions

AE	Auxiliary Engine
AIS	Automatic Identification System
BC	Black Carbon
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DWT	Deadweight Tonnage
EEZ	Exclusive economic zone
ECA	Emission Control Area
EF_e	Energy-Based Emission Factors
EF_f	Fuel-Based Emission Factors
EU MRV	EU Monitoring, Reporting and Verification of CO_2 emissions
FOC	Fuel Oil Consumption
GHG	Greenhouse Gas
GPS	Global Positioning System
GT	Gross Tonnage
GWP	Global Warming Potential
HFO	Heavy Fuel Oil
HSD	High-Speed Diesel
ICE	Internal Combustion Engine
IMO	International Maritime Organization
IMO4	Fourth IMO GHG Study
kW	Kilo Watt
kWh	Kilo Watt-hour
LBSI	Lean Burn Spark-Ignited
LLF	Low Load Factor
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
LSHFO	Low Sulphur Heavy Fuel Oil
MarTraf	Maritime traffic, NCA's AIS processing module
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
ME	Main Engine
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MMSI	Maritime Mobile Service Identity
MS	Medium-Speed
MSD	Medium-Speed Diesel
N_2O	Nitrous Oxide
NCA	The Norwegian Coastal Administration
NECA	NOx Emission Control Area
NG	Natural Gas
Nm	Nautical Mile
NMA	The Norwegian Maritime Authority
NMVOC	Non-Methane Volatile Organic Compounds
NSR	New ShipRep
NO_x	Nitrogen Oxides
OSP	On-Shore Power
Pax	Passengers
PM	Particulate matter
ro-pax	Roll-On/Roll-Off/Passengers
Ro-Ro	Roll-On/Roll-Off

RPM	Revolutions Per Minute
SECA	SOx Emission Control Area
SFC	Specific Fuel Consumption
SOG	Speed Over Ground
Sox	Sulphur Oxides
SS	Slow-Speed
SSD	Slow-Speed Diesel
SSN	SafeSeaNet
TEU	Twenty-foot Equivalent Units
VLSFO	Very Low Sulphur Fuel Oil

1 Introduction

One of the biggest challenges in the world today is how we can reduce greenhouse gas emissions, also at sea. The Norwegian Coastal Administration's role is largely about contributing with knowledge. The aim of MarU is to provide a good knowledge base, which is necessary to be able to assess whether Norway is meeting the climate targets for domestic shipping and fishing, and to identify targeted and cost-effective measures for emission reductions.

Emissions from shipping have traditionally been calculated based on sales figures from fuel traders. This gives a good representation of emissions from the combustion of sold fuel but does not say anything about actual emissions in Norwegian waters, since many vessels along our coast bunker fuel abroad. The first Norwegian AIS satellite was launched in 2010, which started a new era of collection of position data from vessels in Norwegian waters. The access to positional data made it possible to estimate emissions for the vessels that had actually operated in the waters. Shortly afterwards work therefore began to develop an "AIS-based environmental accounting system" for ship traffic, later known as Havbase. The emission estimates from Havbase were to be supplementary information to the statistics for the sales figures.

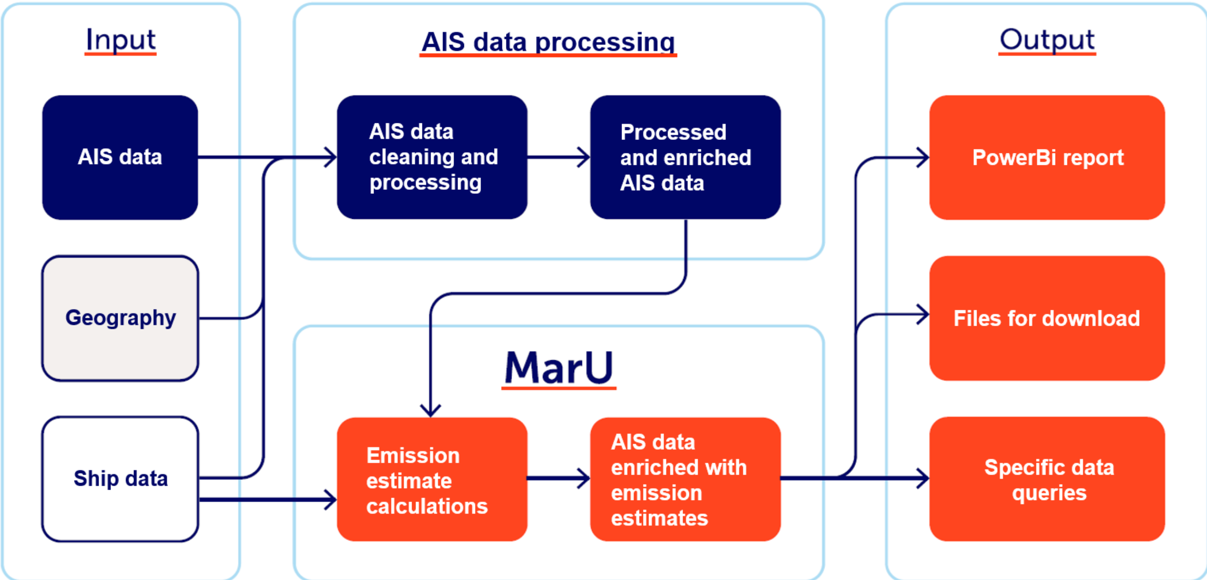

Figure 1 Simplified overview of the MarU model and associated input, modules, and output.

Havbase was developed and operated by an external partner by NCA. Now, MarU is NCA's effort to obtain ownership and insight into the assumptions and calculations of the emission estimation for the ships in Norwegian waters.

The MarU model is considered a "module" dependent on other modules in order to perform the emission calculation. As shown in Figure 1, are AIS data, geography, and ship register info the three other modules involved. This is further elaborated in the following chapters.

Currently, the MarU module is NCA's basis, <u>the starting point</u>, of the development and alterations required to create a model which represents the emissions from the fleet in Norwegian waters as accurate as reasonable.

1.1 Differences between MarU and Havbase

Table 1 shows the features available in MarU compared to the features Havbase could offer.

Table 1 Comparison of MarU and Havbase features.

Feature	MarU	Havbase
CO_2 equivalents	X	
CO_2	X	X
CH_4	X	
N_2O	X	
CO	X	X
NO_x	X	X
SO_x	X	X
PM_{10}	X	X
$PM_{2.5}$	X	
NMVOC	X	
Black carbon	X	
Distance sailed	X	X
Operation hours	X	X
Power demand	X	
Fuel consumption	X	
Municipality specific estimates	X	(x)
County specific estimates, incl. Svalbard	X	
Estimates specific for the integrated management plans for sea areas	X	X
Estimates specific for the Norwegian exclusive economic zone and other maritime boundaries	X	
Estimates per traffic types (domestic, transit, international)	X	
Estimates per voyage type (under way, manoeuvring, at berth, etc.)	X	
Estimates per flag state.	X	
Battery electric vessels	X	
Shore power usage	X	
Estimates aggregated per month	X	X
Estimates aggregated per year	X	X
Estimates aggregated per ship type	X	X
Estimates aggregated per ship size	X	X

In the above table (x) indicates that the information was available in the database, but not publicly available.

Alterations have been made in both ship type and ship size from Havbase. For MarU, *Aquaculture vessels* and *Other service vessels* have been separated from *Other activities*, *Container* and *Ro/Ro ships* have been combined to one category, *General cargo ships* and *Refrigerated cargo ships* have been combined to one category, and the same have *Crude oil tankers* and *Oil product tankers*. The alterations are shown in Table 2.

Table 2 Comparison of MarU and Havbase ship types.

MarU ship types	Havbase ship types
Aquaculture vessels	
Bulk carriers	Bulk carriers

Chemical/product tanker	Chemical tankers
Container/Ro-Ro ships	Container ships
	Ro-Ro cargo ships
Cruise ships	Cruise ships
Fishing vessels	Fishing vessels
Gas tankers	Gas tankers
General cargo ships	General cargo ships
	Refrigerated cargo ships
Offshore vessels	Offshore supply ships
Oil tankers	Crude oil tankers
	Oil product tankers
Other activities	Other activities
Other offshore vessels	Other service offshore vessels
Other service vessels	
Passenger vessels	Passenger ships

The different ship registers might have different data when it comes to ship types. Our main source of ship data is S&P Global, and we have therefore performed a mapping between the lowest level ship types from S&P, called StatCode5, and the aggregated MarU ship types. The mapping is given in Appendix A – S&P Global StatCode5 to MarU mapping. More information about ship data is given in chapter 2.3.

Note, when information about ship type is missing in S&P Markit's dataset, one of the other sources of data will be used. These sources might not follow the StatCode system and deviations in name of ship type and definition might occur.

The size categories below 5 000 gross tonnes (GT) has been split into four categories, while these used to be two categories in Havbase. The reason for the division is to better facilitate for analyses of the smaller vessels, which is necessary as the fleet in the Norwegian waters consist of a considerable amount of ships below 5 000 GT. The MarU ship size categories are shown in the table below.

Table 3 Comparison of MarU and Havbase ship size categories.

MarU size categories, GT	Havbase size categories, GT
<=399	<1 000
400-999	
1 000-2 999	1 000-4 999
3 000-4 999	
5 000-9 999	5 000-9 999
10 000-24 999	10 000-24 999
25 000-49 999	25 000-49 999
50 000-99 999	50 000-99 999
>=100 000	>=100 000

2 Data sources

As will be described in chapter 2.4, MarU is a bottom-up emission model which uses position data from automatic identification system (AIS) messages to calculate each vessel's emissions. Therefore, the key data source for MarU is the AIS data processing module MarTraf (maritime traffic model). Another input to the emission calculations are the ship specific technical data. Further, emission specific input variables are included in order to perform the emission calculations. Lastly, several data sets of geographical information are used in order to allocate the emissions to specific geographical areas.

In the following these data sources are further discussed and explained.

2.1 AIS data

The AIS data cleaning and processing is handled outside the MarU module. The process will be thoroughly explained in a separate methodology document. Meanwhile a short version is presented here.

2.1.1 AIS sources and processing steps

The Norwegian Coastal Administration is responsible for and manages the AIS receivers related to ship traffic in Norwegian waters (*AIS Norway*). We have about 90 base stations on the mainland and Svalbard, and five satellites that can receive signals from vessels over large sea areas. Additional AIS data sources are available to the NCA through exchange agreements. Much of the AIS data can be made available public, but some limitations apply based on source and type of AIS data. For more information see Chapter 5. Currently, the Norwegian base stations and satellites are the only AIS sources included in MarTraf.

The Norwegian AIS data from base stations and satellites are separated into static and dynamic messages. Static messages contain information about vessel characteristics which should remain static over a period of time, e.g.: MMSI number, IMO number, name, type of ship, cargo, ship dimensions. Dynamic messages contain information related to the ship's speed, course, and heading. The information from the dynamic messages undergoes a "cleaning process" where outlying datapoints are removed. These data have "full resolution", meaning that no down-sampling of the dataset is done prior to processing. This approach is chosen to avoid the scenario where noise would be kept and valid data dropped, this is made possible due to availability of computing power. The dataset is not perfect and there is still a small amount of noise present.

As shown in Figure 2, the next step is for the dynamic data to be enriched with geographical information, afterwards it is enriched with operational phases, next voyage segments are established, followed by establishment of complete voyages from port to port, and lastly traffic type categorisation is performed. The steps are elaborated in the following subchapters.

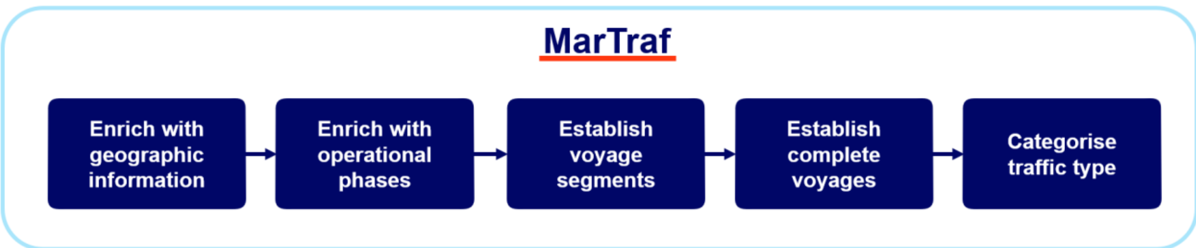

Figure 2 The MarTraf steps for processing and enriching AIS data.

The static AIS messages, however, undergo a process of versioning before they are merged with the associate ship register data. After the merging the static messages are utilised in the establishment of voyage segments.

2.1.1.1 Enrichment by geographical information

To provide context to vessel movements, it is highly beneficial to include geographical data. Conceptually, there are two main reasons for adding this information. The first is to enhance the description of the vessel's activity or phase at any given point, which is crucial for estimating the energy usage. For instance, there is a significant difference between a stationary platform support vessel on dynamic positioning near an oil-producing platform in the North Sea, and the same vessel in a dry dock with its AIS still active. In the former scenario, the vessel is engaged in operational activities with higher energy usage, while in the latter, it is probably undergoing maintenance with minimal energy usage.

The second reason is to gain insights into where the vessel is sailing, including the origin and destination of each trip. This information is important for categorising voyage types, such as distinguishing between domestic and international voyages. Additionally, it enables us to make statistics on areas of interest, where counties, municipalities, and marine management plan areas are particularly significant.

The geographical data that are added consists of points and polygons. There are many methods for performing spatial joins, each with their own advantages and disadvantages. For this project and the amount of data handled, performance have been the main influencing factor for choosing method.

The model runs on the Databricks Platform, and is mainly written using the PySpark library. H3 geospatial functions[1] are efficient built-in functions since Databricks runtime 11.2. Spatial joins with H3 indexing are very fast and efficient, but it has the disadvantage of not returning geodesic distances on a surface. Two points are either inside the same hexagon or a given number of cells separated; it will not return distance in meters.

There is also a precision sacrifice for evaluating whether a point is inside a polygon. The issue has its origin from the problem of representing a complex shape with hexagons. With smaller and smaller hexagons, you get closer but it will never get to a perfect match. In addition, there is a performance cost of going to small.

Reduced precision of H3 in comparison to other methods of spatial joins is not seen as a hindrance to the model's overall precision or results. An example of how H3 index is used can be seen in Figure 3. The model only needs to know whether AIS datapoints are within or outside set threshold limits.

The following description is conceptually correct, however, the implementation uses more datasets and many logic gates. Figure 3 shows an H3 grid of resolution 8 over central Oslo with three semi fictitious harbours, as it is not real data from the model. One of the logic gates in the model uses a conditional statement of being within a distance of one or less to a harbour in combination with resolution 8. That equates to a radius of about 1 100 meters if the point is centred in the hexagon, see Harbour C with its radius circle.

[1] https://docs.databricks.com/en/sql/language-manual/sql-ref-h3-geospatial-functions.html

For Harbours A and B, that lies close to the edge of their respective hexagons, the actual distance from the hexagon centre to a vessel for the vessel to be considered close to a harbour, varies from around 600 to 1 600 meters.

AIS point A would not be categorised as close to a harbour since it is more than one distance from the centres. AIS point B is close to both harbour A and B. Currently, the implementation is deterministic based on the order of the datapoints in the raw data. It will choose the feature with the lowest index from the geographical data. AIS point C is closest to harbour A, but with our implementation of H3 it is technically closer to harbour B. This is because AIS point C is in the centre hexagon of harbour B and in reference to A it is one cell distance away.

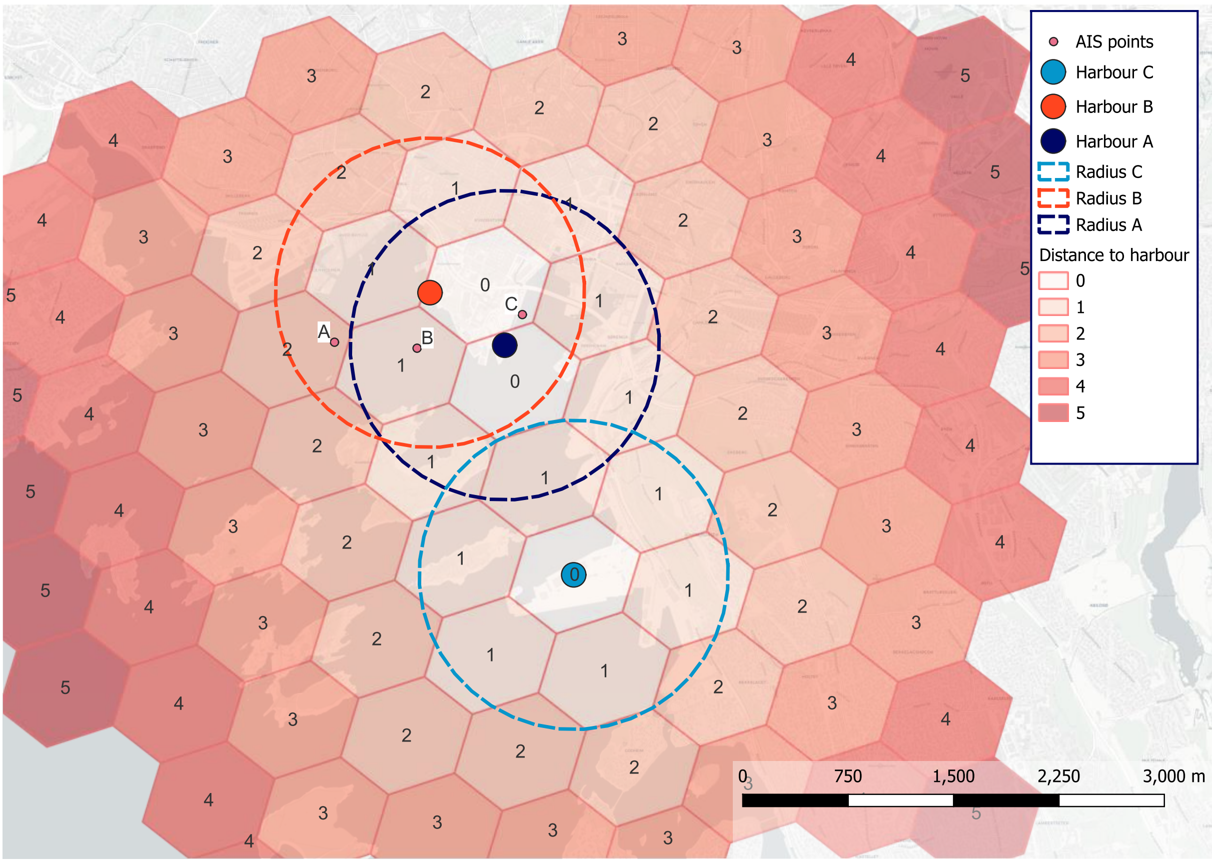

Figure 3 An example of using H3 indexing.

For MarTraf that generates voyage segments, complete voyages, and set operational phases, it is information about closeness to geographical feature types that is of importance, not which of the specific feature is the closest.

2.1.1.2 Enrichment by operational phase

Eleven different operational phases can be identified for a voyage segment. Several conditions need to be in place for a phase to be allocated to the segment. In this process distance is the most frequently used condition, and the H3 method described in the previous chapter is used for indexing of coordinates into hexagonal grids. Note that the size of the hexagons differs depending on the resolution and ring configuration of the applied grid.

The conditions for the different phases are briefly described below.

- Alongside aquaculture facility

    - The ship type is “well boat”, the distance to the aquaculture facility is equal to or less than one hexagon, and the speed is less than one knot.
- In node - 1: Norway
    - Distance to shore is equal to or less than one hexagon and the vessel is identified to not be “underway” based on evaluation of its speed.
- In node - 2: Europe, Svalbard, Hopen, Bjørnøya
    - The country is identified to not be Norway, and the location is identified as being in Europe. In addition, the distance to port is equal to or less than two hexagons, and the speed is equal to or less than one knot.
- In node - 3: anywhere but Norway, Europe, Svalbard, Hopen, or Bjørnøya
    - The location is identified to not be in Europe, the distance to port is equal to or less than four hexagons, and the speed is equal to or less than one knot.
- Dynamic positioning - 1
    - The ship type is “offshore”, the distance to shore is equal to or greater than nine hexagons, the distance to an oil installation is equal to or less than two hexagons, and the speed is equal to or less than half a knot.
- Dynamic positioning - 2
    - Same as above, but the speed can be up to 1.5 knots, given the vessel’s navigation status is set to “restricted manoeuvrability”.
- Fishing
    - The ship type is “fishing vessel”, the distance to shore is equal to or greater than six hexagons, distance to port is equal to or greater than one hexagon, and the speed is less than five knots.
- Anchorage
    - The vessel is identified to be located inside an anchorage area (only Norwegian data available at the moment) and is identified to not be underway/cruising.
- Manoeuvring
    - The speed of the vessel is equal to or less than three knots.
- Cruising
    - If none of the above phases is allocated, “cruising” is chosen. The vessel’s speed is greater than three knots.
- Using shore power
    - Phase node 1, 2, or 3 is allocated and lasts at least two hours, and the distance to a shore power location is equal to or less than one hexagon. The entire berthed period will be given as using shore power.

Note that the phase logic of *Using shore power* is part of MarU, not MarTraf.

2.1.1.3 *Establishment of voyage segments*

Voyage segments can be seen as sequences of enriched AIS-data per vessel that has their own analytical value and are building blocks for the next step in the AIS processing pipeline. The sequences are created by evaluating if the vessel is either consistently *underway* by our logical definition or *not underway*.

Under some vessel operations, it's common for a vessel's speed to fluctuate around our predefined speed thresholds. These fluctuations can sometimes create segments in the data that don't make sense, such as very short segments that don't accurately represent the vessels operation. To avoid this issue, we enforce a rule that no segment can be shorter than 5 minutes. This ensures that only meaningful segments are recorded, and brief, insignificant changes in speed are not treated as separate voyage segments.

If there is a long time gap between the vessel's AIS signals, we start a new segment. This prevents us from mistakenly treating two separate segments as one continuous segment, ensuring that each segment accurately reflects the vessel's voyages, even when there are interruptions in the signal.

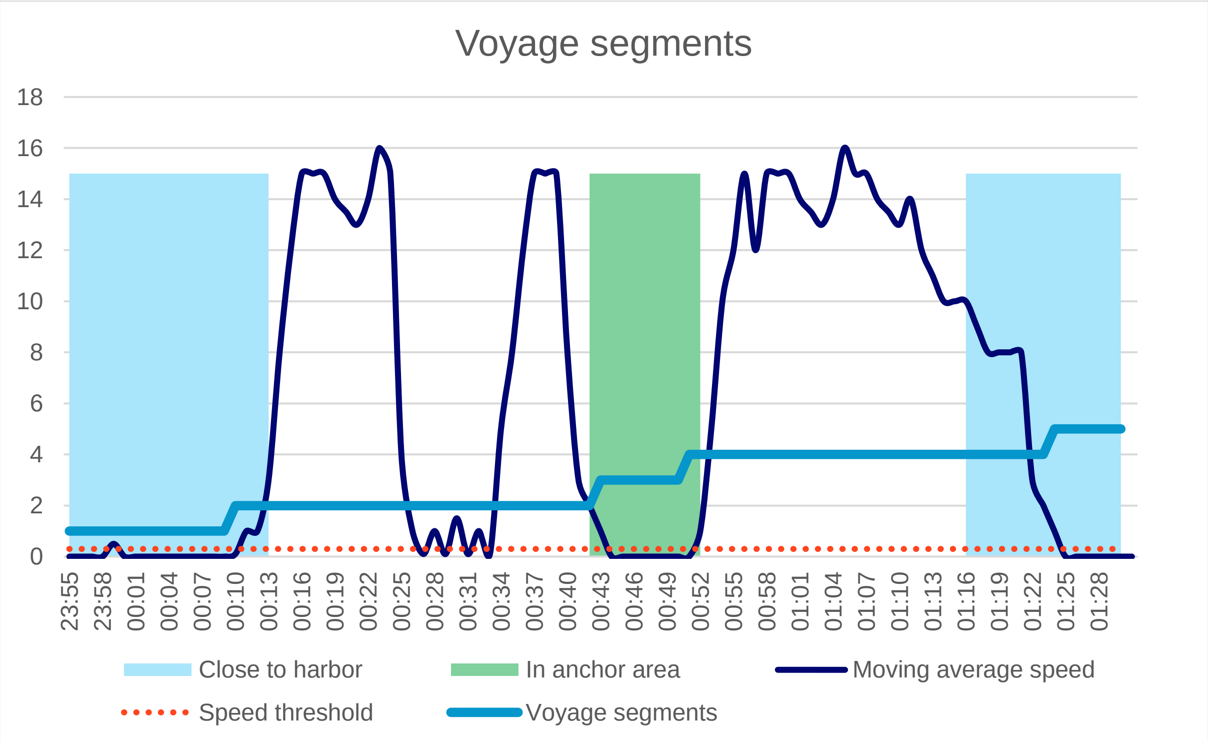

Figure 4 Example of voyage segments.

The result is segments that are mainly either underway or not underway. To be underway the moving average speed needs to be above 0.3 kts. In Figure 4 it is apparent that the segments generally tick up every time the speed crosses the speed threshold, except at the beginning and around 00:30.

Segment id	start	stop	Description	Comments
1	23:55	00:09	Berthed(node)	Smaller inaccuracies in speed values from AIS should not create new segments or arrivals.

2	00:10	00:42	Cruising & manoeuvring	Fluctuating speed around the threshold should not create segments.
3	00:43	00:50	Manoeuvring & anchored	
4	00:51	01:23	Cruising & manoeuvring	
5	01:24	01:30	Berthed(node)	

2.1.1.4 Establish complete voyages port to port

Complete voyages are based on the underlying voyage segment logic. The principle behind complete voyages is to distinguish between times when the vessel is stationary at a harbor and times when it is in on a voyage. Essentially, a complete voyage represents the period when the vessel is not stopped at a harbor and is actively traveling.

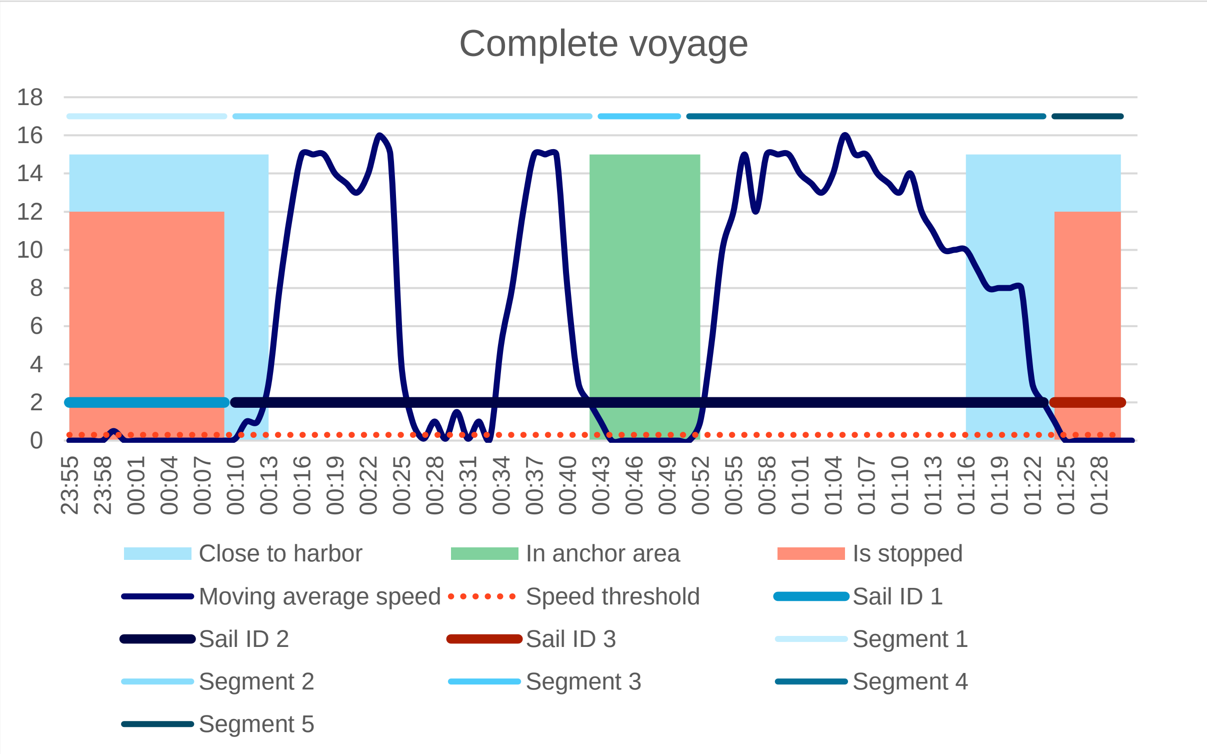

Figure 5 Example of a complete voyage.

From the hypothetical AIS data in Figure 4 we have classified segment 1 and 5 as “Is stopped”, see Figure 5. The complete voyage in this case is segment 2, 3 and 4. The berth at segment 1 will be given a sail ID, segment 2,3 and 4 will be given one sail ID as they combined make a complete voyage between two ports, and segment 5 will be given a sail ID.

A segment is classified as "Is stopped" by evaluating the percentage of time the vessel is in the Node phase. If the Node phase accounts for more than 50 percent of the segment, the segment is marked as "Is stopped”.

There is some more logic to handle loss of data when complete sails are created. For a vessel traveling from harbour A to B, to C this should result in 5 sail ID’s. Three Sail ID’s for berths in each harbour and two for each voyage. If there is large period without data around harbour B the logic will create a voyage from A to last datapoint before the loss of data. And a voyage from the next datapoint to harbour C. The first voyage will end somewhere in the middle of the sea along the route to harbour B and the second will start in the middle of the sea along the route to harbour C.

This method of splitting voyages is preferred for the purpose of categorising traffic types more accurately.

The voyage in Figure 4 and Figure 5 could represent an oil tanker heading to Slagentangen, an oil refinery in the Oslofjord. However, the durations are not to scale, and the time period and speed after anchoring are too large to accurately reflect a typical journey to this location.

The voyage begins with the tanker departing from a harbor at 00:10, heading towards Slagentangen. Upon entering Norwegian waters, the vessel must comply with local regulations by taking on a pilot. The ship slows down near Færder in the pilot area around 00:25. After the pilot boards, the vessel increases its speed. By 00:43, the tanker arrives at a designated anchoring area where it waits for a time slot to unload. At 00:51, the vessel leaves the anchoring area to complete the final segment of its voyage to Slagentangen. By 01:24, the oil tanker has arrived at Slagentangen and is ready to unload.

2.1.1.5 Categorise traffic type

A set of voyage types are defined in order to categorise the traffic and related emissions:

- Berthed: voyage type is set to "Berthed" if the sail ID is categorized as "Is stopped".
- Domestic: First country visited is Norway or Svalbard, and last country visited is Norway or Svalbard.
- International out: First country visited is Norway or Svalbard
- International in: Last country visited is Norway or Svalbard
- Transit: None of the above.

Note that anchorage does not affect the traffic types, as the categorisation is based on complete port to port voyages.

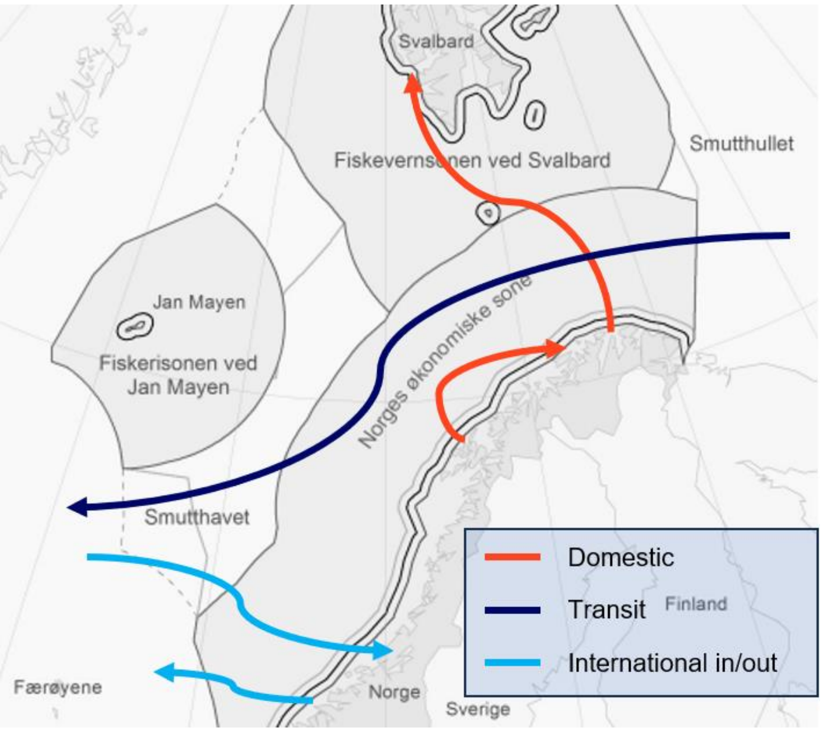

Figure 6 Examples of traffic types. Map from www.kartverket.no.

After the five steps described above in chapter 2.1.1.1-2.1.1.5, the processed and enriched AIS data is ready to be used as is or as input to other modules, such as emission estimation by MarU.

2.1.2 AIS data input to MarU

Throughout 2015 several new AIS ground stations were established by Kystverket, leading to considerable improvements to the AIS coverage along Norway's coast, including the most trafficked fjords. Unfortunately, better coverage affects the emission estimates and would give faultily results in the emission time series. Therefore, 2016 has been chosen as the first year of the MarU emission estimates.

2.2 Geographical information

One main objective of the MarU model is to present emission estimates for geographical areas that are of interest to the NCA and other users of the data. As seen in Figure 7 and Figure 8**Feil! Fant ikke referansekilden.**, there are several sources of geographical data, where some are utilised in MarTraf while others are utilised in MarU.

The MarTraf geographical sources are used when determining voyage segments, phases, and traffic type, and are the following:

- UN/LOCODE (the United Nations Code for Trade and Transport Locations): codes for locations used in trade and transport, e.g., seaports, rail and road terminals, airports. The table of codes contains information about the coordinates for each location code.
- Land contours: The Norwegian coastline is collected from the Norwegian Mapping Authority and consists of line string features.
- Oil installations: Information about oil and gas installations on on the Norwegian continental shelf are collected from Norwegian Offshore Directorate.
- Anchorage polygons: NCA is the regulator of designated anchoring areas that are visible on nautical maps. These anchoring areas is included in the model.
- New ShipRep: Contains data from to SafeSeaNet Norway (see chapter 2.3.1) relating to location of ports, quays, anchorage, pilot boarding points, offshore installations, etc.
- Aquaculture facilities: Information of aquaculture locations in Norway are collected from the Norwegian Directorate of Fisheries
- Outer border of adjacent economic zones: The geographical extent of the dataset is the largest area of Norway's maritime borders, in other words a combination of the outer boundary of the continental shelf and borders with the economic zone of other states.
- North Sea, Norwegian Sea: The maritime boarder depicted in Figure 9 is collected from the Norwegian Mapping Authority.

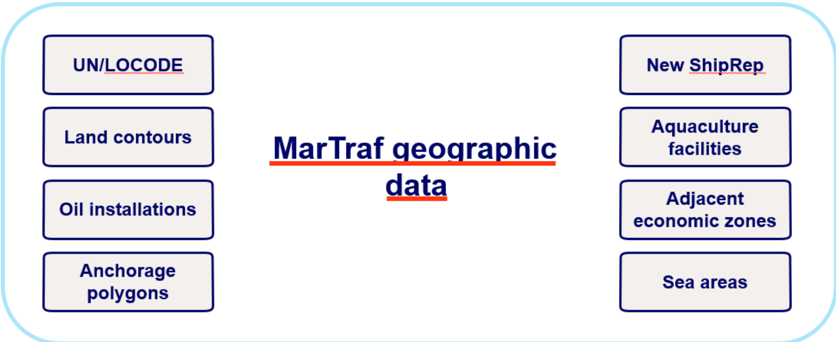

Figure 7 Sources of geographical data utilised in MarTraf.

The MarU specific geographical sources are used either to adjust emission calculations, or to present ship traffic emissions per area, and are the following:

- Sea areas of the integrated management plan: The areas used in connection with management plans for integrated and ecosystem-based management in Norwegian sea areas. The three areas are: the Barents Sea and the waters off Lofoten; Norwegian sea; The North Sea and the Skagerrak. Note that in the map in the link, the areas stop at the baseline. In MarU, the line has been moved all the way inland to include coastal traffic in each planning area.
- The Norwegian exclusive economic zone: The area extends 200 nautical miles from the baseline. The zone is limited by the economic zones of other states.
- The Norwegian continental shelf. Retrieved from the Norwegian Mapping Authority.
- Municipalities: The municipal boundaries extend to the territorial limit, i.e. 12 nautical miles from the baseline. Retrieved from the Norwegian Mapping Authority.
- Counties: Norwegian counties are made up of multiple municipalities. In MarU, we treat Svalbard as a separate county, although it operates under a special jurisdiction outside the regular county system.
- Emission Control Areas: the areas are defined by IMO (as sets of coordinates) and have corresponding emission regulation limits with respect to SOx and NOx emissions.
- Shore power locations: An updated list of location of shore power infrastructure along the Norwegian coast. The locations are used to determine whether a vessel have the possibility to use shore power during its port stay or not.

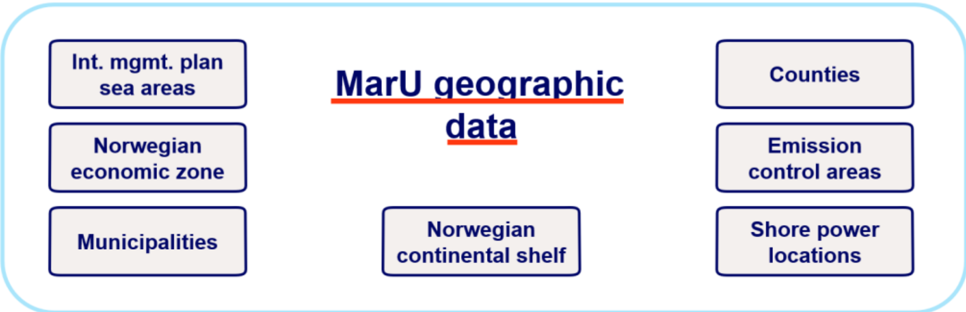

Figure 8 Sources of geographical data utilised in MarU.

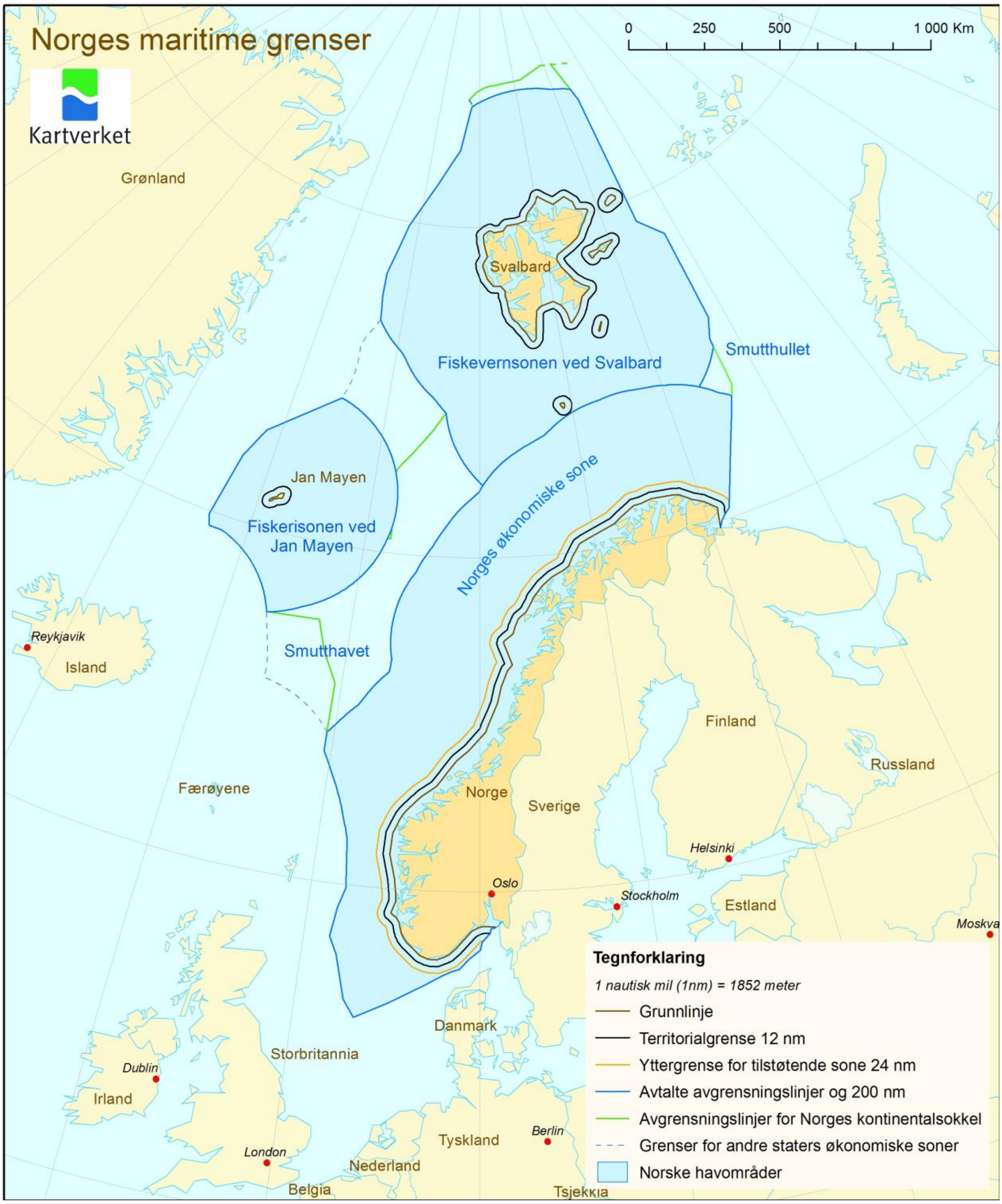

Figure 9 The Norwegian maritime borders. Source: https://www.kartverket.no/til-lands/fakta-om-norge/maritime-grenser

2.3 Ship data

In addition to AIS data for vessel position and geographical information, vessel data is another key ingredient in the emission estimation. Without enough information about each individual ship, the calculations cannot be performed. The parameters required for MarU, are:

- Vessel type
- Year of build
- Size (gross tonnage, deadweight, TEU, length, breadth, draught, etc.)
- Propulsion type
- Fuel type
- Main engine specifications (engine type, RPM, power, stroke type, builder, model, etc.)
- Speed (service speed, max speed)

NCA's sources of the above vessel data are described in the following chapter.

2.3.1 Ship data sources

Information about the different vessels used to perform the emission calculations are gathered from five different sources:

- S&P Global's "Ships" dataset (formerly IHS Markit and Fairplay): This is a dataset the NCA purchases from S&P Global. It contains selected information about 220 000+ ships. This is the main source of vessel information.
- ShipInfo: A comprehensive overview the Norwegian merchant fleet and fishing fleet. The NCA purchases this information.
- SafeSeaNet: SafeSeaNet Norway is the national ship reporting system where vessels can book a pilot and send arrival and departure information to the Norwegian authorities and ports. The portal is managed by NCA and is a source for vessel specific information.
- NOR and NIS flag registers: These registers are Norwegian ship registers, managed by the Norwegian Maritime Authority. They contain vessel specifications for all vessels flying NOR or NIS flag.
- The Directorate of Fisheries: "Fartøysregisteret", or "the vessel register", contains information about Norwegian fishing vessels, which is scarce in e.g. S&P Global's Ships dataset.

The different sources are combined by mapping ship types to one common type (StatCode5). Next, each registry is read and combined into one big registry. Then follows a process of resolving duplicates and checking values which exceed known thresholds. Lastly, the vessels are given the ship type category utilised when presenting MarU results. This final table is input both to the AIS processing steps in MarTraf (as described in chapter 2.1.1) and MarU.

2.3.2 Imputation of missing ship data

The combined vessel registry contains all the necessary vessel attributes to estimate the emissions from each ship given its speed, phase, and vessel attributes. Unfortunately, for many vessels, several of the necessary attributes have to be filled in using the procedure described below.

There is a prerequisite that all vessels in the registry have valid information about length and ship type given as statcode5. If either of these attributes are missing, the vessel will be excluded from further processing.

The process of filling in missing registry data follows the order of Table 4 where it starts with median values, followed by three machine learning (ML) models and ends by adding missing fuel types by a set of rules.

A disadvantage with the method of imputation missing values is that it is based on data from S&P Global's "Ships" dataset. The filled in data will therefore be biased on vessels that are required to register with IMO numbers. The uncertainty of the median values and neural networks will therefor become larger for small vessels.

In general, all vessels not listed in S&P Global's "Ships" dataset need imputation of service speed, RPM and stroke type, as these are values only listed in the "Ships" dataset. This is apparent for "Miscellaneous – fishing" where many of the vessels comes from The Directorate of Fisheries which leads to a large share of vessels needing imputation of vessel data. See Appendix B – Share of vessels needing imputed values

The first step is as mentioned to fill missing values with median values. This is based on a set of finely grained groups on "*StatCode4+"* and length intervals [10, 30, 50, 60, 70, 85, 100, 120, 135, 150, 165, 180, 195, 210, 240, 270, 300, 330, 360, 500]. "StatCode4+" is the four first symbols equivalent to ShipTypeLevel4 in the *StatCode5 ID* plus the next symbol which describes hull type.

Because these groups are so finely grained, the result is several groups without values and some with very few samples. Therefore, it was chosen to only keep groups with a minimum of six samples. To be able to fill data for all vessels, an additional dataset grouped by StatCode3 with the same length intervals was created.

Attribute	Method	Machine Learning - Loss function
Breath moulded	Median value	
Max power (kw)	Median value	
DWT	Median value	
GT	Median value	
Draught	Median value	
Year of build	Median value	
TEU	Median value	
Gas capacity	Median value	
Stroke type	Machine Learning – Neural network	sparse_categorical_crossentropy
Service speed	Machine Learning – Neural network	mean_squared_error
RPM	Machine Learning – Neural network	Custom loss function on relative error.
Fuel type	Other	

Table 4 Values to be imputed.

For three attributes it was selected to train neural networks with Keras and TensorFlow. Note that RPM uses a custom relative error loss function. This was chosen to not overfit the training data on high RPM engines. RPM is required for classification of low, medium and high-speed diesel engines. See Appendix C – Fitness of Neural network model for details in the precision of the ML models.

From Appendix B – Share of vessels needing imputed values., it is clear that many vessels require imputation of one or more values for the emission estimates. The larger the vessels become they generally become more complete in the registry data.

Another imputation which is performed is for fuel type, which is key for estimation of several of the air emission components. About 70 % of the vessels which sailed in Norwegian waters in 2022 and 2023 (our selected test years) had missing fuel type in the ship registers. For these we've used the same approach as in the *Fourth IMO GHG Study* 2020 (IMO, 2020) and allocated fuel type based on the most frequent type of the corresponding ship type and vessel size of the population with known fuel type.

For fishing vessels, an additional, simplified assumption for missing fuel type has been implemented: if no fuel type has been allocated based on the logic in the previous paragraph, the fuel type is set to Distillate fuel. As in Fourth IMO GHG Study, *Distillate fuel* is used about distilled marine fuels in general and includes MGO and MDO.

2.4 Emission specific input variables

Approximately 330 emission specific input variables are used to perform the emission estimation calculations. These are copied from the methodology given in the Fourth IMO GHG Study (IMO, 2020) chapter 2.2.5, annex M, and the ICCT method report (Olmer, 2017). The variable list comprises emission factors, low load adjustment factors for low engine loads, fuel sulphur fraction limits per ECA, and global warming potential factors.

In addition, a table of auxiliary engine and boiler power output by operational mode is given as input. Some values in this table have been changed to better present the ships in Norwegian waters. The values are based on information gathered by Enova through their grant schemes application process.

3 Estimation of ship air emissions

3.1 Methodology

The emission estimates in the MarU model are based on the bottom-up methodology of chapter 2.2 of the Fourth IMO GHG Study (IMO, 2020). The approach is thoroughly described in the study and will not be reproduced here. In the cases where our approach deviates from the one in the Study, this is discussed and explained.

Figure 10 and Figure 11 gives a simplified and a detailed overview of the input, calculation steps and outputs of the emission estimation.

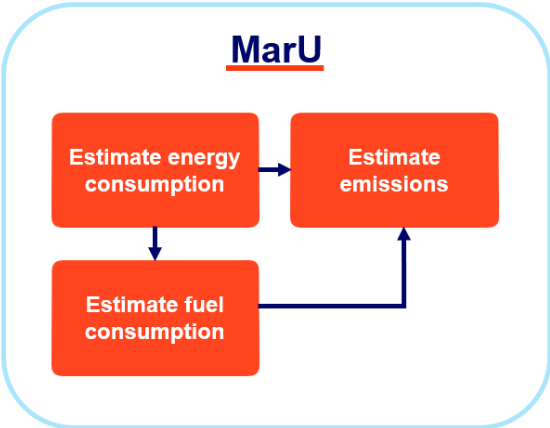

Figure 10 Simplified overview of MarU emission estimation steps.

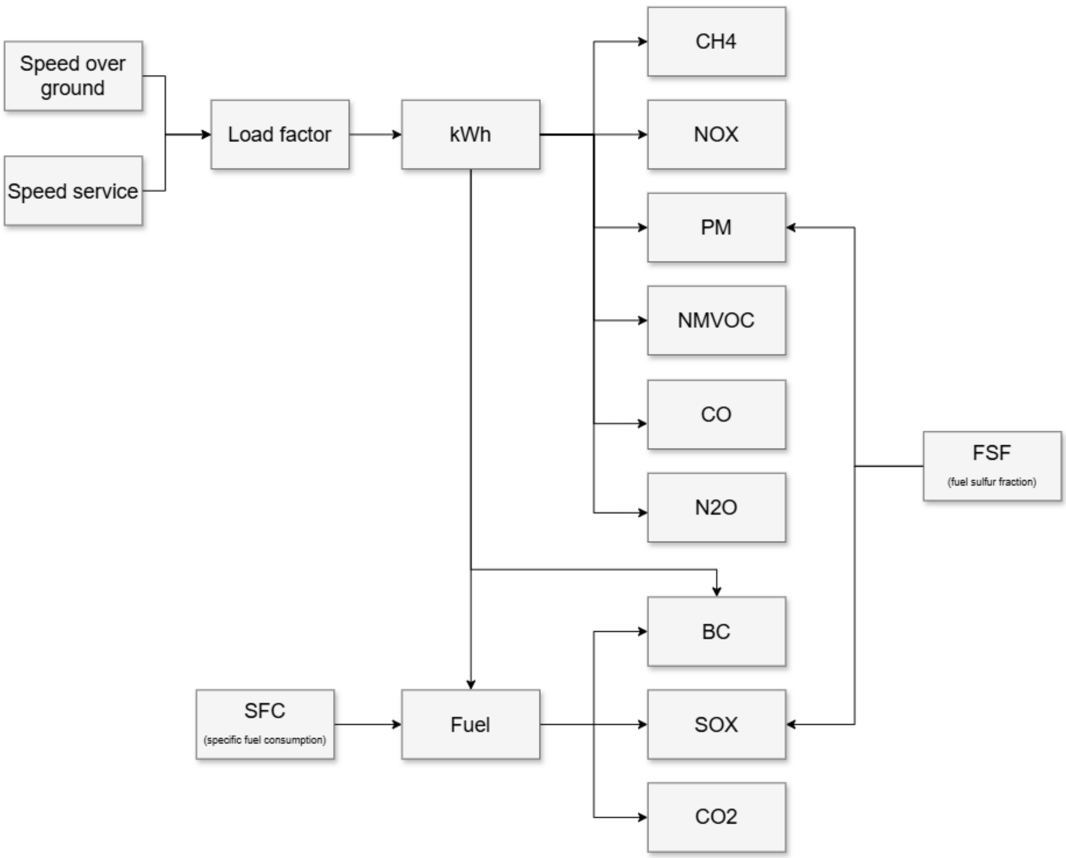

Figure 11 Detailed MarU emission estimation steps.

3.2 Calculation of energy demand

To determine a ship's main engine energy consumption, a *load factor* is multiplied by the installed engine power and the operational time, see Equation 1 and Equation 2. The installed power is obtained from the ship data registers, as mentioned in chapter 2.3.

The load factor represents the estimated engine load as a fraction from 0 to 1. It is calculated using the ship's observed speed over ground (obtained from AIS data) and its registered service speed (obtained from the ship data registers):

$$Load\ factor = \left(\frac{Speed\ over\ ground}{Service\ speed}\right)^3$$

Equation 1 Load factor.

As according to the Fourth IMO GHG Study, the speed ratio exponent is assumed to be 3.

Note that the service speed normally is achieved when the main engine run at about 85 % load. Therefore, a factor of 0.85 is multiplied with the installed power:

$$Energy\ demand\ [kWh] = Load\ factor * Installed\ power\ [kW] * 0.85 * \frac{Operation\ time\ [s]}{3600\ s}$$

Equation 2 Main engine energy demand.

The operational time in seconds is the time from the current to the previous AIS data point.

Equation 2 goes by the name "the propeller law". This is a simplified approach compared to the Fourth IMO GHG Study. The Study uses the somewhat more sophisticated "Admirality formula", which in addition takes into account draught variations, a speed-power relationship adjustment factor, a weather correction factor, and a fouling correction factor. The speed-power relationship adjustment factor is in MarU applied for cruise ships, but not for container ships.

3.3 Calculation of fuel oil consumption

According to the Fourth IMO GHG Study, specific fuel consumption (SFC) is assumed to vary as a function of load factor. The following equation shows how the SFC baseline is adjusted according to the engine load.

$$SFC_{load} = SFC_{baseline} * (0.455 * Load\ factor^2 - 0.71 * Load\ factor + 1.28)$$

Equation 3 Specific fuel oil consumption.

The main engine fuel consumption is derived by multiplying the engine's SFC by the main engine energy demand. The result is then converted to tonnes by dividing by 1 000 000.

$$Fuel\ Consumption = \frac{SFC_{load} * Energy\ demand\ [kWh]}{1\ 000\ 000}$$

Equation 4 Main engine fuel consumption.

The energy consumption for auxiliary engines and boilers is based on an input table (Table 17 from the Fourth IMO GHG Study), which varies depending on the operational phase.

$$Energy\ consumption\ [kWh] = Power\ output\ [kW] * \frac{Operation\ time\ [s]}{3600\ s}$$

Equation 5 Auxiliary engine and boiler energy consumption.

As for the main engine, fuel oil consumption is calculated by multiplying the energy consumption by the specific fuel consumption, but here the only the SFC baseline is used:

$$Fuel\ Consumption = \frac{SFC_{baseline} * Energy\ demand\ [kWh]}{1\ 000\ 000}$$

Equation 6 Auxiliary engine and boiler fuel consumption.

As according to the Study, values from the table 17 are overridden in the following cases,:

- When the main engine power is between 0 and 150 kW, the auxiliary engine and boiler are set to zero.
- When the main engine power is between 150 and 500 kW, the auxiliary engine is set to 5% of the main engine's installed power, while the boiler is set to the value from the table.
- When the main engine power exceeds 500 kW, the values for the auxiliary engine and boiler are used as per the table.

3.4 Calculation of emissions

Emissions are calculated by multiplying emission factors by energy demand or fuel consumption, as shown in Figure 11. CO_2, and SO_x are calculated based on fuel consumption, while black carbon emissions are determined using both fuel and energy consumption. All other emissions are calculated using energy consumption.

The following emissions and pollutants are estimated:

- Carbon dioxide (CO_2) – Fuel-based emission factor
- Sulphur oxides (SO_x) – Fuel-based emission factor
- Nitrogen oxides (NO_x) – Energy-based emission factor
- Particulate matter (PM_{10} and $PM_{2.5}$) – Energy-based emission factor
- Methane (CH_4) – Energy-based emission factor
- Carbon monoxide (CO) – Energy-based emission factor
- Nitrous oxide (N_2O) – Energy-based emission factor
- Non-methane volatile organic compounds (NMVOC) – Energy-based emission factor
- Black carbon (BC) – Fuel- and energy-based emission factor

To calculate the CO_2 equivalents, we use the "Global Warming Potential over a 100-year perspective (GWP100, global)" as provided by the Norwegian Environment Agency:

$$CO_2\ eq. = CO_2 * GWP_{(100,CO_2)} + CH_4 * GWP_{(100,CH_4)} + N_2O * GWP_{(100,N_2O)}$$

Equation 7 Calculation of CO2 equivalents.

Where:
$GWP_{(100,CO2)} = 1$
$GWP_{(100,CH4)} = 28$
$GWP_{(100,N2O)} = 265$

3.5 Results

The results from MarU are presented in a Microsoft PowerBi report, publicly available at www.kystverket.no/maru. The results are aggregated to month, ship type categories and ship size categories. A list of the MarU ship types is given in Table 2, while Table 3 contains the ship sizes.

An overview of the columns used to generate the report is given in Appendix D – Output columns from MarU.

4 Assumptions and adjustments

There are several areas where the Fourth IMO GHG Study and MarU differs. First and foremost, the Study uses global AIS data, while MarU uses AIS data available from NCA's satellites and ground stations filtered for the Norwegian sea areas. Next, the Study is based on a historic dataset for the years 2012 to 2018, while MarU incorporates continuous inclusion of new data as time passes.

Several assumptions and adjustments are included in the logic of MarU for it to better represent actual behaviour of the analysed vessels. IMO's GHG studies are focused on the global fleet, while the NCA has the Norwegian coast and seas as areas of responsibility. This implies that adjustments relevant for the specific ship types and technologies in our area are key to obtain credible emission estimates.

4.1 Reduced auxiliary engine and boiler energy demand during prolonged port stays

For prolonged port stays, a reduction in energy demand is incorporated for auxiliary engines and boilers. The reduction varied with length of stay and type of ship, as described below.

- For liquefied gas tankers and oil tankers:
    - If these vessels are berthed (in the "node" phase) for two days or more, their auxiliary engine and boiler energy demand is reduced to one-third of the original value.
    - If they are berthed for less than two days, the auxiliary engine and boiler energy demand is kept as originally recorded.
- For all other vessels:
    - If the vessel is berthed for at least one day, the auxiliary engine and boiler energy demand is reduced to three-quarters of the original value.
    - If the vessel has been berthed for less than one day, we keep the auxiliary engine and boiler energy demand as originally recorded.

These reductions are based on assumptions about the time required for a tank ship to load or onload its cargo and amount of energy demand during this process.

4.2 Battery electric vessels

Currently, the ship registers do not present electrical vessels using battery as primary energy source in a good way, leading to most battery vessels being considered as fossil fuelled vessels when using the Fourth IMO GHG Study approach. Therefore, a list of battery electric passenger vessels has been put together manually and given as input to the code. For these vessels a degree of electrification has been assumed, varying from 20 % to 95 %. The list contains the following parameters, in addition to those used for identification purposes: degree of electrification, year of battery installation, and battery pack capacity. The information comes from NCA's own sources[2].

The same assumption of 95 % degree of electrification has been utilised for vessels which have 'electric' as fuel type in the ship registers. It should be noted that these vessels are not registered with a secondary fuel. We have assumed 'distillate' as secondary fuel, in order to estimate air emissions.

4.3 On-shore power and charging facilities

In recent years, on-shore power (OSP) capacity has been expanded in Norway, and currently comprise several hundred installations. The first installations served ferry

[2] The Maritime Battery Forum, Fairplay ship register, www.tilnull.no, Corvus Energy.

connections operated by battery electric ferries (charging facilities), while shore power purposed to meet the “harbour mode” energy demand of any vessel soon became available in “regular” ports.

The purpose of using shore power is to reduce a ship’s emission while at quay. In order to reflect this in MarU, a factor for *degree of use* is implemented. Based on numbers of shore power usage, gathered by the Norwegian Environment Agency and NCA, and the report on *Electrification of shipping - Status of shore power in the main grid ports* by the environmental foundation ZERO (Gjerset, 2020), a degree of usage of 10 % is currently implemented.

In the code the length of each port stay is checked. If the stay is longer than two hours AND the ship is identified to be located a given (short) distance from a registered shore power installation, the emissions during the stay is reduced by 10 %. Note that the energy demand remains unchanged.

This is a general simplified approach, which is planned to be further developed once better shore power usage information is available.

For charging facilities serving e.g. ferry connections with battery electric ships exclusively, the degree of usage is set to 100 %.

4.4 Dynamic positioning

In chapter 2.1.1.2, two dynamic positioning (DP) operational phase conditions are described. Both applies to the ship type “offshore”. The purpose for the identifications is to adjust the energy demand during this specific type of operation. Inherently, the speed of the vessel in DP is zero or close to zero. Following the logic of the code, the main engine would be given a very low load factor and have vanishingly small energy demand and emissions. It is known that main engine(s) are kept running during DP to be ready any rapid manoeuvring if needed. Therefore, the main engine load factor is set to minimum 10 % in the DP operational phase.

4.5 Energy demand adjustments for aquaculture service vessels and fishing vessels

As discussed in chapter 2.1.1.2, the operational phase *Alongside aquaculture facility* is identified for well boats. The purpose of this identification is to adjust the energy demand to reflect the ongoing work performed by the vessel while serving the aquaculture facility. Currently, no energy demand adjustment is performed, giving an under-estimation of emissions in this phase. Finding suitable adjustment factors is in the scope of further work.

Similarly, the operational phase *Fishing* is identified, but no energy demand adjustment factors are implemented here neither. This is also in the scope of further work.

5 Data Use Policy

[MarU's data use policy is under development.]

When it comes to data, the NCA's intention is to "share what we can, protect what we must". Therefore, we share as much as possible of the data related to MarU. This is done through this document explaining the methodology, through sharing the results and related information on www.kystverket.no/maru, sharing of the code on GitHub, and sharing of input data. Alas, there are some limitations, e.g.: we can only share NCA's own AIS data, and we cannot share ship registry data which has been purchased.

A simplified summary is given below:

- The NCA's historical AIS data for the Norwegian Economic Zone, Svalbard and Jan Mayen can be retrieved from: https://hais.kystverket.no/ Here data from fishing vessels below 15 meters and pleasure crafts/sailing vessels below 45 meters have been excluded. Note that other AIS data sources and areas available to the NCA usually can be shared with other public authorities.
- The different geographical areas are retrieved from www.kartverket.no, with a few exceptions, e.g., the sea areas of the integrated management plan, which already existed within the NCA.
- For ship register data, the purchased information from S&P Global and ShipInfo cannot be shared. Data from the NMA and the Directorate of Fisheries can be obtained from their respective web pages.

With regards to MarU and sharing of emission estimates and more, the aggregated data available on www.kystverket.no/maru is considered public information.

MarU estimates shall not be used for commercial purposes or for vessel/fleet greenhouse gas accounting.

6 Further work

MarU is a model under development. Here is an overview of points for improvement and further development.

6.1 From global to local emission model

The first version of MarU is largely a copy of the method used in the IMO's fourth greenhouse gas study. The advantage of this is that we know that the method is well prepared and thoroughly documented. The disadvantage is that the method is not adapted to smaller vessels, of which there are many along our coast. The Norwegian Coastal Administration will work continuously to tailor the model for the fleet composition in Norwegian waters.

6.2 Shore power and charging facilities

MarU currently has some simple assumptions related to the use of shore power, applying a general factor of 10 %. Through a collaborative project between the Norwegian Environment Agency, Enova and the Norwegian Coastal Administration, a better knowledge base on shore power and charging infrastructure for vessels will be developed. The project is expected to start in late 2024, and implementation in MarU is expected during the first half of 2025.

6.3 Fishing vessels

Emissions from fishing vessels are challenging to estimate because there is great uncertainty related to which activities are taking place when, and what load the engine(s) on board have during the various activities. Today, MarU contains simple logic to try to identify when a vessel is in active fishing. We will continue to work on developing this logic, e.g. through the research project "Curbing Fisheries and Aquacultures Maritimes Air Emissions" (FAME).

6.4 Offshore vessels

As for fishing vessels, it is challenging to identify different types of activity, and associated emissions, for offshore vessels. In addition, a high degree of hybridisation in some of the vessels makes it even more challenging to match the estimates.

6.5 Rigs and other mobile facilities

Emissions from rigs and other mobile facilities are not included in the estimates from MarU today, but we are working to clarify which emissions from these should be included.

6.6 Layup/switched off engine

MarU does not currently take into account vessels that are laid up or have switched off the engines while still sending AIS signals. We need more information about which vessels this applies to, in which cases, and the use of shore power for this type of activity.

6.7 Changes in ship register data and emission factors

Changes in ship register data and emission factors must be accounted for by MarU. In addition, historical estimates should use the data that was current at the time of the activity. Note that MarU currently uses the same dataset for ship register data and emission factors for the entire time series (2016-present).

6.8 Resistance-based model

MarU currently uses "Propeller law" to estimate emissions. This method is based on observed speed (from AIS) compared to the design speed of a vessel and uses this to estimate the energy demand. This is a simplified approach of the "Admirality law" used in the Fourth IMOGHG study. A weakness in both of these approaches is that lower observed speed is considered as lower engine load, while the reason for low speed can be heavy waves and strong wind and currents, while the engine is at full load. A resistance-based approach will be able to take this into account and is generally considered to be a more accurate approach. The goal is therefore to rewrite MarU to use resistance-based methods.

6.9 Inclusion of other types of estimates

MarU currently only contains estimates for emissions to air. It is desirable to expand the model to also include estimates of discharges to the sea (bilge water, grey/black water, waste) and noise.

7 References

Gjerset, M. &. (2020). *Elektrifisering av skipsfarten - Status for landstrøm i stamnetthavnene.* Oslo: Miljøstiftelsen ZERO. Retrieved from https://zero.no/wp-content/uploads/2024/08/Elektrifisering-av-skipsfarten-Status-for-bruk-av-landstrom-i-stamnetthavner-ZERO-Gront-Skipsfartsprogram.pdf

IMO. (2020). *Fourth IMO GHG Study 2020; Safe, secure and efficient shipping on clean oceans.* London: International Maritime Organization (IMO). Retrieved from https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx

Olmer, N. e. (2017). *Greenhousegas emissions from global shipping, 2013-2015. Detailed methodology.* Washington DC: International Council on Clean Transport (ICCT). Retrieved from https://theicct.org/publication/greenhouse-gas-emissions-from-global-shipping-2013-2015/

8 Appendix A – S&P Global StatCode5 to MarU mapping

StatCode5	ShiptypeLevel5	MarU ship type
A11A2TN	LNG Tanker	Gas tankers
A11A2TQ	CNG Tanker	Gas tankers
A11A2TZ	Combination Gas Tanker (LNG/LPG)	Gas tankers
A11B2TG	LPG Tanker	Gas tankers
A11B2TH	LPG/Chemical Tanker	Gas tankers
A11B2TY	Liquefied Hydrogen Tanker	Gas tankers
A11C2LC	CO2 Tanker	Gas tankers
A12A2LP	Molten Sulphur Tanker	Chemical/product tanker
A12A2TC	Chemical Tanker	Chemical/product tanker
A12B2TR	Chemical/Products Tanker	Chemical/product tanker
A12C2LW	Wine Tanker	Chemical/product tanker
A12D2LV	Vegetable Oil Tanker	Chemical/product tanker
A12E2LE	Edible Oil Tanker	Chemical/product tanker
A12F2LB	Beer Tanker	Chemical/product tanker
A12G2LT	Latex Tanker	Chemical/product tanker
A13A2TS	Shuttle Tanker	Oil tankers
A13A2TV	Crude Oil Tanker	Oil tankers
A13A2TW	Crude/Oil Products Tanker	Oil tankers
A13B2TP	Products Tanker	Chemical/product tanker
A13B2TU	Tanker (unspecified)	Chemical/product tanker
A13C2LA	Asphalt/Bitumen Tanker	Chemical/product tanker
A13E2LD	Coal/Oil Mixture Tanker	Chemical/product tanker
A14A2LO	Water Tanker	Chemical/product tanker
A14E2LJ	Fruit Juice Carrier, Refrigerated	Chemical/product tanker
A14F2LM	Molasses Tanker	Chemical/product tanker
A14G2LG	Glue Tanker	Chemical/product tanker
A14H2LH	Alcohol Tanker	Chemical/product tanker
A14N2LL	Caprolactam Tanker	Chemical/product tanker
A21A2BC	Bulk Carrier	Bulk carriers
A21A2BG	Bulk Carrier, Laker Only	Bulk carriers
A21A2BV	Bulk Carrier (with Vehicle Decks)	Bulk carriers
A21B2BO	Ore Carrier	Bulk carriers
A22A2BB	Bulk/Oil Carrier (OBO)	Oil tankers
A22A2BN	Bulk/Caustic Soda Carrier (CABU)	Chemical/product tanker
A22A2BX	Bulk/Sulphuric Acid Carrier	Chemical/product tanker
A22B2BQ	Bulk/Oil/Chemical Carrier (CLEANBU)	Chemical/product tanker
A22B2BR	Ore/Oil Carrier	Chemical/product tanker
A23A2BD	Bulk Carrier, Self-discharging	Bulk carriers
A23A2BK	Bulk Carrier, Self-discharging, Laker	Bulk carriers
A24A2BT	Cement Carrier	Bulk carriers
A24B2BW	Wood Chips Carrier	Bulk carriers
A24C2BU	Urea Carrier	Bulk carriers

A24D2BA	Aggregates Carrier	Bulk carriers
A24E2BL	Limestone Carrier	Bulk carriers
A24G2BS	Refined Sugar Carrier	Bulk carriers
A24H2BZ	Powder Carrier	Bulk carriers
A31A2GA	General Cargo Ship (with Ro-Ro facility)	Container/Ro-Ro ships
A31A2GE	General Cargo Ship, Self-discharging	General cargo ships
A31A2GO	General Cargo Ship (Open Hatch)	General cargo ships
A31A2GS	General Cargo/Tanker (Container/oil/bulk - COB ship)	General cargo ships
A31A2GT	General Cargo/Tanker	General cargo ships
A31A2GX	General Cargo Ship	General cargo ships
A31B2GP	Palletised Cargo Ship	General cargo ships
A31C2GD	Deck Cargo Ship	General cargo ships
A32A2GF	General Cargo/Passenger Ship	Passenger vessels
A33A2CC	Container Ship (Fully Cellular)	Container/Ro-Ro ships
A33A2CR	Container Ship (Fully Cellular/Ro-Ro Facility)	Container/Ro-Ro ships
A33B2CP	Passenger/Container Ship	Passenger vessels
A34A2GR	Refrigerated Cargo Ship	General cargo ships
A35A2RR	Ro-Ro Cargo Ship	Container/Ro-Ro ships
A35A2RT	Rail Vehicles Carrier	Container/Ro-Ro ships
A35B2RV	Vehicles Carrier	Container/Ro-Ro ships
A35C2RC	Container/Ro-Ro Cargo Ship	Container/Ro-Ro ships
A35D2RL	Landing Craft	Container/Ro-Ro ships
A36A2PR	Passenger/Ro-Ro Ship (Vehicles)	Passenger vessels
A36A2PT	Passenger/Ro-Ro Ship (Vehicles/Rail)	Passenger vessels
A36B2PL	Passenger/Landing Craft	Passenger vessels
A37A2PC	Passenger/Cruise	Cruise ships
A37B2PS	Passenger Ship	Passenger vessels
A38A2GL	Livestock Carrier	General cargo ships
A38B2GB	Barge Carrier	General cargo ships
A38C2GH	Heavy Load Carrier	General cargo ships
A38C3GH	Heavy Load Carrier, semi submersible	General cargo ships
A38C3GY	Yacht Carrier, semi submersible	General cargo ships
A38D2GN	Nuclear Fuel Carrier	General cargo ships
A38D2GZ	Nuclear Fuel Carrier (with Ro-Ro facility)	General cargo ships
A38H2GU	Pulp Carrier	General cargo ships
B11B2FV	Fishing Vessel	Fishing vessels
B12A2FF	Fish Factory Ship	Aquaculture vessels
B12B2FC	Fish Carrier	Aquaculture vessels
B12D2FM	Fish Farm Support Vessel	Aquaculture vessels
B12D2FP	Fishery Patrol Vessel	Other activities
B12D2FR	Fishery Research Vessel	Other activities
B12D2FU	Fishery Support Vessel	Other activities
B12E2FX	Seal Catcher	Fishing vessels
B12F2FW	Whale Catcher	Fishing vessels
B12G2FK	Kelp Dredger	Fishing vessels

B12H2FY	Pearl Shells Carrier	Fishing vessels
B21A2OC	Crew/Supply Vessel	Offshore vessels
B21A2OP	Pipe Carrier	Offshore vessels
B21A2OS	Platform Supply Ship	Offshore vessels
B21B2OA	Anchor Handling Tug Supply	Offshore vessels
B21B2OT	Offshore Tug/Supply Ship	Offshore vessels
B22A2OR	Offshore Support Vessel	Offshore vessels
B22A2OV	Diving Support Vessel	Offshore vessels
B22A2ZA	Accommodation Ship	Offshore vessels
B22A2ZM	Offshore Construction Vessel, jack up	Other offshore vessels
B22B2OD	Drilling Ship	Offshore vessels
B22C2OQ	Pipe Layer Crane Vessel	Offshore vessels
B22C2OX	Pipe Layer	Offshore vessels
B22D2OZ	Production Testing Vessel	Offshore vessels
B22E2OF	FPSO, Oil	Other offshore vessels
B22E2OG	Gas Processing Vessel	Other offshore vessels
B22F2OW	Well Stimulation Vessel	Offshore vessels
B22G2OY	Standby Safety Vessel	Offshore vessels
B22H2OF	FSO, Oil	Other offshore vessels
B22H2OK	FSO, Gas	Other offshore vessels
B22J2OE	Trenching Support Vessel	Offshore vessels
B22K2OB	Pipe Burying Vessel	Offshore vessels
B31A2SR	Research Survey Vessel	Other service vessels
B32A2ST	Tug	Other service vessels
B32B2SA	Articulated Pusher Tug	Other service vessels
B32B2SP	Pusher Tug	Other service vessels
B33A2DB	Bucket Ladder Dredger	Other service vessels
B33A2DC	Cutter Suction Dredger	Other service vessels
B33A2DG	Grab Dredger	Other service vessels
B33A2DH	Backhoe Dredger	Other service vessels
B33A2DL	Bucket Wheel Suction Dredger	Other service vessels
B33A2DS	Suction Dredger	Other service vessels
B33A2DU	Dredger (unspecified)	Other service vessels
B33A2DW	Water Injection Dredger	Other service vessels
B33B2DB	Bucket Hopper Dredger	Other service vessels
B33B2DG	Grab Hopper Dredger	Other service vessels
B33B2DS	Suction Hopper Dredger	Other service vessels
B33B2DT	Trailing Suction Hopper Dredger	Other service vessels
B33B2DU	Hopper/Dredger (unspecified)	Other service vessels
B34A2SH	Hopper, Motor	Other service vessels
B34A2SS	Stone Carrier	Bulk carriers
B34B2SC	Crane Vessel	Other service vessels
B34B2SO	Pile Driving Vessel	Other service vessels
B34C2SI	Icebreaker	Other service vessels
B34C2SZ	Icebreaker/Research	Other service vessels
B34D2SB	Cable Repair Ship	Other service vessels

B34D2SL	Cable Layer	Other service vessels
B34E2SV	Incinerator	Other service vessels
B34E2SW	Waste Disposal Vessel	Other service vessels
B34E2SY	Effluent carrier	Other service vessels
B34F2SF	Fire Fighting Vessel	Other service vessels
B34G2SE	Pollution Control Vessel	Other service vessels
B34H2SQ	Patrol Vessel	Other service vessels
B34J2SD	Crew Boat	Other service vessels
B34K2QT	Training Ship	Other service vessels
B34L2QU	Utility Vessel	Other service vessels
B34M2QS	Search & Rescue Vessel	Other service vessels
B34N2QP	Pilot Vessel	Other service vessels
B34P2QV	Salvage Ship	Other service vessels
B34Q2QB	Buoy Tender	Other service vessels
B34Q2QL	Buoy & Lighthouse Tender	Other service vessels
B34Q2QX	Lighthouse Tender	Other service vessels
B34R2QY	Supply Tender	Other service vessels
B34S2QM	Mooring Vessel	Other service vessels
B34T2ON	Commissioning Service Operation Vessel	Other service vessels
B34T2OO	Service Operation Vessel	Other service vessels
B34T2QR	Work/Repair Vessel	Other service vessels
B34U2QH	Hospital Vessel	Other service vessels
B34V2QC	Tank Cleaning Vessel	Other service vessels
B34W2QJ	Trans Shipment Vessel	Other service vessels
B34X2QA	Anchor Handling Vessel	Other service vessels
B34Y2QK	Rocket Launch Support Ship	Other service vessels
B34Z2QG	Log Tipping Ship	Other service vessels
B35A2QE	Exhibition Vessel	Other activities
B35A2QI	Theatre Vessel	Other activities
B35A2QZ	Mission Ship	Other activities
B35B2SU	Bulk Dry Storage Ship	Bulk carriers
B35B2SX	Bulk Cement Storage Ship	Bulk carriers
B35C2SM	Mining Vessel	Other service vessels
B35D2OI	Wind Turbine Installation Vessel	Other service vessels
B35E2TD	Bunkering Tanker (LNG)	Gas tankers
B35E2TE	Bunkering Tanker (LNG/Oil)	Oil tankers
B35E2TF	Bunkering Tanker (Oil)	Oil tankers
B35F2WE	Power Station Vessel	Other service vessels
B35X2XX	Vessel (function unknown)	Other service vessels
B35Y2XV	Sailing Vessel	Other service vessels
W11A5TC	Chemical Tanker, Inland Waterways	Other activities
W11A5TR	Chemical/Products Tanker, Inland Waterways	Other activities
W11B5TU	Oil Tanker, Inland Waterways	Other activities
W11C5LE	Edible Oil Tanker, Inland Waterways	Other activities
W11C5LO	Water Tanker, Inland Waterways	Other activities
W11C5LV	Vegetable Oil Tanker, Inland Waterways	Other activities

W11D5TG	LPG Tanker, Inland Waterways	Other activities
W12A5BT	Bulk Cement Carrier, Inland Waterways	Other activities
W12A5CC	Container Ship (Fully Cellular), Inland Waterways	Other activities
W12A5GC	General Cargo, Inland Waterways	Other activities
W12A5GD	Pallet Shuttle Pontoon, Inland Waterways	Other activities
W12B5GF	General Cargo/Passenger Ship, Inland Waterways	Other activities
W12C5RR	Ro-Ro Cargo Ship, Inland Waterways	Other activities
W12D5PR	Passenger/Ro-Ro Ship (Vehicles), Inland Waterways	Other activities
W12D5PT	Passenger/Ro-Ro Ship (Vehicles/Train), Inland	Other activities
W12E5PC	Cruise Ship, Inland Waterways	Other activities
W12E5PS	Passenger Ship, Inland Waterways	Other activities
W13A5FV	Fishing, Inland Waterways	Other activities
W13B5SR	Research, Inland Waterways	Other activities
W13C5ST	Towing/Pushing, Inland Waterways	Other activities
W13D5DU	Dredging, Inland Waterways	Other activities
W13E5LR	Hull Cleaning Barge, Inland Waterways	Other activities
W13E5QQ	Other Activities, Inland Waterways	Other activities
X11A2YH	Houseboat	Other activities
X11A2YP	Yacht	Other activities
X11A2YS	Yacht (Sailing)	Other activities
X11B2QN	Sail Training Ship	Other activities
X11C2AD	Replenishment Dry Cargo Vessel	Other activities
X11C2AP	Aircraft Transport, Naval auxiliary	Other activities
X11C2AS	Tug, Naval Auxiliary	Other activities
X11C2AT	Replenishment Tanker	Other activities
X11C2AU	Unknown Function, Naval/Naval Auxiliary	Other activities
X11C2AV	Diving Vessel, Naval Auxiliary	Other activities
X11C2MA	Naval Small Craft	Other activities
X11C2MB	Boom defence Vessel	Other activities
X11C2MD	Degaussing Vessel	Other activities
X11C2MH	Minehunter	Other activities
X11C2ML	Minelayer	Other activities
X11C2MM	Minesweeper	Other activities
X11C2MN	Netlayer	Other activities
X11C2MP	Seaplane Tender	Other activities
X11C2MR	Torpedo Recovery Vessel	Other activities
X11C2MT	Troopship	Other activities
X11C2MU	Munitions Carrier	Other activities
X11C2MV	Submarine Salvage Vessel	Other activities
X11C2NA	Aircraft Carrier	Other activities
X11C2NB	Command Vessel	Other activities
X11C2NC	Corvette	Other activities
X11C2ND	Destroyer	Other activities
X11C2NE	Escort	Other activities

X11C2NF	Frigate	Other activities
X11C2NG	Cruiser	Other activities
X11C2NH	Helicopter Carrier	Other activities
X11C2NK	Attack Vessel, Naval	Other activities
X11C2NU	Torpedo Trials Vessel	Other activities
X11C2NW	Weapons Trials Vessel	Other activities
X11C2NX	Submarine Chaser	Other activities
X11C2NY	Torpedo Boat	Other activities
X11C2AA	Crane Vessel, Naval Auxiliary	Other activities
X11C3MX	Logistics Vessel (Naval Ro-Ro Cargo)	Other activities
X11C3NI	Infantry Landing Craft	Other activities
X11C3NL	Landing Ship (Dock Type)	Other activities
X11C3NT	Tank Landing Craft	Other activities
X11C4NS	Submarine	Other activities
X11D2QT	Training Ship, Stationary	Other activities
X11D2XA	Accommodation Vessel, Stationary	Other activities
X11D2XL	Lightship	Other activities
X11D2XM	Museum, Stationary	Other activities
X11D2XR	Restaurant Vessel, Stationary	Other activities
X11D2XS	Radio Station Vessel	Other activities
Y11A5BA	Bulk Aggregates Barge, non propelled	Other activities
Y11A5BH	Covered Bulk Cargo Barge, non propelled	Other activities
Y11A5BT	Bulk Cement Barge, non propelled	Other activities
Y11A5FH	Fish Storage Barge, non propelled	Other activities
Y11A5GC	General Cargo Barge, non propelled	Other activities
Y11A5LA	Bitumen Tank Barge, non propelled	Other activities
Y11A5LS	Drilling Barge, non propelled	Other activities
Y11A5QJ	Trans Shipment Barge, non propelled	Other activities
Y11A5QO	Water Tank Barge, non propelled	Other activities
Y11A5SH	Hopper Barge, non propelled	Other activities
Y11A5SX	Cement Storage Barge, non propelled	Other activities
Y11A5TC	Chemical Tank Barge, non propelled	Other activities
Y11A5TG	LPG Tank Barge, non propelled	Other activities
Y11A5TN	LNG Tank Barge, non propelled	Other activities
Y11A5TP	Products Tank Barge, non propelled	Other activities
Y11A5TR	Chemical/Products Tank Barge, non propelled	Other activities
Y11A5TV	Crude Oil Tank Barge, non propelled	Other activities
Y11B3DC	Deck Cargo Pontoon, semi submersible	Other activities
Y11B3WJ	Jacket Launching Pontoon, semi submersible	Other activities
Y11B4DB	Bucket Dredger Pontoon	Other activities
Y11B4DC	Deck Cargo Pontoon, non propelled	Other activities
Y11B4DG	Grab Dredger Pontoon	Other activities
Y11B4DS	Suction Dredger Pontoon	Other activities
Y11B4DU	Dredging Pontoon, unknown dredging type	Other activities
Y11B4DW	Water-injection Dredging Pontoon	Other activities
Y11B4SC	Crane Vessel, non propelled	Other activities

Y11B4WE	Power Station Pontoon, non propelled	Other activities
Y11B4WG	Grain Elevating Pontoon, non propelled	Other activities
Y11B4WL	Sheerlegs Pontoon	Other activities
Y11B4WO	Desalination Pontoon, non propelled	Other activities
Y11B4WS	Shopping Complex	Other activities
Y11B4WT	Steam Supply Pontoon, non propelled	Other activities
Y11B4WV	Car Park	Other activities
Y11B4WW	Work/Maintenance Pontoon, non propelled	Other activities
Y11B4XX	Pontoon (Function Unknown)	Other activities
Y11B5WW	Accommodation Pontoon, non-propelled	Other activities
Z11A4PR	Air Cushion Vehicle Passenger/Ro-Ro (Vehicles)	Passenger vessels
Z11A4PS	Air Cushion Vehicle Passenger	Passenger vessels
Z11A4SJ	Air Cushion Vehicle, work vessel	Other service vessels
Z11A4SK	Wing In Ground Effect Vessel	Other activities
Z11A4SQ	Air Cushion Vehicle Patrol Vessel	Other activities
Z11B4WA	Dock Gate	Other activities
Z11B4WF	Floating Dock	Other activities
Z11B4WM	Mechanical Lift Dock	Other activities
Z11C3ZA	Accommodation Platform, semi submersible	Other offshore vessels
Z11C3ZE	Drilling Rig, semi Submersible	Other offshore vessels
Z11C3ZG	Diving Support Platform, semi submersible	Other offshore vessels
Z11C3ZK	Pipe layer Platform, semi submersible	Other offshore vessels
Z11C3ZM	Maintenance Platform, semi Submersible	Other offshore vessels
Z11C3ZP	Production Platform, semi submersible	Other offshore vessels
Z11C4ZA	Accommodation Platform, jack up	Other offshore vessels
Z11C4ZC	Crane Platform, jack up	Other offshore vessels
Z11C4ZD	Drilling Rig, jack up	Other offshore vessels
Z11C4ZM	Support Platform, jack up	Other offshore vessels
Z11C4ZP	Production Platform, jack up	Other offshore vessels
Z11C4ZS	Supply Platform, jack up	Other offshore vessels
Z11C4ZU	Pumping Platform	Other offshore vessels
Z11C4ZW	Wind Turbine Installation Platform, jack up	Other offshore vessels
Z11D4XN	Mooring Buoy	Other activities
Z11E4WK	Linkspan/Jetty	Other activities
Z11F2XZ	Submersible	Other activities
Z11G4XY	Underwater System	Other activities

9 Appendix B – Share of vessels needing imputed values.

9.1 All vessels

Vessel type	powerkwmax	teu	draught	stroketype	speedservice	breadthmoulded	gascapacity	dwt	rpm	one_or_more_missing
Bulk carrier	0,1 %		2,6 %	7,0 %	2,8 %	0,0 %		0,0 %	7,8 %	12,5 %
Chemical tanker	0,1 %		2,3 %	5,4 %	3,8 %	0,0 %		0,0 %	6,7 %	11,7 %
Container	0,1 %	0,2 %	2,3 %	6,9 %	2,1 %	0,0 %		0,0 %	6,8 %	11,7 %
Cruise	2,2 %		5,7 %	16,4 %	13,2 %	0,0 %		12,4 %	27,6 %	39,4 %
Ferry-RoPax	0,5 %		8,9 %	11,5 %	20,5 %	0,1 %		2,9 %	25,2 %	41,5 %
Ferry-pax only	0,9 %		14,6 %	16,9 %	36,3 %	0,2 %		26,6 %	30,4 %	63,2 %
General cargo	0,4 %		5,0 %	9,9 %	15,1 %	0,0 %		0,2 %	16,8 %	31,2 %
Liquefied gas tanker	0,0 %		2,6 %	15,5 %	0,7 %	0,0 %	0,2 %	0,0 %	15,4 %	19,8 %
Miscellaneous - fishing	1,6 %		23,3 %	37,4 %	72,6 %	0,3 %		34,9 %	50,1 %	86,6 %
Miscellaneous - other	0,7 %		5,2 %	24,8 %	13,3 %	0,0 %		13,3 %	33,6 %	47,8 %
Offshore	0,5 %		3,8 %	12,2 %	14,0 %	0,0 %		3,1 %	21,3 %	32,6 %
Oil tanker	0,2 %		2,9 %	8,5 %	7,7 %	0,0 %		0,4 %	11,8 %	19,7 %
Other liquids tanker	1,1 %		9,7 %	7,5 %	26,9 %	0,0 %		3,2 %	23,7 %	45,2 %
Refrigerated bulk	0,0 %		3,2 %	17,4 %	5,9 %	0,0 %		0,0 %	21,1 %	28,9 %
Ro-Ro	1,3 %		17,3 %	6,9 %	53,3 %	0,0 %		27,9 %	15,0 %	67,1 %
Service - other	1,1 %		7,2 %	15,5 %	26,9 %	0,0 %		18,7 %	26,3 %	54,0 %
Service - tug	0,3 %		14,4 %	5,1 %	35,4 %	0,1 %		36,7 %	14,3 %	61,5 %
Vehicle	0,0 %		9,1 %	8,6 %	0,6 %	0,0 %		0,0 %	8,8 %	18,3 %
Yacht	0,9 %		7,8 %	7,6 %	17,2 %	0,1 %		44,4 %	15,8 %	58,5 %

9.2 Vessels over 2000 GT

	powerkwmax	teu	draught	stroketype	speedservice	breadthmoulded	gascapacity	dwt	rpm	one_or_more_missing
Bulk carrier	0,1 %		2,2 %	6,8 %	1,5 %	0,0 %		0,0 %	7,2 %	10,9 %
Chemical tanker	0,1 %		1,7 %	4,9 %	0,4 %	0,0 %		0,0 %	5,3 %	7,5 %
Container	0,1 %	0,1 %	2,3 %	6,9 %	1,5 %	0,0 %		0,0 %	6,7 %	11,1 %
Cruise	1,9 %		3,1 %	13,1 %	3,5 %	0,0 %		2,5 %	16,2 %	22,7 %
Ferry-RoPax	0,3 %		5,3 %	8,0 %	2,7 %	0,0 %		0,7 %	14,0 %	21,3 %
Ferry-pax only	1,4 %		2,7 %	5,5 %	11,0 %	0,0 %		4,1 %	15,1 %	26,0 %
General cargo	0,1 %		3,1 %	8,8 %	6,2 %	0,0 %		0,0 %	12,1 %	20,3 %
Liquefied gas tanker	0,0 %		1,9 %	15,9 %	0,2 %	0,0 %	0,2 %	0,0 %	15,4 %	18,9 %
Miscellaneous - fishing	0,5 %		8,1 %	9,9 %	29,2 %	0,0 %		10,9 %	19,1 %	49,1 %
Miscellaneous - other	0,1 %		3,4 %	23,7 %	7,4 %	0,0 %		5,6 %	29,1 %	38,0 %
Offshore	0,6 %		1,4 %	14,6 %	15,3 %	0,0 %		0,3 %	17,9 %	26,4 %
Oil tanker	0,1 %		1,2 %	8,5 %	1,1 %	0,0 %		0,0 %	9,4 %	11,7 %
Other liquids tanker	0,0 %		0,0 %	0,0 %	0,0 %	0,0 %		0,0 %	0,0 %	0,0 %
Refrigerated bulk	0,0 %		2,0 %	20,7 %	1,1 %	0,0 %		0,0 %	20,8 %	25,8 %
Ro-Ro	0,0 %		4,9 %	19,7 %	27,9 %	0,0 %		6,6 %	18,0 %	39,3 %
Service - other	0,7 %		4,5 %	12,9 %	13,1 %	0,0 %		6,4 %	22,7 %	37,3 %
Service - tug	0,0 %		5,2 %	12,1 %	15,5 %	1,7 %		5,2 %	19,0 %	39,7 %
Vehicle	0,0 %		9,1 %	8,7 %	0,4 %	0,0 %		0,0 %	8,8 %	18,1 %
Yacht	1,1 %		4,8 %	3,8 %	5,4 %	0,0 %		17,7 %	9,1 %	30,1 %

10 Appendix C – Fitness of Neural network model

10.1 Predicted speed service, mean absolute error.

Total mean absolute error is 1.13 knots
Total mean error is 0.16 knots

MarU_type	(0, 399]	(399, 999]	(999, 2999]	(2999, 4999]	(4999, 9999]	(9999, 24999]	(24999, 49999]	(49999, 99999]	(99999, 1000000]
Bulk carrier	0,91	0,87	1,04	0,90	0,85	0,48	0,37	0,39	0,44
Chemical tanker	1,07	0,94	0,96	0,82	0,66	0,57	0,58	0,29	
Container		1,92	0,89	1,03	0,77	0,56	1,12	1,82	1,44
Cruise	1,96	2,19	1,13	1,58	1,09	1,81	1,51	0,98	1,52
Ferry-RoPax	1,82	1,70	1,34	1,95	2,33	1,84	2,33	1,79	
Ferry-pax only	3,33	3,67	1,40	1,09	0,80	1,98			
General cargo	1,19	1,00	1,04	1,00	1,03	0,88	0,62		
Liquefied gas tanker	1,27	0,81	0,88	0,66	0,70	0,68	0,80	0,51	1,25
Miscellaneous – fishing	1,09	0,88	1,17	1,13	1,28	1,43	0,77		
Miscellaneous – other	2,49	0,60	1,61	1,34	4,30	2,17	1,61	4,49	
Offshore	1,75	1,15	1,23	1,25	1,73	1,59	1,95	1,10	2,38
Oil tanker	0,91	0,99	1,12	0,91	0,77	0,64	0,71	0,86	1,21
Other liquids tanker	1,21	0,72	0,81						
Refrigerated bulk	1,21	0,72	0,72	0,89	1,12	1,48			
Ro-Ro	2,33	1,69	1,41	1,47	1,45	1,53	1,01	1,27	1,91
Service – other	2,72	1,89	1,42	1,55	1,53	1,97	1,96	1,50	3,20
Service - tug	0,94	0,86	1,25	2,85					
Vehicle		0,06	1,19	1,27	0,98	1,23	1,06	0,81	
Yacht	2,79	1,80	1,31	1,47	2,59	2,32			

10.2 Predicted correct diesel engine type by rpm [SSD,MSD,HSD]

Total precision is 88.5%.

MarU_type	(0, 399]	(399, 999]	(999, 2999]	(2999, 4999]	(4999, 9999]	(9999, 24999]	(24999, 49999]	(49999, 99999]	(99999, 1000000]
Bulk carrier	66,7 %	50,5 %	77,9 %	70,1 %	86,1 %	99,9 %	100,0 %	100,0 %	100,0 %
Chemical tanker	71,8 %	85,6 %	72,6 %	84,0 %	97,6 %	99,8 %	100,0 %	100,0 %	

Container		50,0 %	79,1 %	96,2 %	99,9 %	100,0 %	100,0 %	100,0 %	100,0 %
Cruise	77,8 %	93,5 %	75,9 %	47,6 %	74,2 %	69,4 %	100,0 %	100,0 %	100,0 %
Ferry-RoPax	77,1 %	71,5 %	81,6 %	71,5 %	72,0 %	94,0 %	99,5 %	100,0 %	
Ferry-pax only	93,0 %	90,9 %	85,5 %	62,5 %	92,9 %	100,0 %			
General cargo	85,1 %	68,5 %	77,5 %	82,1 %	91,9 %	99,1 %	100,0 %		
Liquefied gas tanker	100,0 %	76,2 %	64,2 %	92,9 %	98,7 %	100,0 %	100,0 %	100,0 %	100,0 %
Miscellaneous - fishing	67,0 %	82,2 %	75,7 %	91,9 %	85,9 %	100,0 %	100,0 %		
Miscellaneous - other	100,0 %	40,0 %	87,5 %	56,3 %	85,7 %	75,6 %	100,0 %	100,0 %	
Offshore	84,4 %	74,1 %	71,2 %	75,6 %	79,9 %	87,2 %	81,8 %	100,0 %	100,0 %
Oil tanker	73,6 %	79,2 %	69,3 %	74,8 %	89,4 %	100,0 %	100,0 %	100,0 %	100,0 %
Other liquids tanker	63,3 %	88,2 %	75,0 %						
Refrigerated bulk	78,6 %	78,0 %	63,6 %	96,2 %	98,9 %	100,0 %			
Ro-Ro	95,2 %	97,4 %	91,7 %	76,2 %	92,2 %	99,5 %	100,0 %	100,0 %	100,0 %
Service - other	90,1 %	81,1 %	69,3 %	73,7 %	80,1 %	93,9 %	96,7 %	100,0 %	100,0 %
Service - tug	75,9 %	63,3 %	59,7 %	100,0 %					
Vehicle		100,0 %	77,8 %	100,0 %	93,1 %	100,0 %	100,0 %	100,0 %	
Yacht	98,4 %	97,1 %	95,2 %	82,6 %	57,9 %	45,5 %			

10.3 Predict correct stroke type.

Total precision is 94.6%.

MarU_type	**(0, 399]**	**(399, 999]**	**(999, 2999]**	**(2999, 4999]**	**(4999, 9999]**	**(9999, 24999]**	**(24999, 49999]**	**(49999, 99999]**	**(99999, 1000000]**
Bulk carrier	96,8 %	99,3 %	99,7 %	82,9 %	84,1 %	96,3 %	100,0 %	100,0 %	100,0 %
Chemical tanker	98,5 %	99,8 %	95,9 %	82,5 %	84,1 %	90,6 %	99,3 %	100,0 %	
Container	100,0 %	97,2 %	94,5 %	73,5 %	77,2 %	89,9 %	99,6 %	100,0 %	100,0 %
Cruise	81,8 %	96,6 %	91,2 %	90,9 %	94,9 %	96,0 %	98,1 %	100,0 %	100,0 %

Ferry-RoPax	92,6 %	94,7 %	96,7 %	89,4 %	86,6 %	90,6 %	97,7 %	100,0 %	
Ferry-pax only	95,0 %	97,8 %	97,3 %	81,8 %	93,3 %	100,0 %			
General cargo	93,0 %	97,3 %	97,2 %	87,8 %	85,1 %	87,1 %	99,7 %		
Liquefied gas tanker	100,0 %	99,5 %	91,3 %	72,7 %	81,7 %	91,8 %	99,3 %	100,0 %	95,0 %
Miscellaneous - fishing	96,8 %	96,9 %	89,3 %	91,5 %	89,1 %	83,3 %	25,0 %		
Miscellaneous - other	92,6 %	93,9 %	96,6 %	51,9 %	93,3 %	88,2 %	100,0 %	78,6 %	
Offshore	70,3 %	77,2 %	97,4 %	99,2 %	100,0 %	96,8 %	95,7 %	100,0 %	100,0 %
Oil tanker	97,7 %	98,6 %	95,7 %	85,3 %	86,5 %	88,7 %	99,4 %	99,5 %	99,7 %
Other liquids tanker	84,8 %	93,8 %	50,0 %						
Refrigerated bulk	98,5 %	98,7 %	88,1 %	59,3 %	76,0 %	98,0 %			
Ro-Ro	97,9 %	96,9 %	95,3 %	83,9 %	78,1 %	79,6 %	71,4 %	100,0 %	100,0 %
Service - other	93,1 %	94,5 %	94,1 %	93,8 %	94,3 %	92,4 %	93,5 %	100,0 %	100,0 %
Service - tug	97,2 %	96,0 %	94,6 %	100,0 %					
Vehicle		100,0 %	58,3 %	11,1 %	40,0 %	63,8 %	98,9 %	100,0 %	
Yacht	96,5 %	99,1 %	98,5 %	100,0 %	100,0 %	100,0 %			

11 Appendix D – Output columns from MarU

The following columns are output from MarU:

Column name	Explanation
management_plan_marine_areas_area_id	Identification number
maritime_borders_norwegian_economic_zone_id	Identification number
municipality_id	Identification number
in_norwegian_continental_shelf	Binary value (yes/no)
main_engine_kwh	Main engine energy demand
aux_kwh	Auxiliary engine energy demand
boiler_kwh	Boiler energy demand
fuel_mdo_equivalent_tonnes	MDO equivalents in tonnes
pm2_5_tonnes	Particulate matter in tonnes
bc_tonnes	Black carbon in tonnes
ch4_tonnes	Methane in tonnes
co_tonnes	Carbon monoxide in tonnes
co2_tonnes	Carbon dioxide in tonnes
n2o_tonnes	Nitrous oxide in tonnes
nmvoc_tonnes	Non-methane volatile organic compounds in tonnes
nox_tonnes	Nitrogen oxides in tonnes
pm10_tonnes	Particulate matter in tonnes
sox_tonnes	Sulphur oxides in tonnes
fuel_tonnes	Fuel consumption in tonnes
co2e_tonnes	Carbon dioxide equivalents in tonnes
version	Version of the MarU model
electric_shore_power_at_berth_reduction_factor	Factor for emission reduction in relation to shore power usage
shore_power_id	Identification number

The following columns are used in the MarU PowerBi report, but originates from MarTraf:

Column name	Explanation
vessel_id	Identification number
id	Identification number
mmsi	Maritime Mobile Service Identity number
date_time_utc	Timestamp
sail_id	Identification number
phase	Operational phase
delta_previous_point_seconds	Time difference between two AIS points
distance_previous_point_meters	Distance between two AIS points
unlocode_country_code	UN/LOCODE codes of countries
unlocode_location_code	UN/LOCODE codes of locations
voyage_type	I.e. traffic type
in_coast_and_sea_area	Binary value (yes/no)
ship_is_stopped	Operational phase

management_plan_marine_areas_area_name_norwegian	Names of the integrated management plan marine areas
maritime_borders_norwegian_economic_zone_id	Identification number
maritime_borders_norwegian_economic_zone_area_name	Names of the Norwegian economic zone areas

KYSTVERKET

https://www.kystverket.no
post@kystverket.no
Switchboard: 07847
Postal address: Norwegian Coastal Administration, p.b. 1502, 6025 Ålesund