

POTAMIS+ 1.0

**A bottom-up Prognosis Of Transport Air
emissions Model for Inland Shipping**

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1 Introduction

Inland shipping is a major source of air pollutant emissions in the Netherlands. Future emissions of inland shipping in the Netherlands, including impacts of government policies, are modelled using the POTAMIS model: Prognosis Of Transport Air emissions Model for Inland Shipping. The first version of the model was developed in 2009 by TNO for PBL Netherlands Environmental Assessment Agency. In recent years new activity data for the inland fleet has become available. Within the Dutch Emission Inventory (Pollutant Release and Transfer Register (PRTR)) inland shipping makes use of precise activity data: the exact number of ships and their hours and kilometres on the different waterways within the Netherlands can now be extracted from AIS data. Because of the nature of this data, a new bottom-up model has been developed: POTAMIS+. This model builds upon the knowledge gained in the development and usage of the earlier POTAMIS model, (Hulskotte, 2021)), as well as a stochastic bottom-up heavy-duty fleet development model (Mulder, 2024).

POTAMIS+ leans heavily on the PRTR-data to extrapolate currently observed trends and observations to the future.

There are three main factors which characterise the model:

1. Changes in fleet,
2. Changes in activity, and
3. Changes in technology.

The model uses these changes to predict the development of the Inland Waterway Transport (IWT) fleet on the level of individual ships per year based on current trends and proposed scenarios.

The strength of this approach is that the current activity of a certain ship is propagated to the future: this allows the model to take into account ships with atypical activity behaviour. For example, if an old, small ship with a small engine makes a large number of kilometres in the Netherlands now, it is expected that it will continue to do so in the future. Comparatively, a large ship with a modern engine which has a regular route abroad that leads to only a few kilometres within the Netherlands will also be forecasted to continue this behaviour (taking into account forecasted changes in transport demand).

This model can be used to model a number of different scenarios or assumptions, with examples such as:

- "From 2030 25% of autonomous engine replacements will be hybrid"
- "From 2025 all new ships must be electric"
- "100 ships get a new subsidised engine in 2028"
- "Engine replacement is only based on age, and not on the accumulated hours/kilometres"
- "Ships are installing more engine power"

In Chapter 2 we provide a brief overview of the model, which is then explained in detail in Chapter 3. In Chapter 4 we discuss the current caveats of POTAMIS+ 1.0, as well as possible points for development. Chapter 5 offers a technical description including the validation tests which have been performed.

2 Model overview

The architecture of the model is shown in Figure 2.1. The 'base year' is taken from the output of the PRTR and includes a list of ships and their total annual emissions and activities. The list of ships include both Dutch ships as well as international ships visiting the Netherlands. The POTAMIS+ model includes passenger ships as part of its analysis, but explicitly excludes smaller private boats and recreational vessels. This distinction is made in the PRTR definitions and is reflected in the ship type categories used in the model. As a result, the emissions and activity calculations focus on commercial and larger vessels, such as cargo ships, tankers, passenger ships, convoys, and hotels, while smaller private boats are not part of the dataset or the model's forecasts. Each ship has a certain engine age, vessel age, as well as yearly domestic kilometres and hours. The model calculates a forecast of the emissions per ship on a year-to-year basis.

Per modelled year t the following steps are taken:

1. An outflow of ships is calculated. This is based on chance: each specific ship type has a probability that a ship of that age will leave the fleet.
2. It is assumed that the outflow of (old) vessels is being replaced by new vessels. For the group of ships that are replaced, POTAMIS+ 1.0 replaces each ship with a ship with identical activity, but with a new engine. The technology of the new engine is randomly selected based on probabilities per technology type.
3. For the group of ships that remained in the fleet, the number of ships that will adjust their engine is selected based on age-dependent probabilities. The specific ships are then selected randomly with a weighing for the approximated distance a certain engine has already covered. I.e. the more kilometres on an engine (and thus the more hours it has run), the higher the probability of it being replaced.
4. The replacement technology probabilities are used to determine which technology is assigned to a specific engine if it is replaced, or whether the engine is revised. Recent studies showed that none of the ship types had a significant yearly dependence in engine size, thus, the current POTAMIS+ model assumes the same engine size for engine replacements. This assumption, however, can easily be changed and adopted within one of the POTAMIS+ input files.
5. If there are subsidies in place for specific technologies, a certain number of the new or replaced engines are randomly selected and assigned as subsidised. If the technology of that new or replaced engine is not the subsidised technology, the technology is updated to match the subsidy. This therefore allows for the cases where a ship owner was intending to replace their engine anyway, but applied for subsidy to do so.
6. The change in activity is determined by a year-on-year factor change in kilometres depending on the ship size (e.g. if there is a 5% increase in activity for a M8 ship from year t to year $t + 1$, then the annual distance in year $t + 1$ for that ship will be $1.05 \times d_t$).
7. If the engine technology has been changed, the emissions per kilometre are scaled accordingly.
8. The new total annual emissions are calculated from the updated change in kilometres and (updated) emissions per kilometre.

In POTAMIS+ the supplied input is divided into four categories, indicated as different shape types, as shown in Figure 2.2:

- The PRTR output of the base year
- Ship
- Engine
- Activity

These are discussed in detail in Section 3.2.

When running POTAMIS+, users typically need to adjust certain input files to reflect updated scenarios or annual changes. In particular, the [Activity](#) file (which contains year-on-year changes in ship activity) and the [Replacement/New tech number](#) file (which specifies the number of engines replaced and new technologies introduced) are most likely to require editing. These files correspond to the categories shown in Figure 2.2 and can be updated either annually or for each scenario run, depending on the requirements of the analysis.

The output of the model is a folder containing one csv file per forecasted year, analogous to the PRTR year, with total annual emissions and activity per ship. These can then be aggregated during post-processing to give total emissions for the entire fleet.

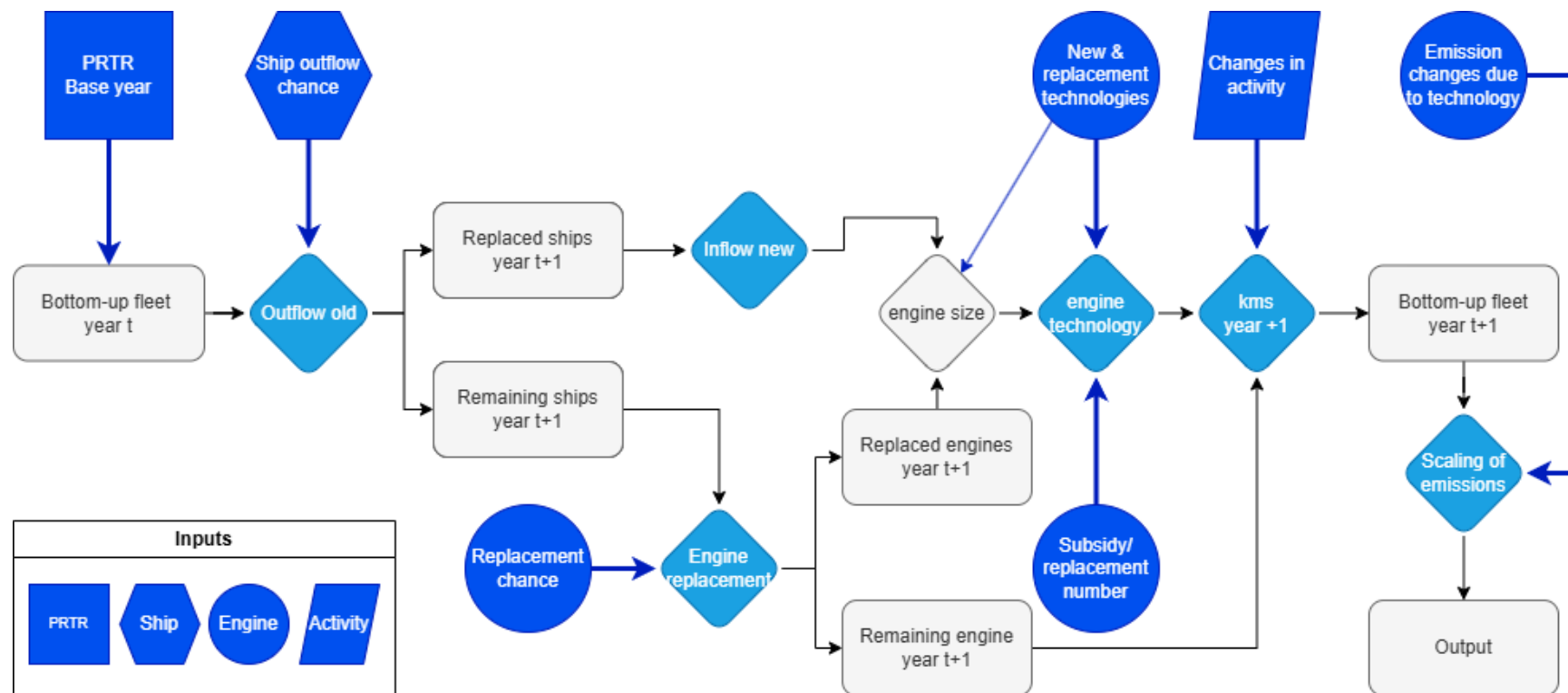


Figure 2.1: POTAMIS+ model architecture

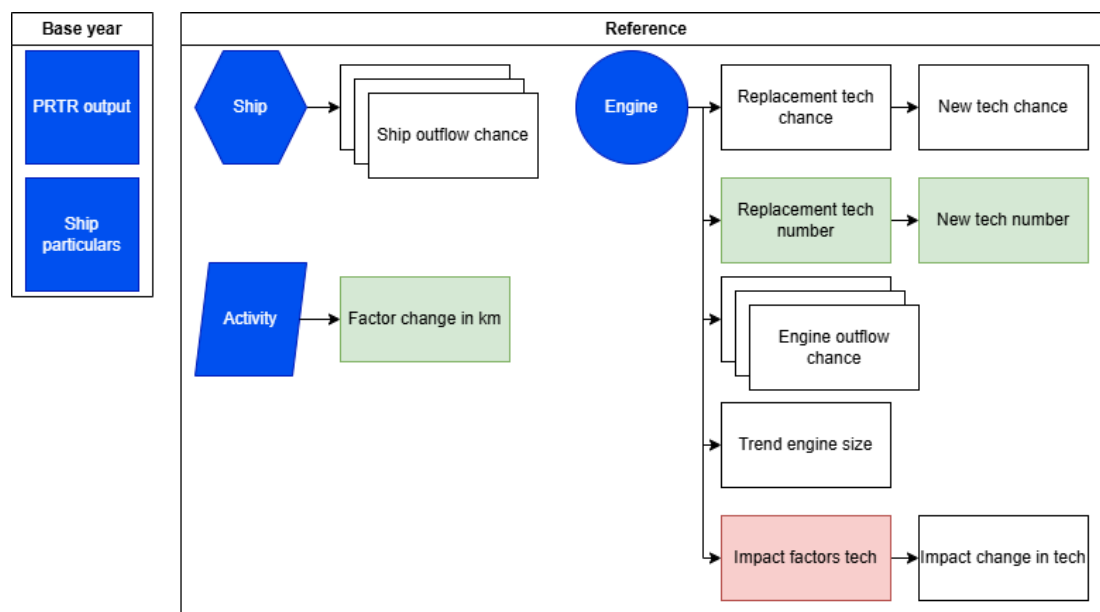


Figure 2.2: Input files used in POTAMIS+ 1.0 (blue) along with the relevant worksheets. Green worksheets indicate those that are most likely to be edited when running POTAMIS+. The red sheet has no influence on the model run, but is included to allow for increased human readability of the **Impact change in tech** worksheet (see also explanation in the next chapter).

The file and worksheet names that were used in POTAMIS+ 1.0 are noted in Table 2.1. These names can be edited in the **a_settings.py** file (see also Section 3.1.2), and are generally referred to in this manual by the name in the 'Input file' column.

Table 2.1: The specific file and worksheet names used in POTAMIS+ 1.0 (as defined in the settings file) where *PC* is one of the ship types, and *L* one of the tonnage categories used for engine replacement chances, as defined in Section 3.2.1.

Input file	Name as used in POTAMIS+ 1.0	Input file	Name as used in POTAMIS+ 1.0
<i>PRTR output</i>	summary_NL_2022_updated_v2.csv	<i>Engine</i>	invoer_instroom_motoren.xlsx
<i>Ship particulars</i>	ShipParticulars_2022_v2.csv	Replacement tech chance	vervanging_tech_kans
<i>Ship</i>	invoer_instroom_schepen.xlsx	New tech chance	nieuw_tech_kans
Ship outflow chance	schip uitval kans <i>PC</i>	Replacement tech number	vervanging_tech_aantal
Trend tonnage	trend_tonnage	New tech number	nieuw_tech_aantal
Trend length	trend_length	Engine outflow chance	motoren uitval kans <i>L</i>
<i>Activity</i>	invoer_activiteit.xlsx	Trend engine size	trend_vermogen
Factor change in km	Factor change in km	Impact change in tech	impact_verandering_techniek
		Impact factors tech	impact_factors_techniek

3 Manual

This section is split into two parts:

- Section 3.1 outlines the steps needed to run POTAMIS+
- Section 3.2 describes the input in detail, as well as how the input is used in the calculation of each forecast years

3.1 Running POTAMIS+

3.1.1 Installation

To install the software, first clone the GitHub repository using the command

```
git clone https://github.com/pbl-nl/model-POTAMIS-plus
```

After cloning, install the required packages by running

```
pip install -r requirements.txt
```

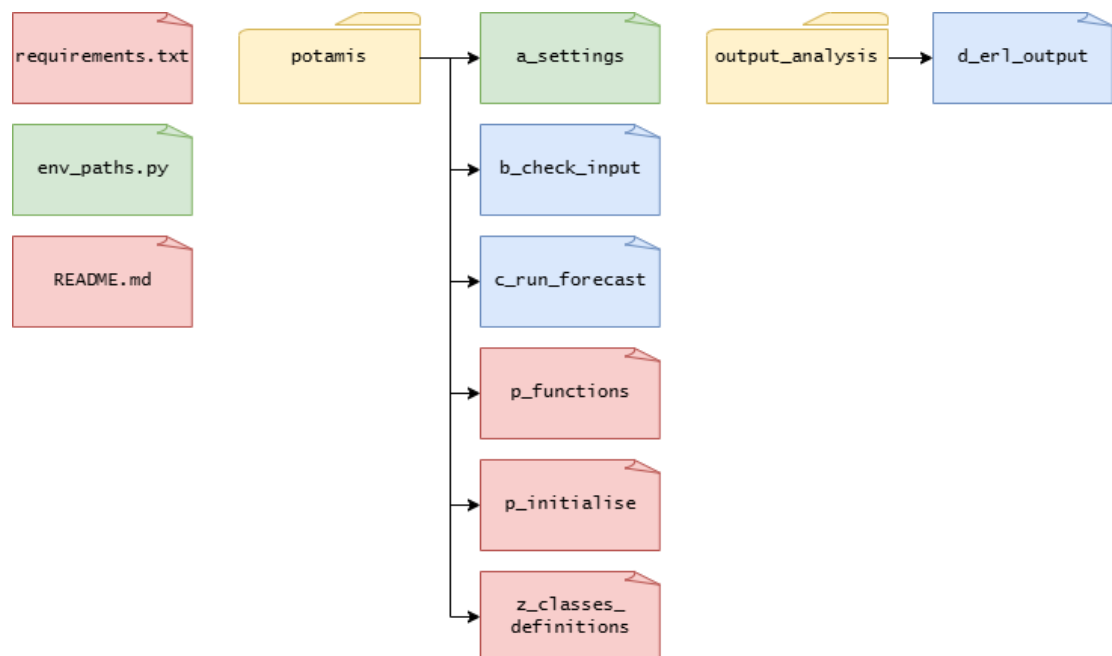


Figure 3.1: POTAMIS+ 1.0 files downloaded by cloning the GitHub repository. Red files should not be edited, green files should be edited, and blue files should be edited then used to run the calculation and post-processing.

3.1.2 Folder structure and input data

Next, adjust the paths in the `env_paths.py` file to specify where your input and output data will be stored. This path will be referred to as `IN_PATH`.

Modify the `path_runs` variable in the `potamis/a_settings.py` file to match your requirements, for example:

```
path_runs=fr'{IN_PATH}\runs\
```

Create the necessary directories within the `IN_PATH` path (see also Figure 2.2). For the "Basisjaar" directory, create for the specific input folder `IN_FOLDER` (e.g. `vastgesteld_voorgenomen`)

```
{IN_PATH}\runs\{IN_FOLDER}\Basisjaar\
```

For the "Reference" directory, create

```
{IN_PATH}\runs\{IN_FOLDER}\Reference\
```

Ensure the following files are present in the specified directories:

The *Activity* file should be located at

```
{IN_PATH}\runs\{IN_FOLDER}\Reference\invoer_activiteit.xlsx
```

The *Engine* file should be at

```
{IN_PATH}\runs\{IN_FOLDER}\Reference\invoer_instroom_motoren.xlsx
```

The *Ship* file should be at

```
{IN_PATH}\runs\{IN_FOLDER}\Reference\invoer_instroom_schepen.xlsx
```

The *Ship particulars* file should be at

```
{IN_PATH}\runs\{IN_FOLDER}\Basisjaar\ShipParticulars_2022_v2.xlsx
```

The *PRTR output* file should be at

```
{IN_PATH}\runs\{IN_FOLDER}\Basisjaar\summary_NL_2022_updated_v2.xlsx
```

3.1.3 Usage

To run the forecasting, execute the script

```
potamis\c_run_forecast.py
```

To generate the ERL output files, run

```
output_analysis\d_erl_output.py
```

The post-processing `d_erl_output.py` aggregates the fleet emissions to annual totals per forecasted year, which it exports as an Excel file. The various input parameters which can be changed are discussed below.

3.2 The input in detail

As mentioned earlier, the supplied input is divided into four categories (as was shown in Figure 2.2):

- The PRTR output of the base year
- Ship
- Engine
- Activity

In this section, these input files will be discussed in detail, as well as linked to the relevant calculation within the POTAMIS+ calculation. Furthermore, where appropriate, more information is given as to the origin of the current input values. Several of the current inputs are based on trend analyses of the four years of AIS data available in the PRTR, to be published in (de Ruiter *et al.*, 2025).

3.2.1 Aliases of relevant ship properties used in the PRTR

The PRTR makes use of a number of different aliases, acronyms and categorisations. In the following tables we reproduce the relevant ones for ship type, size, and tonnage, as defined in the PRTR and in the earlier version POTAMIS (Emissieregistratie, 2025; Hulskotte, 2021).

The inland shipping fleet is categorised using a number of different ship properties. The different ship types are noted in Table 3.1. The PRTR definition is in Dutch, and therefore an English translation is also provided. In the earlier version of POTAMIS, three tonnage categories were devised as a categorisation for trends in engine replacement (Table 3.2). One of the most common properties used to categorise a ship is its size, for which we use the 'AVV types' as defined by (Roelse *et al.*, 2002) and which are listed in Table 3.3.

Table 3.1: Ship type aliases as used in the PRTR. Note that this does not include recreational vessels.

Ship type	PRTR definition	English translation
MVS	MotorVrachtSchip	Cargo ship
MTS	MotorTankSchip	Tanker
P	Passagiersschip	Passenger ship
D	Duwstel	Pusher
C	Convoy	Convoy
O	Overig	Other
H	Hotel	Hotel

Table 3.2: Tonnage categories that are used as a dependency for the engine replacement chances

Tonnage category	Definition
L1	Tonnage ≤ 1050 t
L2	$1050 \text{ t} < \text{Tonnage} \leq 2050$ t
L3	Tonnage > 2050 t

Table 3.3: Ship size (also known as AVV type) as defined in (Roelse *et al.*, 2002), with the respective tonnage category as defined above. The width, length and draft values for ship sizes M9-M12 are taken from Rijkswaterstaat (2020).

Ship size	Description	Width [m]	Length [m]	Draft (loaded) [m]	Tonnage category
M0	Overige Motorvrachtschepen (B ≤ 5 m of L ≤ 38 m)	-	-	-	L1
M1	Spits	5.05	38.5	2.5	L1
M2	Kempenaar	6.6	50-55	2.6	L1
M3	Hagenaar	7.2	55-70	2.6	L1
M4	Dortmund-Eems (L ≤ 74)	8.2	67	2.7	L1
M5	Verlengde Dortmund (L > 74 m)	8.2	80-85	2.7	L2
M6	Rijn-Herne schip (L ≤ 86 m)	9.5	80-85	2.9	L2
M7	Verlengde Rijn-Herne schip (L > 86 m)	9.5	105	3.0	L2
M8	Groot Rijnschip	11.4	95-110	3.5	L3
BI	1 baksduwstel Europa I	9.5	85-105	3.0	L2
BII-1	1 baksduwstel Europa II	11.4	95-110	3.5	L2
BII-2L	2 baksduwstel (lang)	11.4	170-190	3.5-4.0	L3
BII-2B	2 baksduwstel (breed)	22.8	95-145	3.5-4.0	L3
BII-4	4 baksduwstel	22.8	185-195	3.5-4.0	L3
BII-6L	6 baksduwstel (lang)	22.8	270	3.5-4.0	L3
BII-6B	6 baksduwstel (breed)	34.2	195	3.5-4.0	L3
C1I	2 Spitsen lang	5.05	77-80	2.5	L1
C1b	2 Spitsen breed (L ≤ 80 m)	10.1	38.5	2.5	L1
C2I	Klasse IV + 1 Europa I bak lang	9.5	170-185	3.0	L2
C2b	Klasse IV + 1 Europa I bak breed (L ≤ 136 m)	19.0	85-105	3.0	L2
C3I	Klasse Va + 1 Europa II bak lang (L > 80 m)	11.4	170-190	3.5-4.0	L3

Ship size	Description	Width [m]	Length [m]	Draft (loaded) [m]	Tonnage category
C3b	Klasse Va + 1 Europa II bak breed (L ≤ 136m)	22.8	95-110	3.5-4.0	L3
C4	Klasse Va + 3 Europa II bakken (L > 136m)	22.8	185	3.5-4.0	L3
M9	Verlengd Groot Rijnschip (L > 111m)	11.4	135	3.5	L3
M10	Verbreed Groot Rijnschip	13.5	110	4.0	L3
M11	Verlengd en verbreed Groot Rijnschip	14.2	135	4.0	L3
M12	Rijnmax Schip	17.0	135	4.0	L3

3.2.2 Base year

The base year is the initial year on which the model run is based. As outlined in Figure 2.2 the input consists of two different input files: a *PRTR output* file, and a *Ship particulars* file. We refer the reader to the PRTR for more information on this data and how it is determined (Emissieregistratie, 2025; Geilenkirchen *et al.*, 2024).

3.2.2.1 PRTR output file

The *PRTR output* file consists of one row per ship ID observed in the relevant year in the Netherlands, containing relevant details about that ship as well as the annual activity and emissions per ship. The ship details and activity columns are listed in Table 3.4.

The activity columns include both total annual time and distance, where a distinction is made between when the ship is moving (travelling at speeds ≥ 1 knot) and when it is stationary or manoeuvring (travelling at speeds < 1 knot). The annual emissions per ship are reported in tonnes, and are also split into annual total, stationary/manoeuvring and moving emissions. A list of the relevant columns currently used in the PRTR are noted in Table 3.5. Note that the stationary emissions here only cover auxiliary engines running while the vessel is stationary, not the main engine at partial load. Auxiliary engines usually operate at steady loads for onboard power, which can lead to lower emissions per litre compared to main engines under varying loads during sailing. Also note that residual emissions are present for the “100% electric” and the “fuel cell” technologies, which originate from the assumption that there are diesel backup generators within these vessels that therefore still contribute to emissions.

Table 3.4: Ship details and activity columns produced as output from PRTR22. See also Table 3.1 and Table 3.3 for aliases for ship type and ship size.

Column	Column name used in the PRTR22
Ship ID	ship_code
Ship type	PC
Ship size	AVV_type
Moving time (in NL) [h]	T_moving_domestic
Time < 1 knot [h]	T_static_domestic
Total time in NL [h]	T_domestic

Column	Column name used in the PRTR22
Moving distance [km]	D_moving_domestic
Distance covered speed < 1 knot [km]	D_static_domestic
Total distance in NL [km]	D_domestic

Table 3.5: Pollutant columns produced as output from PRTR22 where the annual totals are in tonnes. The emission columns follow the pattern 'Emis_x', 'Emis_moving_x' and 'Emis_static_x' where x is the relevant pollutant. These prefixes are also defined in the `a_settings.py` file

Emission columns		
Emis_moving_VOS	Emis_moving_NOx	Emis_moving_CO2
Emis_static_VOS	Emis_static_NOx	Emis_static_CO2
Emis_VOS	Emis_NOx	Emis_CO2
Emis_moving_SO2	Emis_moving_NH3	Emis_moving_PM10
Emis_static_SO2	Emis_static_NH3	Emis_static_PM10
Emis_SO2	Emis_NH3	Emis_PM10
Emis_moving_N2O	Emis_moving_CO	Emis_moving_Dieselolie
Emis_static_N2O	Emis_static_CO	Emis_static_Dieselolie
Emis_N2O	Emis_CO	Emis_Dieselolie
		Emis_moving_LNG
		Emis_static_LNG
		Emis_LNG

3.2.2.2 Ship particulars file

The *Ship particulars* file contains additional information that is used in the calculation of the PRTR, but is not part of the *PRTR output* file. This includes the highly relevant build year of both vessel and engine, as well as the relevant fuel and engine size. This file also includes an Approx. year of build column, which is calculated in a data pre-processing step to approximate the year of build for ships where there is no known engine data in the PRTR. This approximation is performed by randomly selecting an engine age from the known engine ages of ships of the same age, size and/or type.¹ The Year of build engine, filled with the Approx. year of build where PRTR data is unavailable, can be used to approximate the relevant emission standard of that engine and therefore link it to the relevant technology as will be discussed later.

¹ This is done sequentially: if there are other ships with the same build year, size and type the engine age is selected randomly from this group. If this is not the case, the group of ships with the same size and type is used to select from. As a last resort, the engine age is selected randomly from all ships of the same ship type.

Table 3.6: Ship particulars columns produced as part of the PRTR22.

Column	Column name used in the PRTR22
Ship ID	ship_code
Year of build vessel	YOB_VESSEL
Year of build engine	YOB_engine
Ship type	PC
Ship size	AVV_type
Fuel	Fuel
Total main engine size	ME_kW
Tonnage category	Vervangingsprofiel
Approx. year of build	yob_engine_approx

3.2.3 Ship input file

In the current POTAMIS+, each ship in the fleet is replaced with a new ship that is identical, but with a new engine. This therefore considers as negligible the changes in total fleet size, expecting that current changes in activity may be absorbed by the current fleet. Considering the changes in fleet size observed over the last four PRTR years, as well as the currently forecasted changes in activity, this is likely to be the case (see also Chapter 4 for more discussion on this point).

3.2.3.1 Ship outflow chance

Each ship is assigned a certain probability based on its ship type and age that it will leave the fleet in a certain year. For the example in Table 3.7, the probability that a 16 year old ship will leave the fleet in 2022 is 0.9524%. For each ship type, the POTAMIS+ model uses outflow probabilities from a separate and independent [Ship outflow chance](#) sheet. These probabilities are used to determine how many, and which ships leave the fleet each year ([Ship outflow chance](#) in Figure 2.1). Note that this currently ignores the possibility for 'imported' old ships (discussed in Chapter 4).

The probabilities that were used in the ERL25 were based on analyses of ship scrappage data per ship type. Per age interval, the number of scrapped ships were divided by the total number of ships in that PRTR year. As of yet this was not sufficient to observe clear trends, and therefore averages were used to forecast these outflow probabilities into the future. In the case of passenger ships in Table 3.7 the number of scrapped ships was so low that all the available data was averaged (giving the 0.003107 shown for 2023 on). For cargo ships, the number of ships is higher, and therefore the probabilities for the three available years were averaged per age bracket for 2023 onwards. I.e. while the ship outflow probabilities for passenger ships are identical and independent of the ship age from 2023 on, the ship outflow probabilities of cargo ships vary depending on the ship age from 2023 on. For years earlier than 2023, the outflow probabilities of all ship types always depend on the ship age as this is currently observed data. The resulting influx of new ships was confirmed as feasible based on the current ship-building capacity.

Table 3.7: Example [Ship outflow chance](#) sheet for the passenger ship type. It shows the ship outflow probabilities based on the ship age and year.

Age	2020	2021	2022	2023	2024	2025	...	2040
(-0.001, 10.0]	0.00625	0.006383	0.003226	0.003107	0.003107	0.003107		0.003107
(10.0, 20.0]	0.001538	0.001754	0.009524	0.003107	0.003107	0.003107		0.003107
(20.0, 30.0]	0	0.001235	0.007229	0.003107	0.003107	0.003107		0.003107
(30.0, 40.0]	0	0.002041	0.001786	0.003107	0.003107	0.003107		0.003107
(40.0, 50.0]	0.01087	0.003704	0	0.003107	0.003107	0.003107		0.003107
...								
(110.0, 250.0]	0.000448	0.001215	0.00332	0.003107	0.003107	0.003107	...	0.003107

3.2.4 Engine input file

The engine worksheets shown in Figure 3.2 share the same three initial columns defined in `potamis/a_settings.py` as `list_reference_headings`: **Emission standard**, **Fuel** and **Technology**.

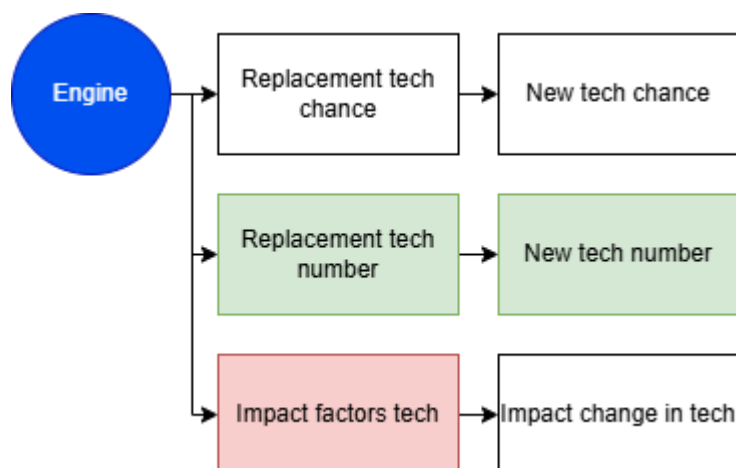


Figure 3.2: Engine input worksheets which are defined dependent on the three reference headings identifying the emission standard, fuel, and relevant technology of an engine. The two green worksheets are those that are likely to be edited when running POTAMIS+. The red sheet has no influence on the model run, but is included to allow for increased human readability of the [Impact change in tech](#) sheet.

The three reference headings identifying the emission standard, fuel, and relevant technology of an engine are used to define the different types of engines that could be installed in the ships in the inland shipping fleet. The different combinations of the three reference headings used in POTAMIS+ 1.0 are shown in Table 3.8.

Some things to note:

- For the existing PRTR fleet, the fuel and age of the engines are used to assign their emission standards.
- We refer to changes in technology for the main engine only, and not the auxiliary engine, due to the main engine being the main source of emissions in the PRTR22.
- Distinction is made in Stage V legislation between different engine sizes. Prior to this, no distinction was made.

- An “engine revision” is treated as an engine replacement event. This means that when an engine is revised, it is assigned a new technology type based on probabilities, which can lead to cases where a CCR1 engine is replaced by a CCR2 engine instead of remaining CCR1 revised. The opposite scenario can also occur. However, when considering the fleet as a whole, this effect is expected to have only a minimal impact. Note that this is nonetheless listed as a point for improvement in Chapter 4.
- Technology here refers to different cases that can affect emissions. This can include:
 - Technologies that are required by legislation
 - E.g. for the ‘2019 - 2050 stage Va 3 (130 - 300 kW)’ emission standard, engines are required to have a SCR (Selective Catalytic Reduction) aftertreatment system
 - Alternative drivetrains
 - E.g. ‘100% electric’
 - Installed aftertreatment systems
 - E.g. ‘Retrofit SCR + DPF’ where both a SCR and DPF (Diesel Particulate Filter) have been added as emission aftertreatment systems to the original CCR1 or CCR2 engine.
 - Euro VI heavy-duty engines are often outfitted with an EGR (Exhaust Gas Recirculation) aftertreatment system as well as an SCR and DPF to comply with Euro VI NO_x emission limits.
 - Tampered engines
 - In POTAMIS+ 1.0 the changes in emissions due to tampering are included as a post-processing analysis step, and not as part of the model run itself. Tampered engines are included in the model to account for real-world situations where emission control systems may be disabled or bypassed, resulting in higher emissions. The effects on emissions due to tampering are noted in the ‘Impact factors tech’ and ‘Impact change in tech’ worksheets.

Table 3.8: The different types of engines that are considered in POTAMIS+ 1.0 as defined by their inferred emission standard, fuel and technology.

Emission standard	Fuel	Technology
1900 - 1974	Diesel	
1975 - 1979	Diesel	
1980 - 1984	Diesel	
1985 - 1989	Diesel	
1990 - 1994	Diesel	
1995 - 2002	Diesel	
2003 - 2007 ccr-1	Diesel	
2003 - 2007 ccr-1	Diesel	Retrofit SCR
2003 - 2007 ccr-1	Diesel	Retrofit SCR + DPF
2003 - 2007 ccr-1	Diesel	Tampered Retrofit
2003 - 2007 ccr-1	Diesel	Stage V Retrofit SCR + DPF
2008 - 2018 ccr-2	Diesel	

Emission standard	Fuel	Technology
2008 - 2018 ccr-2	Diesel	Retrofit SCR
2008 - 2018 ccr-2	Diesel	Retrofit SCR + DPF
2008 - 2018 ccr-2	Diesel	Tampered Retrofit
2008 - 2018 ccr-2	Diesel	Stage V Retrofit SCR + DPF
2019 - 2021 ccr-2	Diesel	
2019 - 2021 ccr-2	Diesel	Retrofit SCR
2019 - 2021 ccr-2	Diesel	Retrofit SCR + DPF
2019 - 2021 ccr-2	Diesel	Tampered Retrofit
2019 - 2021 ccr-2	Diesel	Stage V Retrofit SCR + DPF
2019 - 2021 ccr-2	LNG	
2019 - 2050 stage Va 1, 2 (< 130 kW)	Diesel	
2019 - 2050 stage Va 3 (130 - 300 kW)	Diesel	SCR
2019 - 2050 Euro VI (130 - 300 kW)	Diesel	SCR + DPF + EGR
2019 - 2050 stage Va 3 (130 - 300 kW)	Diesel	diesel-electric & hybrid
2019 - 2050 stage Va 3 (130 - 300 kW)	Diesel	hybrid with battery (plugin)
2019 - 2050 stage Va 3 (130 - 300 kW)	Battery	100% electric
2019 - 2050 stage Va 3 (130 - 300 kW)	Hydrogen	fuel cell
2019 - 2050 stage Va 4 (> 300kW)	Diesel	SCR + DPF
2019 - 2050 stage Va 4 (> 300kW)	Diesel	diesel-electric & hybrid
2019 - 2050 stage Va 4 (> 300kW)	Diesel	hybrid with battery (plugin)
2019 - 2050 stage Va 4 (> 300kW)	Battery	100% electric
2019 - 2050 stage Va 4 (> 300kW)	Hydrogen	fuel cell

3.2.4.1 Replacement/New tech chance

If a ship is selected to have its engine adjusted, the technology the new engine is designated is based on a certain probability. This probability is likely to be different depending on whether the engine is being replaced (into an old ship) or whether the engine is being installed into a new ship. For this reason the two sheets [Replacement tech chance](#) and [New tech chance](#) are very similar but can be populated with different values. Table 3.9 shows an excerpt of the former where in e.g. 2035 an adjusted engine in an old ship has a 65.5% (0.655 in the 2035 column) probability of being replaced with a new Stage V engine and a 6% probability of being revised (i.e. the CCR2 rows). If the `potamis/b_check_input.py` script is run, it will check whether the probabilities per year add to 1. Note that in the current POTAMIS+ model, the engine replacement chances are independent of the current engine and its history. This is discussed in more detail in Section 4.1.

The numbers in the [New tech chance](#) sheets were estimated in the ERL25 based on expert judgment including consultation with the sector.

Table 3.9: Example of excerpt of the [Replacement tech chance](#) sheet: the numbers in the year columns indicate the probability that an engine will have that technology in that year. For each year and power range, the probabilities add up to 1.

Emission standard	Fuel	Technology	2022	...	2035
2008 - 2018 ccr-2	Diesel		0.5		0.05
2019 - 2021 ccr-2	Diesel		0.02		0.01
2019 - 2050 stage Va 1, 2 (< 130 kW)	Diesel		0.48		0.94
2019 - 2050 stage Va 3 (130 - 300 kW)	Diesel	SCR	0.48		0.655
2019 - 2050 Euro VI (130 - 300 kW)	Diesel	SCR + DPF + EGR			0.01
2019 - 2050 stage Va 3 (130 - 300 kW)	Diesel	diesel-electric & hybrid			0.075
2019 - 2050 stage Va 3 (130 - 300 kW)	Diesel	hybrid with battery (plugin)			0.2
2019 - 2050 stage Va 4 (> 300kW)	Diesel	SCR + DPF	0.48		0.665
2019 - 2050 stage Va 4 (> 300kW)	Diesel	diesel-electric & hybrid			0.075
2019 - 2050 stage Va 4 (> 300kW)	Diesel	hybrid with battery (plugin)		...	0.2

3.2.4.2 Replacement/New tech number

These sheets are the most relevant when determining the effect of engine subsidies on emissions. They were edited in the ERL25 dependent on the forecasting scenario.

In contrast to the [tech chance](#) sheets, the [tech number](#) sheets allow for a discrete number of engines of a certain technology to enter the fleet in a certain year. E.g. if we forecast that in a certain year exactly 3 new ships will enter the fleet with a hydrogen engine, then the hydrogen tech probability can be set to 0, while the hydrogen tech number can be set to 3. In the example shown in Table 3.10 we forecast that in 2025 (due to subsidies) 24 engines apply a retrofit technology, 108 ships install a new Stage V diesel engine and 8 install a 100% electric engine. Comparatively in 2026, no diesel engines are subsidised, though 1 ship installs a hydrogen fuel cell engine in addition to the 8 that install a 100% electric one.

Table 3.10: Example of excerpt of the [Replacement tech number](#) sheet

Emission standard	Fuel	Technology	..	2025	2026
2003 - 2007 ccr-1	Diesel	Stage V Retrofit SCR + DPF		7	
2008 - 2018 ccr-2	Diesel	Stage V Retrofit SCR + DPF		17	
2019 - 2050 stage Va 4 (> 300kW)	Diesel	SCR + DPF		108	
2019 - 2050 stage Va 4 (> 300kW)	Battery	100% electric		8	8
2019 - 2050 stage Va 4 (> 300kW)	Hydrogen	fuel cell	...		1

If the [tech chance](#) for a certain subsidised technology in a certain year is not set to 0 (as is the case for e.g. Stage V diesel engines), then there is a chance that an engine that is selected to be subsidised will already have the subsidised technology. This therefore allows for the cases where a ship owner was intending to replace their engine anyway, but applied for subsidy to do so. The fraction of subsidised engine replacements that fall into this category is of specific interest in the evaluation of the effectivity of subsidies, and is discussed further in Chapter 4.

3.2.4.3 Engine outflow chance

The probability that an engine of an existing ship is replaced or revised is determined by both the [Engine outflow chance](#) sheets as well as the **outflow scaling factor**.

In the ERL25 the engine adjustment (i.e. replaced or revised) probabilities were based on the Weibull functions calculated in earlier work outlined in Section 3.3 of (Hulskotte, 2021).² Depending on three tonnage categories (defined in Table 3.2), the age of the engine, and the calculation year, there is a certain probability of an engine being adjusted. For example, in Table 3.11, an engine that is 2 years old in 2025 will have an engine outflow probability of 1.4%.

Table 3.11: Example of the [Engine outflow chance](#) sheet

Age	2022	2023	2024	2025	...	2030
(-0.001, 1.0]	0.013	0.013	0.013	0.013		0.014
(1.0, 2.0]	0.014	0.014	0.014	0.014		0.015
(2.0, 3.0]	0.015	0.015	0.015	0.015		0.016
(3.0, 4.0]	0.016	0.016	0.016	0.016		0.017
(4.0, 5.0]	0.017	0.017	0.017	0.017		0.018
(5.0, 6.0]	0.018	0.018	0.018	0.018		0.019
(6.0, 7.0]	0.019	0.019	0.019	0.019		0.020
(7.0, 8.0]	0.020	0.020	0.020	0.020		0.021
(8.0, 9.0]	0.021	0.021	0.021	0.021		0.022
(9.0, 10.0]	0.022	0.022	0.022	0.022		0.024
...					...	
(30.0, 199.0]	0.050	0.050	0.050	0.050...		0.052

To provide an easily accessible method of globally increasing or decreasing the total number of engines that are replaced per year, the **outflow scaling factor** can be used. This scaling factor is multiplied with the probabilities in the [Engine outflow chance](#) sheet to increase or decrease the probability of engine outflow for all ages and ship types. For the example above, if the **outflow scaling factor** = 0.3 is used, then $0.3 \times 0.14 = 0.0042$ or 0.42%. In the ERL25 the **outflow scaling factor** was set to 0.55 such that the yearly number of engine replacements did not exceed the current capacity for the installation of replacement engines.

3.2.4.4 Trend engine size

The data in the [Trend engine size](#) sheet are used to apply a linear trend function to engine size values over time. This trend is defined by two coefficients, a and b , which represent a linear relationship of the form $a \cdot year + b$. The function calculates the ratio between the trend value in the target year and that in the reference year, and this ratio is then used to scale the engine size accordingly. This allows for consistent adjustment of engine size data across different years. An example of the [Trend engine size](#) sheet is shown in Table 3.12.

² This work was based on the investigation of ship insurance data as to how many ships had had their engines replaced. Data was not available as to *how often* engines had been replaced, which is more relevant for forecasting in this manner. Work is ongoing within the PRTR to obtain data which can provide time-dependent engine ages of the IWT fleet.

Equation 3.1: Calculation of new engine sizes

$$engine\ size_{t+1} = \frac{a \cdot year_{t+1} + b}{a \cdot year_t + b} \times engine\ size_t$$

with

- a and b being the coefficients from the fit provided in the trend engine size sheet
- $engine\ size_t$ the engine size of the ship leaving the fleet in $year_{t+1}$,
- $engine\ size_{t+1}$ the engine size of the new ship entering the fleet

Table 3.12: Example of the [Trend engine size](#) sheet

Ship type	a	B
MVS	0	1301
MTS	0	1205
...		
H	0	1673

In the ERL25 these trends were determined using a linear regression of the engine data available in the [Ship particulars](#) list of the PRTR24, for engines built in the last twenty years (de Ruiter *et al.*, 2025). In this analysis, none of ship types had a significant yearly dependence (hence 0 in the a column of Table 3.12). There is therefore also no concrete influence on annual emissions (see also Chapter 4).

3.2.4.5 Impact factors tech

The [Impact factors tech](#) sheet is used to increase the readability and aid with the interpretation of the [Impact change in tech](#) sheet and to give insight into how the various technologies relate to the current 'default' diesel engine emissions. It is not actually used in the POTAMIS+ 1.0 calculation, though this may be changed in a future version (see also Chapter 4). Table 3.13 shows an excerpt demonstrating the effect of retrofit technology on a CCR1 engine. The emissions are noted in g/L fuel per engine type (i.e. per **Emission standard, Fuel** and **Technology** combination) available in the PRTR and indicated in the Reference column via the prefix 'ref': CCR1 is ref. 8 in Table 3.13. The effects of retrofit technology on the NO_x-emissions are shown by the rows containing R8 in the Reference column: in this example Retrofit SCR technology leads to 60% lower NO_x-emissions (the multiplication factor is 0.4) compared to a 80% decrease using Stage V Retrofit SCR + DPF (multiplication factor 0.2). References for the values used in the [Impact factors tech](#) and [Impact change in tech](#) sheets are provided within the respective sheets themselves.

Table 3.13: Example of an excerpt of the [Impact factors tech](#) sheet

Emission standard	...	Technology	...	Emis_moving_ NO _x _g_L	Emis_static_ NO _x _g_L	...	Reference
2003 - 2007 ccr-1				36.541	18.027		ref. 8
2003 - 2007 ccr-1		Retrofit SCR		0.4	0.4		R8
2003 - 2007 ccr-1		Retrofit SCR + DPF		0.4	0.4		R8
2003 - 2007 ccr-1		Tampered Retrofit		1	1		R8
2003 - 2007 ccr-1		Stage V Retrofit SCR + DPF		0.2	0.2		R8

The NO_x-emissions impact factor (in g/L fuel) of a CCR1 engine with Retrofit SCR is therefore
 $0.4 \times 36.541 = 14.616$
 and it is these calculated values that are noted in the [Impact change in tech](#) sheet.

The reference values ('ref' in Table 3.13) for the ERL25 were calculated using the PRTR24: per ship the annual pollutant emissions are converted to emissions in g/L fuel, then averaged per engine type (**Emission standard**, **Fuel** and **Technology** combination). These annual averages were also checked to ensure that they reflected current knowledge based on engine test data. The current multiplication factors are based on measurements, engine tests, and sector consultation.

3.2.4.6 Impact change in tech

The impact factors for the different engine types are used to determine changes in emissions after adjusting an engine. The impact factors are currently calculated in a pre-processing step as outlined in the section above: Table 3.14 is the excerpt from the [Impact change in tech](#) sheet corresponding to the [Impact factors tech](#) shown in Table 3.13.

Table 3.14: Example of an excerpt of the [Impact change in tech](#) sheet

Emission standard	...	Technology	...	Emis_moving_ NOx_g_L	Emis_static_ NOx_g_L	...	Reference
2003 - 2007 ccr-1				36.541	18.027		ref. 8
2003 - 2007 ccr-1		Retrofit SCR		14.616	7.211		R8
2003 - 2007 ccr-1		Retrofit SCR + DPF		14.616	7.211		R8
2003 - 2007 ccr-1		Tampered Retrofit		36.541	18.027		R8
2003 - 2007 ccr-1		Stage V Retrofit SCR + DPF		7.308	3.605		R8

The emission impact factors are used to calculate changes in emissions using Equation 3.2:

Equation 3.2: Emission projection formula

$$Emission_{t+1} \left[\frac{\text{tonne}}{\text{km}} \right] = \frac{IF_{t+1}}{IF_t} \times Emission_t \left[\frac{\text{tonne}}{\text{km}} \right]$$

with

$Emission_{t+1} \left[\frac{\text{tonne}}{\text{km}} \right]$ the new emission factor per ship due to changed technology in tonne/km,
 IF_{t+1} the impact factor of the new technology, as per the [Impact change in tech](#) sheet,
 IF_t the impact factor of the old technology, as per the [Impact change in tech](#) sheet,
 $Emission_t \left[\frac{\text{tonne}}{\text{km}} \right]$ the old emission factor in tonne/km,

In the case of where a CCR1 engine is retrofitted with an SCR aftertreatment system, the new NO_x emission factor would be

$$NO_{x,t+1} \left[\frac{\text{tonne}}{\text{km}} \right] = \frac{14.616}{36.541} \times NO_{x,t} \left[\frac{\text{tonne}}{\text{km}} \right]$$

as per Table 3.14.

The total new annual emissions would therefore be

Equation 3.3: Calculation of total new annual emissions

$$Emission_{t+1}[\text{tonne}] = \frac{IF_{t+1}}{IF_t} \times Emission_t \left[\frac{\text{tonne}}{\text{km}} \right] \times d_{t+1}$$

with

$Emission_{t+1}[\text{tonne}]$ the total annual emissions in year $t + 1$, in tonnes, and
 d_{t+1} the total annual distance travelled in year $t + 1$ (discussed in the next section).

This equation also holds for ships where the technology has not been changed, in that case $IF_{t+1} = IF_t$.

3.2.5 Activity input file

The [Activity](#) input file contains the forecasted year-on-year change in goods throughput through the Netherlands. This change per goods category is forecasted then converted to the expected change per ship size using the BasGoed model and was supplied by PBL for the different scenarios.

The year-on-year change is calculated in a pre-processing step using the BasGoed output data per ship size for the different scenarios forecasted in the ERL25. The [Activity](#) input is one of the primary inputs to be edited.

Within the ERL25 the expected growth in transported goods was very stable over the forecasting period. It was therefore assumed that this would not lead to a large influx in much larger ships nor large changes in load fraction (see also Chapter 4). For this reason, an increase in transported goods is currently assumed to directly correlate with an increase in annual kilometres:³ This assumption implicitly considers that shifts in types of goods (e.g., less coal and oil due to climate policies) do not significantly affect vessel size or load factor, and that more voluminous goods will be accommodated within the existing fleet capacity rather than requiring larger ships.

Equation 3.4: Distance adjustment based on activity change

$$d_{t+1} = \Delta_{activity} \times d_t$$

with

d_{t+1} the total annual distance travelled in year $t + 1$,
 d_t the total annual distance travelled in year t , and
 $\Delta_{activity}$ the year-on-year change in activity, as shown in Table 3.15.

For example, if there is a 6% decrease in activity for a B03 ship from year t to year $t + 1$, then the annual distance in year $t + 1$ for that ship will be

$$d_{t+1} = 0.94 \times d_t .$$

³ This assumption should be investigated further when PRTR load information becomes available (as discussed in Chapter 4).

Table 3.15: Example of the activity input sheet where year-on-year changes in activity are noted per ship size.

Category	2023	2024	2025	2026	...	2040
B01	0.942503	1.04367	1.013282	1.013257		1.009246
B02	0.934447	1.034752	1.004626	1.004603		1.000845
B03	0.94286	1.044062	1.013659	1.013631		0.998039
B04	0.931026	1.030919	1.000859	1.000791		1.001583
BI	0.931601	1.031566	1.001496	1.001438		1.001954
...						
M9	0.935426	1.035844	1.005694	1.005679	...	1.004414

3.2.6 The distance scaling factor

This is an empirically determined scaling factor which is used to weigh the importance of the cumulative distance on the probability of an engine being replaced. The cumulative distance is the approximate total distance travelled by the ship since either the base year, or since the engine was last replaced. As discussed further in Chapter 4, distance is currently used instead of active engine hours due to the data that is currently available.

Note that this is calculated annually from the domestic time fraction:

Equation 3.5: The cumulative distance per engine

$$d_{cumulative} = \sum_t \left(\frac{T_{year,t}}{T_{domestic}} \times d_{domestic} \right)$$

with

- $d_{cumulative}$ the inferred cumulative distance,
- t the calculation year,
- $T_{domestic}$ the total annual time in the Netherlands,
- $T_{year,t}$ the number of hours in year t ,
- $d_{domestic}$ the total annual distance in the Netherlands in year t .

Equation 3.6: The weighing using the distance scaling factor

$$weighing\ factor = p_{age, i} \times \left(\frac{d_{cumulative,i}}{d_{cumulative,all,p75}} \right)^\alpha$$

with

- α the empirically determined distance scaling factor
- $p_{age, i}$ the probability of replacement due to age for the engine in ship i
- $d_{cumulative,i}$ the approximated cumulative distance for the engine in ship i
- $d_{cumulative,all,p75}$ the 75th percentile of the $d_{cumulative}$ observed in the fleet for that year

Setting the **distance scaling factor** to 0 will remove the impact of the cumulative distance on which engines are replaced. In the ERL25, $\alpha = 10$ was used.

4 Caveats and points for future development

POTAMIS+ 1.0 is based on the current implementation of the PRTR. Because of this, there are a number of differences in the scope of POTAMIS+ with respect to the earlier POTAMIS. This also results in a number of different points for development for both the PRTR and POTAMIS+. In Figure 4.1 at the end of this chapter, an expanded architecture shows a number of these points.

In the current POTAMIS+ a conscious choice was made to calculate changing emissions only based on annual totals, and not to take into account detailed changes in emissions due to e.g. changing draught or changing sailing speeds. We are of the opinion that considering the current uncertainties at play within the modelling (and forecasting) of inland shipping emissions, including such measures would only create a false sense of accuracy. Furthermore, wide-ranging real-world emission data is often not available to allow for the quantification of detailed emission changes.

This choice has also limited the types of measures which can currently be forecasted to changes in activity (per AVV type) and technology (incl. via subsidies). These were the only measures that were of significance for the ERL25 and therefore the current implementation of POTAMIS+ 1.0 was considered sufficient to meet the objectives of that study.

4.1 Engine

One of the largest uncertainties in the current PRTR (and therefore also POTAMIS+) are the engines installed per ship.

This therefore leads to a number of different points that should be investigated with regards to engines:

- For the existing PRTR fleet, the fuel and age of the engines are used to determine their emission standards. However, as an increasing number of ships install a variation of Stage V or alternative (hybrid) drive train, it will become increasingly important to have precise data on the installed engine: fuel and age will no longer be sufficient to assign the correct technology. A correct and detailed inventory of installed engines and their technology (fuel, size, drivetrain) remains an ongoing challenge within the PRTR.
- Update of replacement probabilities
 - An update of the current replacement probabilities based on the earlier POTAMIS can largely be performed within the scope of the current model version as they are primarily dependent input parameters.
 - The current dependence of replacement probability on the (inferred) kilometres an engine has travelled is highly dependent on expert insight. More data is needed to quantify this relationship, as well as (likely) make distinctions to different ship types, sizes, or ship ages.
 - It is highly likely that for some ship types and sizes the total active engine hours would be more relevant than the inferred kilometres for replacement probabilities.

The annual moving hours would therefore need to be included in the year-by-year calculations. Upon quantification of the relationship between total engine hours and replacement probability (likely needing e.g. interviews with the sector), this could also be implemented.

- Implementation of multiple engines per ship
 - At the moment the PRTR only includes the total power per ship. The accuracy of these numbers is unsure due to the lack of information with regards to what is installed on board. If the PRTR can access information with respect to how many engines a ship has, this could also be included.
 - Replacement probabilities per ship type or size.
 - Replacement rate from one engine to two.
 - Whether there are ship types that are more likely to have multiple engines.
- Engine history
 - In the earlier POTAMIS it was assumed that in the forecasting period engines would only be replaced once. Although the current POTAMIS+ now has the flexibility to allow for multiple engine replacements over the forecasting period, it does not yet take into account the history of a ship (e.g. guaranteeing that a CCR0 engine is replaced with a Stage V engine, or that engine revisions are limited to a certain number of times).
 - This currently forms one of the weaknesses of the current modelling approach: it is possible that e.g. a CCR1 engine is replaced by a CCR2 engine, which would have been intended to indicate the revision of a CCR2 engine but in this case is not entirely accurate. However, considering the current uncertainties in installed engine ages as well as the much more significant impact of replacement with a Stage V engine, it was concluded that, in the calculation of the ERL25, this weakness was acceptable.

4.2 Activity

A significant difference in scope between POTAMIS and POTAMIS+ is the unit in which changes in activity/growth is determined. In POTAMIS, this was applied to the annually expected ton.km that would be sailed within the Netherlands. However, when the PRTR methodology moved from ton.km to the AIS-based annual kilometres, the relevant load based information was no longer available.

The following points outline current assumptions and potential improvements related to activity forecasting in POTAMIS+:

- It is currently assumed that an increase in transport demand (per AVV type) is linearly correlated with an increase in annual ship-kilometres. This is based on the assumption that no great change in the load factor of ships will occur. Considering the forecasted change in activity, as well as there being no current evidence for the changing sizes of ships (as discussed below), we consider this a valid assumption at this time.
- Include load-based calculations when made available within the PRTR
 - To allow for a better alignment in the case of highly volatile transport demand, it would be necessary to include the annual tonnage per ship, which can then be linked to a total fleet capacity.
 - This is likely also relevant when considering different scenarios of water depth in the case of increasing drought.
- Changing activity based on age
 - There is evidence for a decrease in annual kilometres based on ship age, which could be implemented per ship type.

- Due to the uncertainty in installed engine ages, no investigation has been performed as to whether there is a relationship between engine age and annual kilometres. If this data is made available it could also be implemented.
- Streamline calculation of the [Activity](#) file to allow for direct input from BasGoed.

4.3 Fleet

In the current POTAMIS+, each ship in the fleet is replaced with a new ship that is similar, but with a new engine. This therefore ignores the fact that the total fleet size may change, and that a ship which does not visit the Netherlands in one year, may return several years later (i.e. it leaves the fleet but when it returns, it returns as an old ship instead of a new one).

The following points summarise current limitations in fleet modelling and potential improvements for future versions of POTAMIS+:

- The initial intention when building POTAMIS+1.0 was to vary the properties of the new ship compared to the old one (e.g. changes in tonnage, length or depth). However, trend analyses performed on the ships in the PRTR that were built over the last 20 years showed no clear trends (de Ruiter *et al.*, 2025). For most ship types, regression analyses suggested that these properties were not significantly changing over time. We recommend that if future analyses show more obvious trends, these also be included (along with a quantified relationship with the associated changes in emissions).
- Increase or decrease in the total number of ships dependent on fleet capacity and transport demand.
- Change number of ships and the fleet composition based on transport demand for different freight categories.
- Inflow of old ships that have not been detected in the Netherlands in a prior year (i.e. import from abroad).
- Investigation of long-term trends in the fleet observed in the Netherlands.
 - Improved quantification of outflow probabilities
 - Quantification of replacement rates (e.g. two smaller 60 T ships being replaced by one larger 100 T)

4.4 Emissions and energy efficiency

Emissions are calculated based on the output of the PRTR. However, many of the new technologies that are expected to lead to significant decreases in emissions have not been extensively monitored for real-world emissions. When more data becomes available, the emission factors used within the PRTR can be updated for these new technologies at which point they can also be updated here.

- Energy efficiency of newer drivetrains
 - As mentioned above, there is not yet sufficient real-world data monitoring data of alternative drivetrains. If this becomes available, this can also be used to implement changes in energy efficiency. POTAMIS+ 1.0 currently follows the PRTR in assuming that there is no increase in energy efficiency for e.g. hybrids and plug-ins.
- Streamline calculation of emissions from [PRTR output](#) to [Impact change in tech](#) sheet
- Update multiplication factors in [Impact factors tech](#) as more measurement data becomes available
- Time-dependent tampering for all technologies. This is currently calculated as a post-processing step due to the uncertainty in how often tampering occurs.

- Especially for Stage V technologies it is likely that if a larger engine is installed than explicitly needed for a particular use case, this can lead to higher emissions (de Ruiter *et al.*, 2023). This remark refers both to the current PRTR situation, where the actual installed engine power is often unknown, and to future uncertainty regarding shipowners' choices of engine size. It is currently unclear as to how much this would affect total annual emissions, especially in light of the other uncertainties at play (this is likely significantly less than e.g. the uncertainties regarding load). Furthermore, current trend analyses showed no significant increase in engine size over the last 20 years (de Ruiter *et al.*, 2025). If data becomes available that demonstrates the contrary, and a quantitative relationship is available for the increased emissions, this should be implemented.

4.5 Subsidies

One of the largest measures that is currently implemented in inland shipping are the engine replacement subsidies. With the POTAMIS+ the impact of these subsidies can be investigated at a more detailed level, as the actual annual kilometres per ship that has an engine replacement is forecasted.

- Subsidies can only be applied for by Dutch ships. Within the PRTR, the flag that a ship is sailed under is currently not documented, and therefore ship cannot be filtered to comply with this. When the flag information is available, this filter can be implemented.
- There is currently little information available as to whether certain ship types or size are more likely to apply for a subsidy. For this reason, subsidy allocation is random. This can be adjusted when more information becomes available.
- It is highly likely that ship owners due to replace their engines choose to apply for subsidy to do so (Stroeken *et al.*, 2024). The current POTAMIS+ implicitly takes this into account by how subsidised engines are selected. However, it could also be useful to allow for a so-called 'free-rider' percentage as an input parameter.

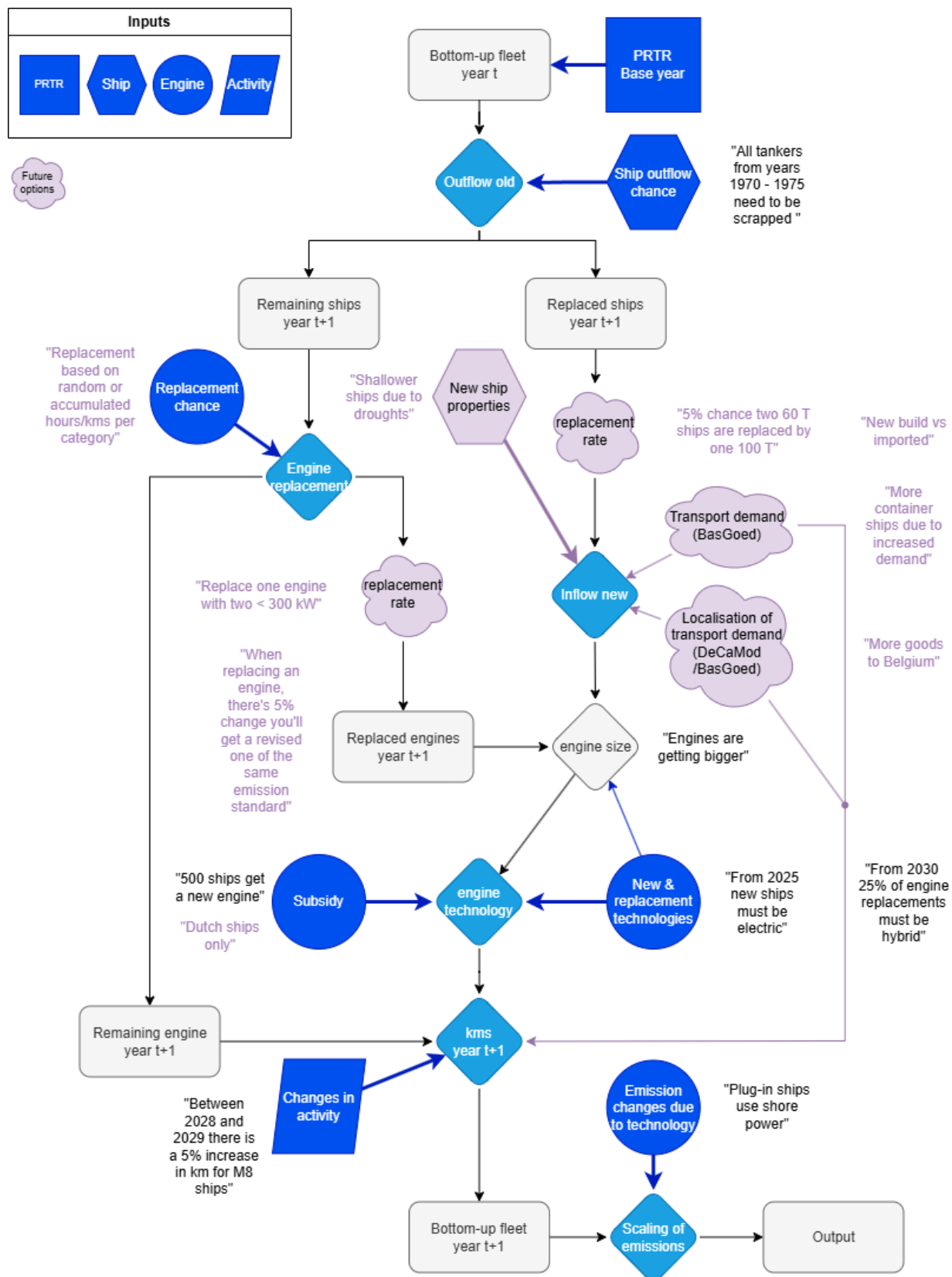


Figure 4.1: Proposed architecture of POTAMIS+ including several future options (in purple) as well as the various situations that could be investigated (where purple again indicates future possibilities).

5 Technical description

5.1 Validation

In this section we describe the various validation steps of the POTAMIS+ code that have been performed.

5.1.1 Initialisation

The fleet is initialised using the `initial_run` function located in the `potamis/p_initialise.py` module.

This function is responsible for loading, merging, and preparing the baseline fleet data by combining two input files:

- 1.) Ship particulars: [ShipParticulars_2022_v2.csv](#)
- 2.) Activity and emissions data: [summary_NL_2022_updated_v2.csv](#)

The function performs several preprocessing steps, including data duplicate handling, data cleaning, and adding additional technical attributes. The merged dataset forms the foundation for subsequent modelling and analysis.

To ensure the correctness and robustness of the fleet initialisation process, the following unit tests have been developed and implemented in `validation/test_initial_run.py`.

5.1.1.1 Unit tests

5.1.1.1.1 Correct merging of input files

Test: `test_merge_correctness`

Case 4.1.1.1.1	
Description	Verifies that the ship particulars and emissions data are merged accurately using the ship identifier.
Expected result	Merged output including only ships present in both datasets, excluding specified columns.
Input	Two DataFrames: one with ship data, one with emissions data; merge key is <code>ship_code</code> . Mimicking <code>ShipParticulars_2022_v2.csv</code> , <code>summary_NL_2022_updated_v2.csv</code>
Result	OK

5.1.1.1.2 Duplicate handling

Test: **test_duplicate_handling**

Case 4.1.1.1.2	
Description	Ensures that duplicate ship entries are removed by keeping the most relevant records based on CO ₂ emissions.
Expected result	Merged output containing unique ships, retaining the row with highest CO ₂ per ship.
Input	Two DataFrames: one with ship data, one with emissions data; merge key is ship_code. Mimicking ShipParticulars_2022_v2.csv, summary_NL_2022_updated_v2.csv
Result	OK

5.1.1.1.3 Year of build estimation

Test: **test_fill_yob_vessel**

Case 4.1.1.1.3	
Description	Confirms that missing ship year-of-build values are correctly filled using estimated values.
Expected result	Output has missing values in yob_ship filled from yob_ship_estimated; original DataFrame remains unchanged.
Input	DataFrame with columns for actual and estimated vessel year of build. Mimicking ShipParticulars_2022_v2.csv, summary_NL_2022_updated_v2.csv
Result	OK

5.1.1.1.4 Engine year estimation

Test: **test_fill_yob_engine**

Case 4.1.1.1.4	
Description	Validates that missing or implausible engine build years are replaced using estimated or corrected values.
Expected result	Output has valid yob_engine values, corrected using estimated values, ship year, or a minimum threshold.
Input	DataFrame with actual, estimated engine year of build, and ship year of build. Mimicking ShipParticulars_2022_v2.csv, summary_NL_2022_updated_v2.csv
Result	OK

5.1.1.1.5 Engine power imputation

Test: **test_fill_engine_power**

Case 4.1.1.1.5	
Description	Checks that missing engine power values are filled using representative values from similar ships.
Expected result	Output has no zero or missing engine power values; values are filled from the same group or fallback values.
Input	DataFrame with engine power and a grouping property used for imputation. Mimicking ShipParticulars_2022_v2.csv, summary_NL_2022_updated_v2.csv
Result	OK

5.1.1.1.6 Technology impact factor assignment

Test: **test_fill_impact_factor**

Case 4.1.1.1.6	
Description	Ensures that emission impact factors are correctly assigned based on ship characteristics and technology.
Expected result	Output includes relevant impact factor columns; irrelevant columns are excluded.
Input	Two DataFrames: one with inflow data, one with impact factor data; merged on fuel, technology, and emission standard. Mimicking ShipParticulars_2022_v2.csv, summary_NL_2022_updated_v2.csv
Result	OK

5.1.2 Outflow ships

The **outflow_age** function within the **potamis.p_functions** module is responsible for simulating the annual replacement of ships. This function determines which ships are phased out and replaced based on age, type, and predefined scaling factors.

Since the replacement of ships is partly based on random choice, the approach for the unit test for this function significantly differs from the unit tests introduced in the previous section. The unit test developed in this section therefore relies on an independent function which includes both deterministic checks and stochastic simulations. The unit test can be found in **validation/test_schepen.py**.

5.1.2.1 Unit test simulation setup

5.1.2.1.1 Input data:

Ship replacement scaling factors are loaded from [invoer_instroom_schepen_scale.xlsx](#). For the base year, the fleet is initialized using the output of **initial_run**. For subsequent years, the simulation uses the output of the previous year's **outflow_age** run as input.

5.1.2.1.2 Replacement logic:

The tests cover the years 2022 to 2027, simulating annual ship aging and replacement. For each year, ship ages are calculated. Ships are replaced based on their age, type, and the corresponding scale values from the input file.

5.1.2.1.3 Monte Carlo simulation

To account for variability and uncertainty in ship replacement:

- The simulation is repeated 1,000 times per year.
- For each ship type and year, the mean and standard deviation of ship counts are computed.

5.1.2.1.4 Validation criteria

The output of the **p_functions.outflow_age** function is compared against the Monte Carlo simulation results. For each year and ship type, the actual output is expected to fall within the mean ± 2 standard deviations of the simulated predictions.

This range corresponds to a 95% confidence interval, ensuring that the model's predictions align with expected statistical behaviour.

Furthermore it is tested if higher/lower scaling values within the [invoer_instroom_schepen_scale.xlsx](#) file lead to more/less ships being replaced.

5.1.2.2 Unit test results

5.1.2.2.1 Number of replaced ships per type in expected range

Test: **test_n_ships_per_type**

Case 4.1.2.2.1	
Description	Checks the number of replaced ships per ship type for a given year
Expected result	Number of replaced ships per type and per year should fall within expected results from Monte Carlo simulations
Input	invoer_instroom_schepen_scale.xlsx
Result	OK

Below is an example output of the unit test, that checks for each ship type (PC) if the actual value is within the expected range of the Monte Carlo simulation:

```

Checking year 2023
Year 2023, PC C: actual 0 in range [-0.48, 0.64]
Year 2023, PC D: actual 5 in range [0.01, 8.18]
Year 2023, PC H: actual 1 in range [-0.96, 3.34]
Year 2023, PC MTS: actual 3 in range [-0.09, 8.60]
Year 2023, PC MVS: actual 18 in range [7.99, 24.02]
Year 2023, PC O: actual 3 in range [-0.92, 3.85]
Year 2023, PC P: actual 4 in range [-0.27, 7.03]
Checking year 2024
Year 2024, PC C: actual 0 in range [-0.46, 0.62]
Year 2024, PC D: actual 5 in range [0.05, 8.07]
Year 2024, PC H: actual 2 in range [-1.04, 3.43]
Year 2024, PC MTS: actual 5 in range [0.28, 8.44]
Year 2024, PC MVS: actual 14 in range [8.10, 24.46]
Year 2024, PC O: actual 3 in range [-0.97, 3.73]
Year 2024, PC P: actual 2 in range [-0.43, 7.12]
Checking year 2025
Year 2025, PC C: actual 0 in range [-0.50, 0.69]
Year 2025, PC D: actual 4 in range [0.11, 8.05]
Year 2025, PC H: actual 3 in range [-0.95, 3.32]
Year 2025, PC MTS: actual 6 in range [0.36, 8.63]
Year 2025, PC MVS: actual 17 in range [8.55, 24.83]
Year 2025, PC O: actual 2 in range [-0.90, 3.64]
Year 2025, PC P: actual 4 in range [-0.20, 7.14]
Checking year 2026
Year 2026, PC C: actual 0 in range [-0.48, 0.63]
Year 2026, PC D: actual 3 in range [-0.11, 7.81]
Year 2026, PC H: actual 1 in range [-0.97, 3.41]
Year 2026, PC MTS: actual 1 in range [0.60, 9.13]
Year 2026, PC MVS: actual 14 in range [8.47, 25.05]
Year 2026, PC O: actual 3 in range [-0.97, 3.91]
Year 2026, PC P: actual 5 in range [-0.35, 6.90]
Checking year 2027
Year 2027, PC C: actual 0 in range [-0.47, 0.62]
Year 2027, PC D: actual 4 in range [0.01, 8.01]
Year 2027, PC H: actual 1 in range [-0.97, 3.22]

```

Year 2027, PC MTS: actual 3 in range [0.40, 9.62]
Year 2027, PC MVS: actual 17 in range [8.95, 25.35]
Year 2027, PC O: actual 2 in range [-0.93, 3.71]
Year 2027, PC P: actual 3 in range [-0.25, 7.14]

100% of the actual values fall within the expected range.

5.1.2.2.2 Number of replaced ships per type scaling

Test: **Manual check**

Case 4.1.2.2.2	
Description	Checks if scale factors have expected impact on the number of replaced ships per ship type for a given year
Expected result	Number of replaced ships per type and per year should increase for increasing scale factor and vice versa
Input	invoer_instroom_schepen_scale.xlsx
Result	OK

An example of this scaling behaviour is shown below. The table show the number of replaced ships for a given year for each ship type and two different scaling factors (the same scaling factor was used across all ship types for this test).

Scaling	Ship type						
	MVS	MTS	P	D	O	H	C
0.1	381	134	100	93	53	26	6
0.2	766	290	210	172	91	56	13

The fact that a scaling factor of 0.1 to 0.2 does not result in exactly twice as many replaced ships is due to the model's partially random selection process.

5.1.3 Outflow engines

The outflow function within the **potamis.p_functions** module is designed to simulate the annual replacement of ship engines. This function identifies which engines are phased out based on vessel age, cumulative distance travelled, and predefined failure probabilities.

Similarly to the previous Section, the unit test for this function incorporates both deterministic checks and Monte Carlo simulations to validate its output. The unit test can be found it **validation/test_outflow.py**.

5.1.3.1 Unit test simulation setup

5.1.3.1.1 Input data:

Engine replacement probabilities are loaded from the **motoren uitval kans** sheets (L1, L2, L3) within the **invoer_instroom_motoren_vv_no_srvb.xlsx** file. The simulation uses the output of **p_functions.outflow_age** as the input fleet for each year.

5.1.3.1.2 Replacement logic:

The test covers the years 2022 to 2027. For each year, ships are evaluated for engine replacement based on age and cumulative distance travelled.

5.1.3.1.3 Monte Carlo simulation

To account for variability and uncertainty in ship replacement:

- The engine replacement simulation is repeated 100 times per year.
- For each year, the mean and standard deviation of replaced engine counts per ship type (PC) and the total cumulative distance are calculated.

5.1.3.1.4 Validation criteria

The actual output of `p_functions.outflow` is compared against the simulation results. For each year and ship type, the actual number of replaced engines must fall within the mean ± 2 standard deviations of the simulated predictions. Similarly, the total cumulative distance of replaced ships is validated against the same statistical range. This approach ensures a 95% confidence level in the agreement between predicted and actual outcomes.

5.1.3.2 Unit test results

5.1.3.2.1 Number of ships with new engine

Test: `test_outflow`

Case 4.1.3.2.1	
Description	Checks the number of ships per ship type for a given year that get a new engine
Expected result	Number of ships per type and per year that get a new engine should fall within expected results from Monte Carlo simulations
Input	invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

Below is an example output of the unit test, that checks for each ship type (PC) if the actual value is within the expected range of the Monte Carlo Simulation:

Checking year 2023

Year 2023, PC D: actual 7 in range [1.85, 7.82]
 Year 2023, PC H: actual 6 in range [2.14, 10.85]
 Year 2023, PC MTS: actual 46 in range [23.36, 46.64]
 Year 2023, PC MVS: actual 42 in range [40.58, 69.94]
 Year 2023, PC O: actual 4 in range [0.28, 7.10]
 Year 2023, PC P: actual 15 in range [10.83, 20.82]

Checking year 2024

Year 2024, PC C: actual 0 in range [-0.21, 0.24]
 Year 2024, PC D: actual 6 in range [1.74, 7.89]
 Year 2024, PC H: actual 10 in range [3.03, 11.59]
 Year 2024, PC MTS: actual 34 in range [23.66, 46.96]
 Year 2024, PC MVS: actual 63 in range [39.68, 70.23]
 Year 2024, PC O: actual 5 in range [2.20, 10.38]
 Year 2024, PC P: actual 12 in range [8.91, 18.46]

Checking year 2025

Year 2025, PC C: actual 0 in range [-0.21, 0.24]
 Year 2025, PC D: actual 6 in range [0.61, 6.84]

Year 2025, PC H: actual 8 in range [3.46, 12.77]
 Year 2025, PC MTS: actual 33 in range [23.57, 47.43]
 Year 2025, PC MVS: actual 75 NOT in range [41.51, 70.73]
 Year 2025, PC O: actual 7 in range [2.46, 10.43]
 Year 2025, PC P: actual 15 in range [9.56, 19.04]
 Checking year 2026
 Year 2026, PC C: actual 0 in range [-0.21, 0.23]
 Year 2026, PC D: actual 4 in range [0.90, 6.92]
 Year 2026, PC H: actual 7 in range [1.07, 10.69]
 Year 2026, PC MTS: actual 31 in range [25.52, 50.79]
 Year 2026, PC MVS: actual 62 in range [44.62, 75.02]
 Year 2026, PC O: actual 6 in range [1.95, 9.51]
 Year 2026, PC P: actual 16 in range [9.52, 19.12]
 Checking year 2027
 Year 2027, PC C: actual 0 in range [-0.22, 0.25]
 Year 2027, PC D: actual 1 in range [0.64, 7.17]
 Year 2027, PC H: actual 7 in range [3.88, 13.34]
 Year 2027, PC MTS: actual 34 in range [26.98, 52.60]
 Year 2027, PC MVS: actual 52 in range [42.32, 71.99]
 Year 2027, PC O: actual 7 in range [1.92, 9.71]
 Year 2027, PC P: actual 14 in range [10.25, 19.58]

Only in year 2025, PC MVS does not fall within the expected range. However, 97% of the actual values fall within the expected range and therefore still fall within the expected confidence interval of 95%. Furthermore, the value of 75 is reasonably close to the expected range of [41.51, 70.73]. The unit test for the outflow function is therefore be considered as successful.

5.1.3.2.2 Total distance

Test: **test_outflow**

Case 4.1.3.2.2	
Description	Checks the total cumulative distance of ships per ship type for a given year that get a new engine
Expected result	Total cumulative distance of ships per type and per year that get a new engine should fall within expected results from Monte Carlo simulations
Input	invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

Below is an example output of the unit test, that checks for each ship type (PC) if the actual value is within the expected range of the Monte Carlo Simulation:

Checking year 2023
 Year 2023, actual distance 1651712 in range [1528635, 2197460]
 Checking year 2024
 Year 2024, actual distance 2036710 in range [1554160, 2224926]
 Checking year 2025
 Year 2025, actual distance 2200970 in range [1602446, 2246307]
 Checking year 2026
 Year 2026, actual distance 1990339 in range [1509050, 2187507]

Checking year 2027

Year 2027, actual distance 1883010 in range [1674568, 2334550]

100% of the actual values fall within the expected range. Furthermore it has been tested that higher scaling values lead to larger total distances and vice versa, which meets the expected behaviour.

5.1.3.2.3 Number of ships with new engine scaling

Test: **Manual check**

Case 4.1.3.2.3	
Description	Checks if scale factors have expected impact on the number of ships with new engine per ship type for a given year
Expected result	Number of ships with new engine per type and per year should increase for increasing scale factor and vice versa
Input	invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

An example of this scaling behaviour is shown below. The table show the number of ships with a new engine for a given year for each ship type and two different scaling factors (the same scaling factor was used across all ship types for this test).

Scaling	Ship type					
	MVS	MTS	P	H	O	D
0.1	195	139	29	18	13	11
0.2	378	267	40	59	19	20

The fact that a scaling factor of 0.1 to 0.2 does not result in exactly twice as many ships with new engine is due to the model's partially random selection process.

5.1.4 Engine size

The **apply_linear_trend** function, located in the **potamis.p_functions** module, is used to apply a linear trend to a specified fleet property over time.

The trend is defined by coefficients a and b, representing a linear function of the form $a * \text{year} + b$. The function calculates the ratio of the trend value in the new year to that in the old year and scales the target property accordingly. To validate the correctness of this transformation, dedicated unit tests have been implemented in **validation/test_apply_linear_trend.py**.

5.1.4.1 Unit tests

5.1.4.1.1 Correct application of the trend formula

Test: **test_apply_linear_trend**

Case 4.1.4.1.1	
Description	Computing scaling factor using the provided trend coefficients and apply it to the specified feature
Expected result	Correctly scaled features

Input	Two DataFrames: one with base values and year range, one with trend coefficients; joined on a key column.
Result	OK

5.1.4.1.2 Proper merging of trend data

Test: **test_apply_linear_trend**

Case 4.1.4.1.2	
Description	Verifies that the trend data is correctly merged with the fleet data
Expected result	Merged output based on key column
Input	Two DataFrames: one with base values and year range, one with trend coefficients; joined on a key column.
Result	OK

5.1.4.1.3 Cleanup of intermediate columns

Test: **test_apply_linear_trend**

Case 4.1.4.1.3	
Description	Check if temporary columns are removed after merging
Expected result	Merged data without temporary columns
Input	Two DataFrames: one with base values and year range, one with trend coefficients; joined on a key column.
Result	OK

5.1.5 Change in engine technology

The **replace_engines** function in the **potamis.p_functions** module is responsible for assigning new engine technologies to ships that require engine replacement.

The selection of new engine technologies is guided by predefined probabilities, which vary by power category and are loaded from the [nieuw_tech_kans](#) and [vervangende_tech_kans](#) data sheets in the [invoer_instroom_motoren_vv_no_srvb.xlsx](#) input file.

5.1.5.1 Unit test simulation setup

5.1.5.1.1 Input data:

The number of ships requiring new engines is determined using the output of the **p_functions.calc_inflow** function. Technology assignment probabilities are loaded from the [nieuw_tech_kans](#) and [vervangende_tech_kans](#) sheet using the **p_functions.open_technology** function.

5.1.5.1.2 Replacement logic:

The test covers the years 2022 to 2027. For each year, ships needing engine replacement are identified. New engine technologies are assigned based on the ship's power category and the corresponding probability.

5.1.5.1.3 Monte Carlo simulation

To account for variability and uncertainty in new engine technology:

- The simulation is repeated 100 times per year to account for randomness in technology assignment.

- For each year, the mean and standard deviation of the number of ships assigned to each technology type are calculated.

5.1.5.1.4 Validation criteria

The actual output of `p_functions.replace_engines` is compared to the simulation results. For each technology and year, the actual number of assigned engines must fall within the mean ± 2 standard deviations of the simulated predictions. This ensures a 95% confidence level in the agreement between the model's output and expected behaviour.

5.1.5.2 Unit test results

5.1.5.2.1 Number of new engines per technology in expected range

Test: `test_replace_engines`

Case 4.1.5.2.1	
Description	Checks the number of engines per technology for a given year
Expected result	Number of engines per technology and per year should fall within expected results from Monte Carlo simulations
Input	invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

Below is an example output of the unit test, that checks for each engine technology if the actual value is within the expected range of the Monte Carlo Simulation:

Checking year 2023

Year 2023, technology SCR: actual 182 in range [156.18, 192.58]

Year 2023, technology SCR + DPF: actual 674 in range [657.07, 724.55]

Year 2023, technology SCR + DPF + EGR: actual 26 in range [20.03, 42.21]

Year 2023, technology diesel-electric & hybrid: actual 308 in range [283.67, 352.75]

Year 2023, technology hybrid with battery: actual 147 in range [105.38, 147.80]

Year 2023, technology hybrid with battery (plugin): actual 41 in range [26.02, 47.76]

Checking year 2024

Year 2024, technology SCR: actual 213 in range [192.23, 229.55]

Year 2024, technology SCR + DPF: actual 718 in range [674.14, 735.18]

Year 2024, technology SCR + DPF + EGR: actual 9 in range [1.45, 11.59]

Year 2024, technology diesel-electric & hybrid: actual 275 in range [268.36, 326.12]

Year 2024, technology hybrid with battery: actual 152 in range [126.21, 178.47]

Year 2024, technology hybrid with battery (plugin): actual 50 in range [32.31, 58.39]

Checking year 2025

Year 2025, technology SCR + DPF: actual 692 in range [664.18, 725.16]

Year 2025, technology diesel-electric & hybrid: actual 266 in range [236.76, 289.64]

Year 2025, technology SCR: actual 187 in range [183.41, 218.55]

Year 2025, technology hybrid with battery: actual 179 in range [145.89, 192.45]
 Year 2025, technology hybrid with battery (plugin): actual 59 in range [38.80, 62.78]
 Year 2025, technology SCR + DPF + EGR: actual 2 in range [1.13, 11.25]
 Checking year 2026
 Year 2026, technology SCR + DPF: actual 662 in range [617.85, 673.49]
 Year 2026, technology diesel-electric & hybrid: actual 199 in range [194.72, 251.04]
 Year 2026, technology SCR: actual 196 in range [181.83, 213.25]
 Year 2026, technology hybrid with battery: actual 182 in range [153.79, 204.55]
 Year 2026, technology hybrid with battery (plugin): actual 64 in range [44.61, 68.55]
 Year 2026, technology SCR + DPF + EGR: actual 5 in range [1.47, 10.85]
 Checking year 2027
 Year 2027, technology SCR: actual 187 in range [176.14, 209.82]
 Year 2027, technology SCR + DPF: actual 681 in range [644.41, 700.97]
 Year 2027, technology SCR + DPF + EGR: actual 3 in range [0.81, 12.25]
 Year 2027, technology diesel-electric & hybrid: actual 204 in range [174.19, 229.41]
 Year 2027, technology hybrid with battery: actual 210 in range [183.51, 234.09]
 Year 2027, technology hybrid with battery (plugin): actual 57 in range [44.37, 74.03]

100% of the actual values fall within the expected range.

5.1.5.2.2 Number of new engines per technology scaling

Test: **Manual check**

Case 4.1.5.2.2	
Description	Checks if scale factors have expected impact on the number of engines per technology for a given year
Expected result	Number of engines per technology and per year should increase for increasing scale factor and vice versa
Input	invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

An example of this scaling behaviour is shown below. The table show the number of engines per technology for a given year and two different scaling factors (the same scaling factor was used across all engine technologies for this test).

Scaling	Engine technology		
	SCR+DPF+EGR	diesel-electric & hybrid	hybrid with battery
0.1	9	60	93
0.2	27	116	153

5.1.6 Engine subsidies

Several different runs were performed with varying numbers of subsidies with different technologies in different years and the outputs checked to ensure that this corresponded to the number of engines assigned the label 'subsidy'.

5.1.6.1.1 Number of subsidised engines

Test: **test_subsidy_assignment**

Case 4.1.6.1.1	
Description	Verifying correct assignment of subsidy labels to new engines.
Expected result	Output contains the expected number of subsidised and organic engines based on the subsidy configuration.
Input	DataFrame of new engines, a subsidy configuration dictionary, a target year, and technology identifier columns. Mimicking invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

5.1.6.1.2 Technology of subsidised engines

Test: **test_technology_assignment**

Case 4.1.6.1.2	
Description	Verifying that subsidised engines are assigned the correct technology.
Expected result	All subsidised engines have the expected technology as defined in the subsidy configuration.
Input	DataFrame of new engines, a subsidy configuration dictionary, a target year, and technology identifier columns. Mimicking invoer_instroom_motoren_vv_no_srvb.xlsx
Result	OK

5.1.7 Changes in activity

The POTAMIS+ model allows for the adjustment of ship activity levels through an activity scale factor, which modifies the annual distance travelled (in kilometres) by each ship category. To validate the correct implementation of this scaling mechanism, a series of test scenarios were developed and evaluated over the simulation period from 2022 to 2027.

5.1.7.1 Test scenarios and expected behaviour

5.1.7.1.1 No change in activity

Test: **Manual check**

Case 4.1.7.1.1	
Description	Checks the annual km with no change in activity (scale factor of 1)
Expected result	Annual km stay the same for each year
Input	invoer_activiteit_scale.xlsx
Result	OK

Substance	2022	2023	2024	2025	2026	2027
Annual km	6,35E+07	6,35E+07	6,35E+07	6,35E+07	6,35E+07	6,35E+07

5.1.7.1.2 Tenfold increase in activity

Test: **Manual check**

Case 4.1.7.1.2	
Description	Checks the annual km with tenfold change in activity (scale factor of 10)
Expected result	Annual km increases by 10 for each year
Input	invoer_activiteit_scale.xlsx
Result	OK

Substance	2022	2023	2024	2025	2026	2027
Annual km	6,35E+07	6,35E+08	6,35E+09	6,35E+10	6,35E+11	6,35E+12

5.1.7.1.3 Zero activity

Test: **Manual check**

Case 4.1.7.1.3	
Description	Checks the annual km with zero activity (scale factor of 0)
Expected result	Annual km decreases to 0 after base year
Input	invoer_activiteit_scale.xlsx
Result	OK

Substance	2022	2023	2024	2025	2026	2027
Annual km	6,35E+07	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00

5.1.8 Scaling of emissions

The `calc_emission_changed_engine` function in the `potamis.p_functions` module is responsible for calculating emissions from ships that have received new engines.

To ensure the correctness of these emission calculations, a dedicated unit test has been developed. The test verifies that emissions respond appropriately to changes in key input parameters such as cumulative distance, initial emission rates, and impact factors.

5.1.8.1 Input parameters

- Cumulative distance: approximate distance travelled by the ship since either the base year, or since the engine was last replaced. Note that this is calculated annually from the domestic time fraction (as per Equation 3.5):

$$d_{cumulative} = \sum_t \left(\frac{T_{year\ t}}{T_{domestic}} \times d_{domestic} \right),$$

with $d_{cumulative}$ the inferred distance, t the calculation year, $T_{domestic}$ the total annual time in the Netherlands, $T_{year\ t}$ the number of hours in year t , $d_{domestic}$ the total annual distance in the Netherlands in year t .

- Initial emissions: baseline emission per pollutant.
- Impact factors (IF): coefficients applied to emissions.

5.1.8.2 Test Coverage:

- The test covers the years 2022 to 2027.
- For each year, emissions are recalculated under varying conditions to verify expected behaviour.

5.1.8.3 Test scenarios and expected behaviour

5.1.8.3.1 *Effect of cumulative distance*

Test: **test_calc_emission_changed_engine_distance**

Case 4.1.8.3.1	
Description	Checks dependency of pollutant emissions based on travelled distance
Expected result	Pollutant emissions increase when travelled distance increases and vice versa
Input	Inflow of ships with changed engine
Result	OK

5.1.8.3.2 *Effect of initial emission*

Test: **test_calc_emission_changed_engine_distance**

Case 4.1.8.3.2	
Description	Checks dependency of pollutant emissions based on initial emissions
Expected result	Pollutant emissions increase when initial emissions increases and vice versa
Input	Inflow of ships with changed engine
Result	OK

5.1.8.3.3 *Effect of impact factors*

Test: **test_calc_emission_changed_engine_distance**

Case 4.1.8.3.3	
Description	Checks dependency of pollutant emissions based on impact factors
Expected result	Pollutant emissions increase when impact factors decreases and vice versa
Input	Inflow of ships with changed engine
Result	OK

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Signature

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