



Needs

*Dynamic Techno - Economical Scenario
Simulation Model for Sustainable
Waterborne Activities and Transport*

Overview of the first version of the generic model
for application use



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Document information	
Short description	<p>The present document summarises the realised technical developments and status of the simulation model achieved 10 months after the start of the project.</p> <p>The developments appeared to be much more interlinked and dependent than originally imagined in steps. As a matter of fact, activities went parallel and could hardly be reported after each other as one would provide input to the other and vice-versa.</p> <p>The consequence is that such report covers deliverables D1 of WP1, and its realisation comes at about the same time frame than the regional maritime applications that will be detailed in deliverables D4 and D6. The deliverables D2 (final version of the generic model) will also follow shortly.</p>
Work Package	WP1
Task	First version and final version of the generic model
Deliverable	D1
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1. Management summary

This report provides a description of the structure of the generic model but also the specific structure as developed when working on the two regional application.

While the generic framework contains all possible elements to describe a region and its elements, which can basically be defined in ships, ports and route, it appeared to their interaction and dependency imposed quite some fine tuning and additional definition. Such interactions are now also part of the generic framework, as well as the databases governing the properties of each elements of the framework.

This deliverables brings as consequence much more than an architecture with empty elements, but also defines the interaction between each elements and the databases giving content of the elements themselves but also the databases influencing the time histories of the upcoming scenario's (external elements such as environment).

This framework appears to be able to model any type of regional waterborne transport and including many parameters, fixed in time or varying, or being dependent on each other. This offers great possibilities of variations but will require a good methodology in its use as the number of variations and then scenarios are quite infinite.



2. Introduction and methodology

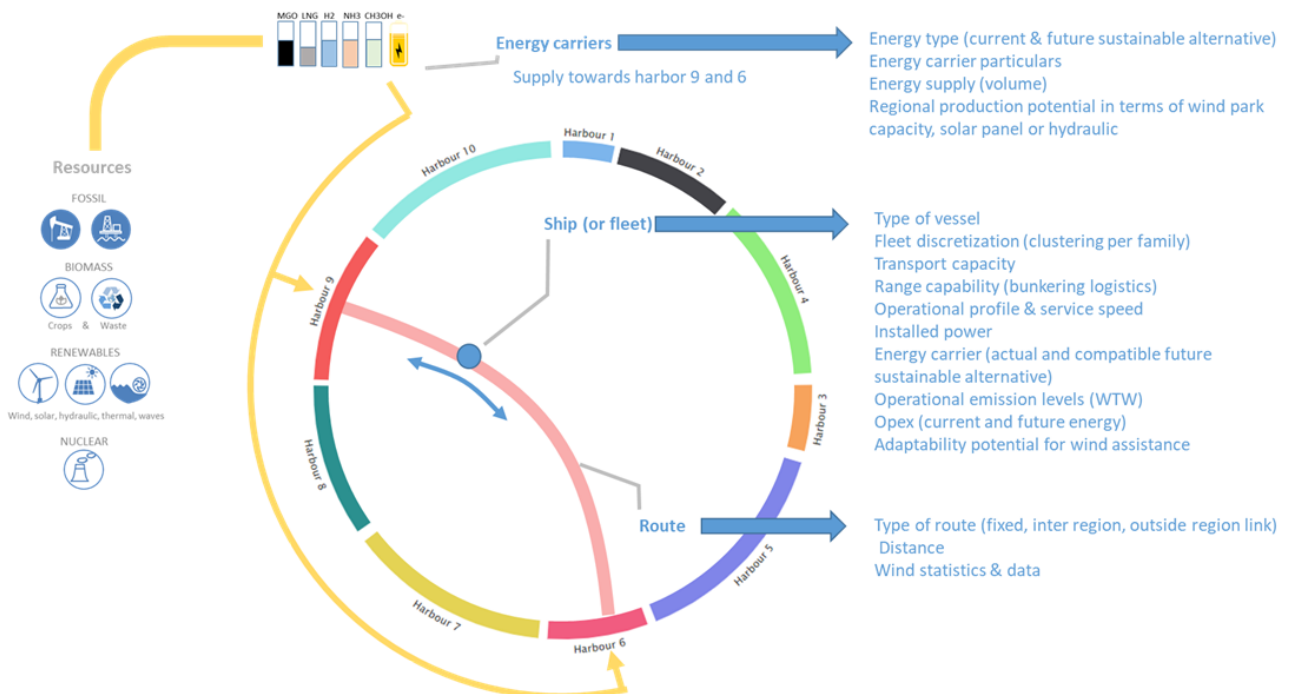
The objective of this phase was to develop a generic model defining a region with all possible elements that can compose the waterborne network. The methodology applied is similar to the one originally thought as concept during the project preparation for each individual elements and databases necessary to perform a simulation. Concerning the interdependency and relations that governs the consequences of a given scenario and the dynamic aspect of such simulation, we had to wait for the input and the specificity in the regional model to create them. On that part, we originally thought that the development tasks could be much more independent and step-wise, while the development work appeared to be much more combined between the WP1 and the two applications of WP2 and WP3. This explains the change in planning of the deliverables.

As anticipated, the first part of the work consisted in identifying and describing parameters defining the different elements taking place in the modelled eco-system: Energy, Harbour Infrastructure, Ships and Transport.

Entities describing the eco-system are not modelled individually as their number is too large (unless a region would be small enough to do so, which is not the case for the two cases).

The smallest element in the energy infrastructure is an energy bunkering site and energy type. One harbour represents the smallest element in terms of destination and bunkering location. One ship represents the smallest element in terms of transport mean and capacity.

Each element, or cluster of elements, is defined with parameters that will be specified as constant entities or time-dependent variables when modelling a specific region.





Needs



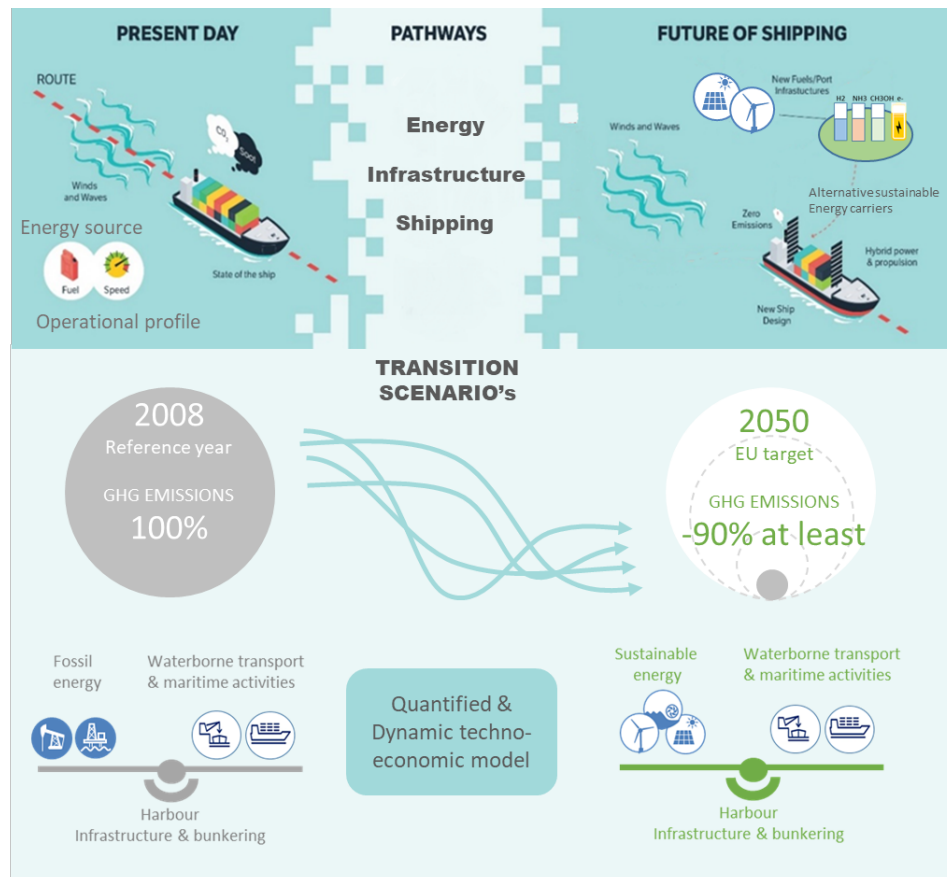
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The next step was to create ways to define relevant dependency relations that create the techno-economic model, and can make it dynamic. The basic principle of that task was to attribute relations between entities with logical consequences and inter-dependencies. Another source of dynamic behaviour resides in the variation in environmental conditions. On that aspect we have succeeded in taking into account a larger number of information than originally expected, especially for the river region where variability over time for water depth and current speed could be integrated.



3. Modelling steps, techniques and structure of the framework

It is important to remind the overall goal of simulation, which is to analyze influence and consequences of scenarios on GHG emissions at regional level, for entities and variables related to fleet (ship types, power and energy system, operational conditions, payload, Opex and Capex, logistics), routes and infrastructure (energy carriers requirements at bunkering/charging locations), taking into account the influence of environmental conditions (current and water depth on rivers, waves and wind at sea).



The steps necessary to model a waterborne region and create scenarios are the following:

- Discretise a region and transport network in main routes and ship families (clustering)
- Calculate consumption, emissions and bunker behavior of each single vessel type
- Extend this model to an entire fleet (multiplying the elements of a family)
- Define interactions and inter-dependency between given parameters
- Prepare a database of alternative ships (refit or newbuild with upgrade characteristics) based on the original families
- Model ship operations, routes and ports and run the simulation to obtain the current steady conditions (used as benchmark)
- Apply scenario by defining fixed and evolving parameters, defining also parameters left “open” that are calculated (consequences of parameters changing) and re-run the simulation

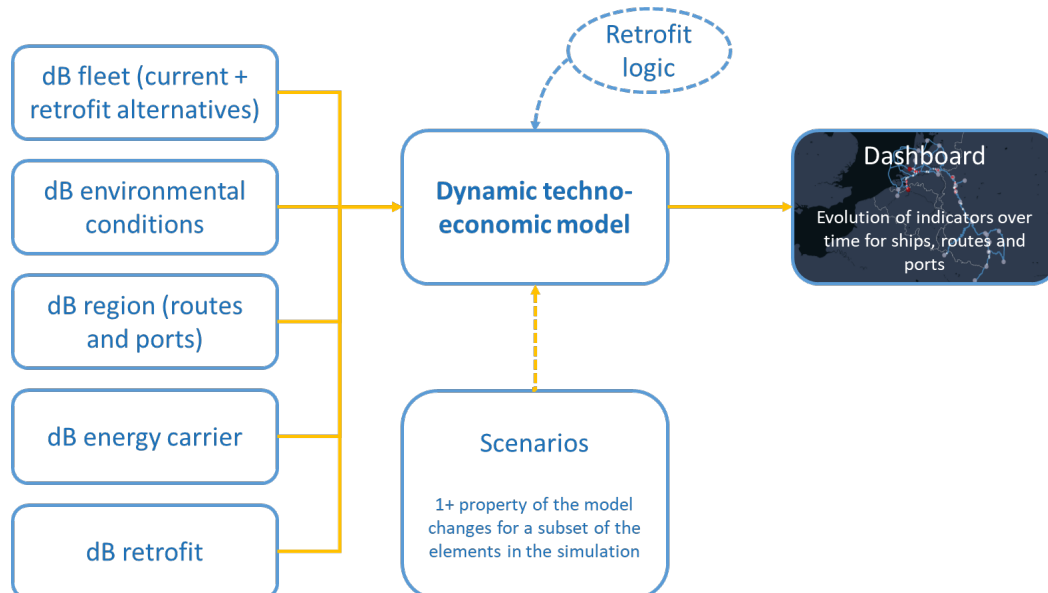


- Analyse the consequences of the scenario
- Optimisation of a transition pathway can be obtained by re-running scenario by changing / fine tuning parameters.

The programming language of the tool is in Python, on top of **SimPy**¹, which is a process-based discrete-event simulation framework, SimPy is released as open source software under the MIT License.

The main elements composing the simulation model are:

- 4 important objects: Ships, Ports and Scenarios
 - Ship: a representation of a real ship, with consumption modelling and bunkering logic (when to bunker where)
 - Port: a representation of a port, with bunker capacity for a limited number of ships, stocking specific 'fuel' types
 - Scenario: an external influence over time on both ports and/or ships.
 - Region: a representation of a region containing ports and geographical relations between ports
- Important databases:
 - Environmental conditions (hindcast data over 30 Years / period): for current, waterdepth, waves, wind
 - Power database (ship power system specific)
 - Alternative ship dB (refit or new build with sustainable alternative power systems)



Besides those elements, which require quite some specialized knowledge in python programming, in hydrodynamic performance assessment, in marine power system and data handling techniques, the results are being made available through dashboard and a simple visualisation web-based. An upcoming development will also be to allow the input of prepared parameters to play with different scenarios and rerun simulations.

¹ <https://en.wikipedia.org/wiki/SimPy>

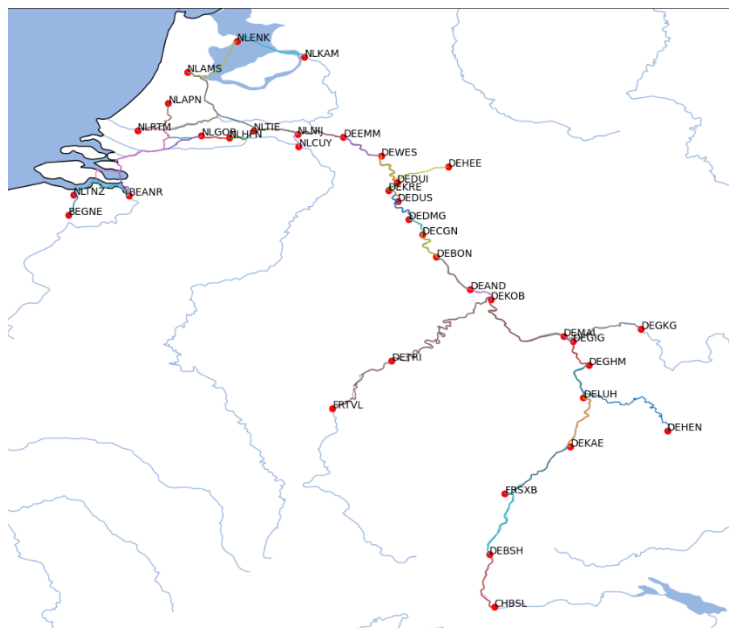


4. Modelisation of regions

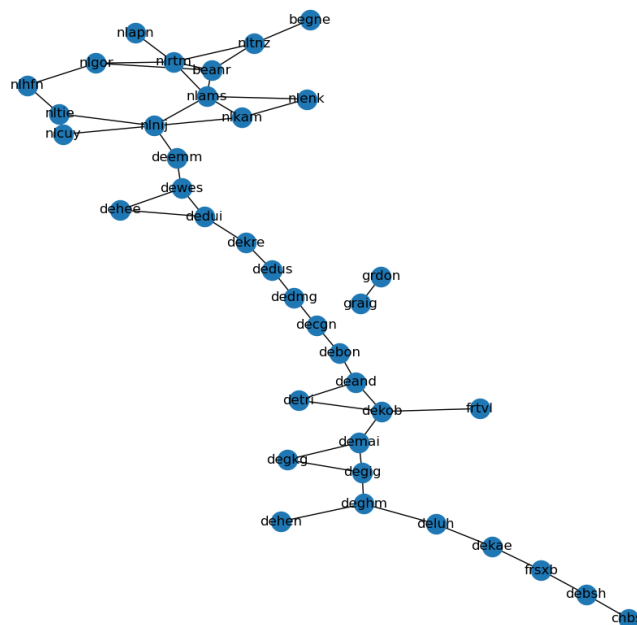
A region describes a geographically limited region of ports and waterways.

Each region contains:

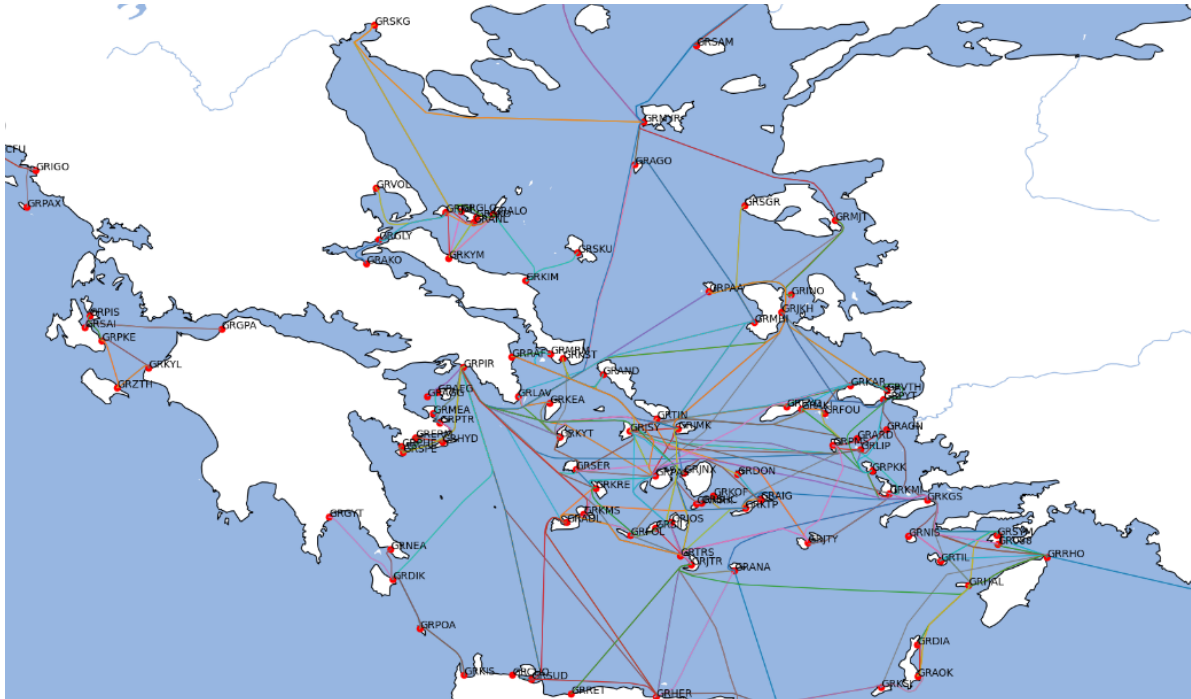
- A graph of the ports and the routes between them. This is a description of the geographic relations between all ports in a region
 - The ports are the nodes of the graph, the routes between them are the graph edges. A shortest path algorithm can be used to find the entire route between two random ports, which will return a list of intermediate ports that will be passed en route.
- An array of ports in the region, of which the parameters can be modified by scenarios



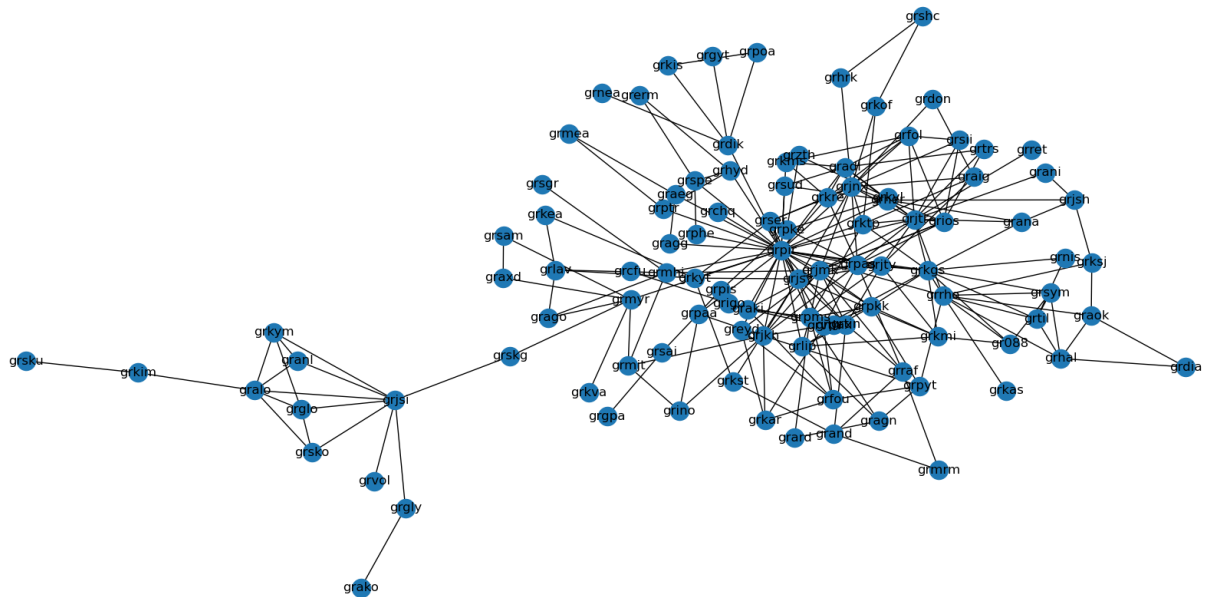
Map of region with all available ports – Rhine region



Graph of the same region with geographical relations – Rhine region



Map of region with all available ports – Greece region



Graph of the same region with geographical relations –Greece region



5. Modelisation of ports

A port is a simplified representation of a geographical port area. It is defined by the following parameters:

- Location (latitude, longitude)
- Name
- [UN LOCODE](#)²
- Ship capacity for bunkering
- A bunker point, describing the various types of fuel/energy are available, at which price

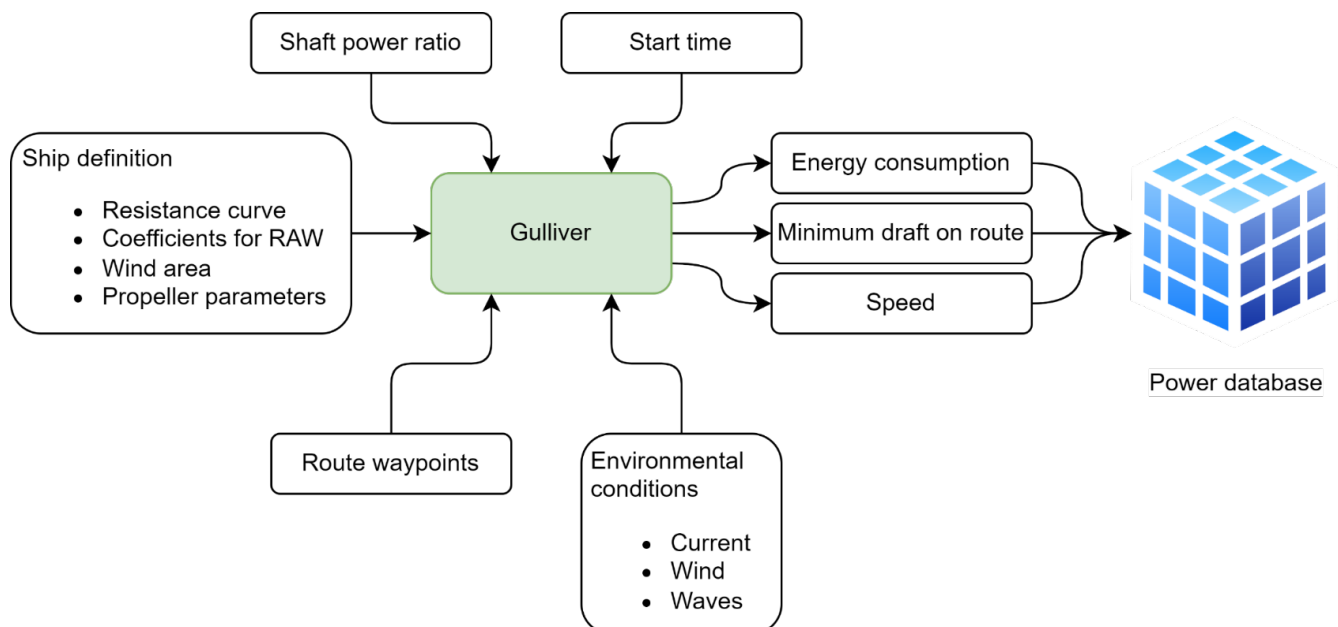
² <https://unece.org/trade/cefact/unlocode-code-list-country-and-territory>



6. Power database and pre-processed Gulliver simulations

For each region, a power database is precomputed with MARIN Gulliver³ simulation tools.

- A set of unique sections is created.
 - A section is unique by a combination of start port, end port, ship type and loading condition.
- For each unique section, a number of Gulliver calculations is performed
 - The ship type linked to the section will start sailing from the start port, and will follow a list of waypoints to the end port. The loading condition and resulting resistance curve is applied. The ship will sail at a preset shaft power ratio, and the resulting ship speed and energy consumption are recorded.
 - The Gulliver simulation will be started at a range of start times (to incorporate fluctuating environmental conditions) and a range of shaft power ratios (to see the influence of ship speed variation)
 - Used time range:
 - Rhine region: Start: 1-1-2015, end 1-1-2020, interval \approx 36 days
 - Greek region: still to be determined
 - Used shaft power ratio range: [0.01, 0.15, 0.3, 0.6, 0.9, 1.0]
 - The minimum water depth encountered in the section is recorded
 - This is used in the simulation model to revert to the 'reduced draft' condition
- Each unique combination of section, start time and shaft power ratio is recorded in the power database



³ <https://www.marin.nl/en/publications/voyage-scenario-simulation-with-gulliver>



7. Route database

The route database defines the fleets that will be simulated by the simulation model in a certain region.

Each entry in the regional fleet database describes a ‘fleet’, i.e. a ship type sailing on a specific sailing schema (which is a combination of route, loading condition and sailing speed).

It can be modified to only simulate a subset of the entire regional fleet.

	Ship Type	Port A	Port B	#ships	Empty Return	Up Speed [kn]	Down Speed [kn]	Port Waiting time [h]	Port consumption [kWh/day]
1	PushB4	nrltm	dedui	8	TRUE	5.174586033	9.553081907	8	1
2	C3L/B	nrltm	beanr	39	FALSE	5.399568035	5.399568035	48	1
3	MTS 135m	nrltm	dekae	21	TRUE	5.652672786	6.029517639	10	1
4	C3L/B	nlams	dekae	16	TRUE	5.344728672	5.60758418	17	1
5	C3L/B	nrltm	chbsl	6	FALSE	5.319801689	5.345572354	64	1
6	MVS 110m	beanr	frtv1	15	FALSE	4.790889456	4.805615551	9	1
7	C3L/B	nlams	beanr	8	FALSE	5.842609514	5.831533477	36	1
8	C3L/B	nrltm	degkg	4	FALSE	5.153347732	5.129589633	27	1
9	MTS 135m	nlams	nrltm	5	TRUE	5.399568035	7.199424046	6	1
10	MVS 135m	beanr	demai	6	FALSE	5.150008167	5.150008167	36	1
11	MVS 110m	debsh	nlcuy	11	FALSE	5.324683514	5.324683514	15	1
12	C3L/B	beanr	dedui	3	FALSE	5.570080709	5.570080709	36	1
13	MVS 110m	nrltm	dedui	14	FALSE	5.619958567	5.619958567	26	1
14	MTS 86m	nrltm	deluh	15	FALSE	5.536845188	5.536845188	8	1
15	MTS 110m	nrltm	nlkam	3	FALSE	7.112534446	7.112534446	9	1
16	MVS 110m	nrltm	frsxb	3	FALSE	5.47353472	5.47353472	15	1
17	MVS 105m	nlams	dehen	3	FALSE	5.16214022	5.16214022	12	1
18	MVS 110m	dedui	beanr	2	FALSE	5.669546436	5.669546436	12	1
19	MVS 105m	nrltm	nlapn	1	FALSE	5.111591073	5.111591073	18	1
20	MTS 110m	nltzn	nrltm	2	FALSE	5.474044835	5.474044835	9	1
21	MVS 67m	dewes	nlenk	1	FALSE	5.473198508	5.473198508	6	1
22	MVS 86m	nrltm	dehee	1	FALSE	5.152469158	5.152469158	9	1
23	MVS 110m	dedus	beanr	1	FALSE	5.626918268	5.626918268	12	1
24	MVS 110m	beanr	begne	1	FALSE	5.579553636	5.579553636	9	1
25	MVS 86m	nrltm	dedui	1	FALSE	5.645002945	5.645002945	12	1

Example of part of Rhine region database

If all fleets in the Rhine route database are simulated, a total of 189 ships is sailing simultaneously. According to EICB (based in the Prominent project), this total fleet should corresponds to the majority of the emissions from inland shipping.

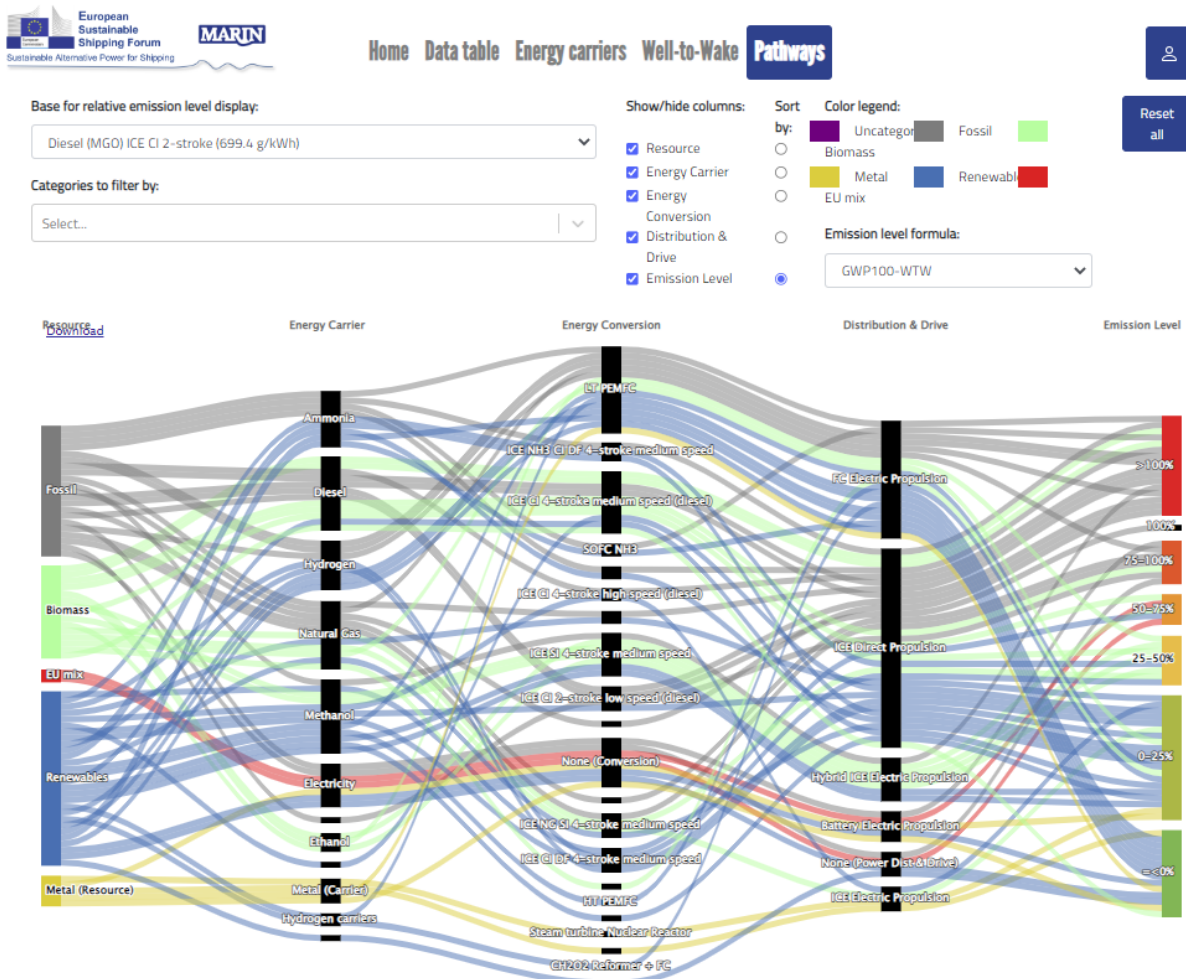


8. Retrofit database (sustainable alternative power system)

The retrofit database contains the ship parameters that will potentially be influenced by a retrofit:

- The Tank-To-Shaft efficiency of the propulsion train
- The payload
- The reduced power (resulting in a lower sailing speed)
 - Some retrofit options have a lower installed power to have either longer endurance or more payload, but this will influence sailing speed
- The bunker capacity

In order to create such alternative power system, we use the SPEC⁴ (Ship Power and Energy Concepts) tool developed by MARIN. Such tool relies on information set in a database that MARIN made publicly available in the course of her involvement in the European Sustainable Shipping Forum, as task leader of a study in the Sustainable Alternative Power for Ships working group. Such database is publicly available on dedicated portal⁵.



Screenshot of the exploration of sustainable alternative power system

⁴ <https://www.marin.nl/en/news/webinar-on-ship-power-and-energy-concepts-tool>

⁵ <https://sustainablepower.application.marin.nl/>



9. Energy and energy carrier database

The energy database contains for every energy type

- The bunker speed in kW
- The base fuel price and expected price development
- The TTW and WTW conversion ratio
- The calorific value

For each energy carrier, there are multiple mixes available, from grey to green.

fuel	Storage	fuel_type	transfer_method	Contained_MJ_kg	bunkerspeed_kWh_h	WTT_CO2Kg_GJ	TTW_CO2Kg_GJ	price_euro_kWh_aicb_2020
Diesel (MGO)	Tank	fdiesel	Stat2Ship	30.09	335476	14.261	75.1	0.06
Diesel (20%FAME UCO, 30% HVO rapeseed)	Tank	bdiesel	Stat2Ship	31.13	350242	-10.3	72.1	0.07
eDiesel(renewable electricity + Flue CO2)	Tank	rdiesel	Stat2Ship	30.36	335476	-68.3	75.1	0.18
LNG	Tank	fNG	Stat2Ship	28.37	202500	13.7	57.3	0.04
Electricity	Li_NMC_Battery	gm	Charging	0.33	188	11.6	0	0.09
Electricity	Li_NMC_Battery	gm	Swapping	0.33	36000	11.6	0	0.09
Electricity	Li_NMC_Battery	renewable	Charging	0.33	188	0	0	0.12
Electricity	Li_NMC_Battery	renewable	Swapping	0.33	36000	0	0	0.12
Hydrogen	H2Tank_700bar	fHydrogen	Stat2Ship	6.6	156	75.6	0	0.11
Hydrogen	H2Tank_700bar	ccsHydrogen	Stat2Ship	6.6	156	39.7	0	0.13
Hydrogen	H2Tank_700bar	rHydrogen	Stat2Ship	6.6	156	0	0	0.47
Hydrogen_Diesel4%	H2Tank_700bar_Tank	rHydrogen_fdiesel	Stat2Ship	7.46	13569	3.5	18	0.45
Hydrogen_Diesel4%	H2Tank_700bar_Tank	fHydrogen_fdiesel	Stat2Ship	7.46	13569	60.6	18	0.11
eLNG(renewables + fluegas CO2)	Tank	bNG	Stat2Ship	28.37	83100	-50.4	57.3	0.09
Methanol	Tank	fmethanol	Stat2Ship	14.533	148500	27.35	69.66	0.05
Methanol (black liquor)	Tank	bmethanol	Stat2Ship	14.533	148500	-33.1	69.66	0.10
Methanol(renewable electricity + flue gas C2 = H2O)	Li_NMC_Battery_Tank	rmethanol	Stat2Ship	14.533	148500	-62.1	69.66	0.10
Methanol_Diesel5%	Tank	bmethanol_fdiesel	Stat2Ship	15.26	148500	-55.8	70	0.09
Methanol_Diesel35%	Tank	bmethanol_fdiesel	Stat2Ship	19.79	148500	-20.5	71.7	0.08

Example of the list of parameters lined to the energy type

Most of the fuel prices have been given as input by SPB. For the fuel types that did not have a price the spec database was used. The prices of the spec database were scaled with the price of SPB for a fair comparison. Detail of how the prices were derived can be seen in the Database_Fuel.xlsx in the tab Costs.

The bunkering speeds were provided by SPB but the hydrogen. The latter was taken from the DNV report 11I1RCRW-2 titled "RH2INE-Kickstart-Study-Scenario-building-Hydrogen-Bunkering-Scenarios".

The costs of the retrofit database have been based on the spec database. Report [https://eibip.eu/wp-content/uploads/2018/08/D7.1 Move-it-Final-Report System-Integration.pdf](https://eibip.eu/wp-content/uploads/2018/08/D7.1_Move-it-Final-Report_System-Integration.pdf) was used to validate the retrofit costs of diesel.

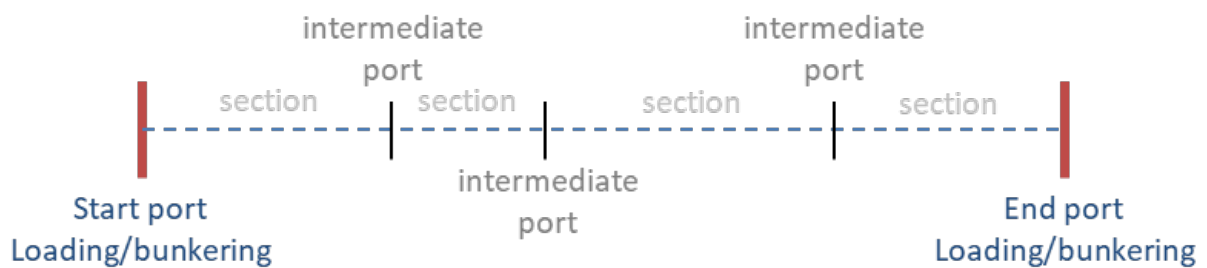
The retrofit time is for now assumed to 60 days for each energy source. A more accurate value should be discussed with the other NEEDS participants.



10. The ship operations on a given route

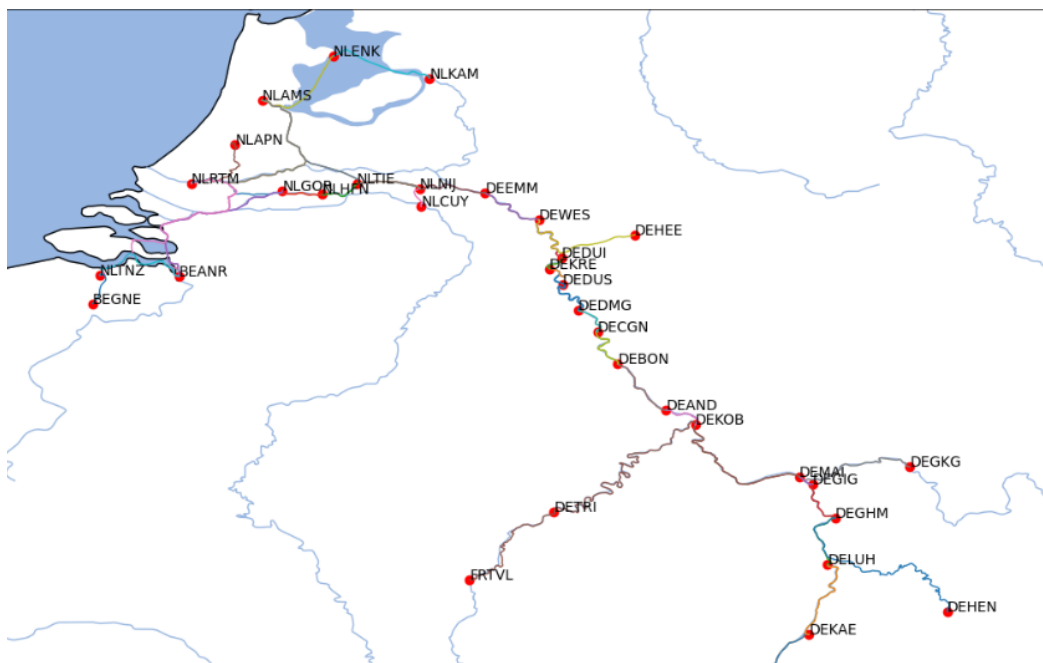
The ship follows a predefined sailing schedule:

- From start port to end port and back, with an average speed and loading condition for the in- and outbound journey
- Shaft power is kept constant, resulting in varying speed per section
- The ship can only load/unload and bunker in either start or end port
 - Unless the ship has insufficient endurance
- It will pass intermediate ports, every port passing is an 'event'.
- Loading and bunkering are also 'events'.



For every section between the intermediate ports, average speed and resulting power demand and duration are calculated, depending on:

- ship type
- % of shaft power
- loading condition
- time of year
-



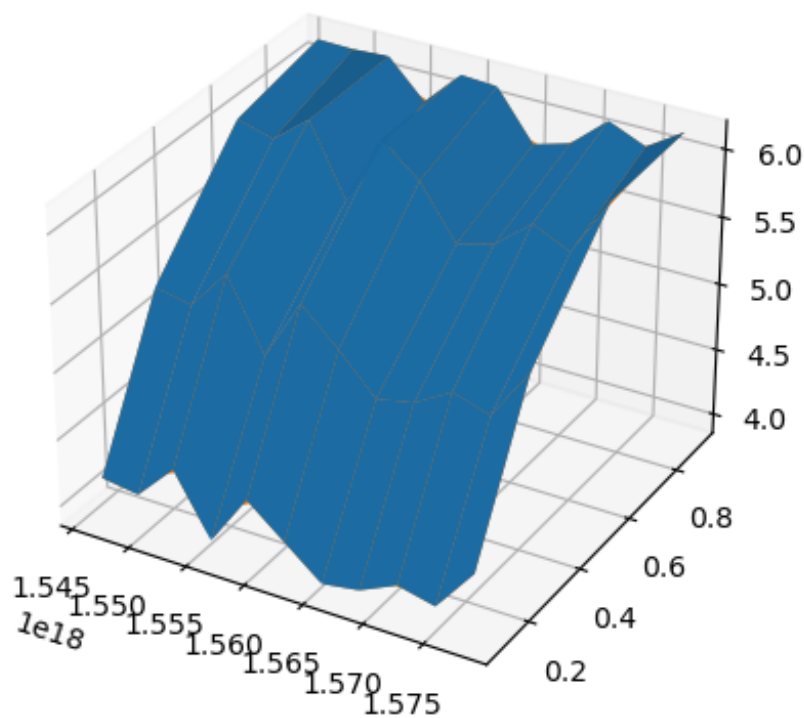


11. Consumption calculation during the simulation

From power database an interpolator is built for each ship on each section, so required power can be calculated for any time and any %MCR

- Used for both actual required power and required power prediction (bunkering logic)

The actual consumption of the ship depends on the power system; the consumption is calculated by multiplying the required shaft power with the TTS (tank-to-shaft) efficiency of the specific power system (from Retrofit database)

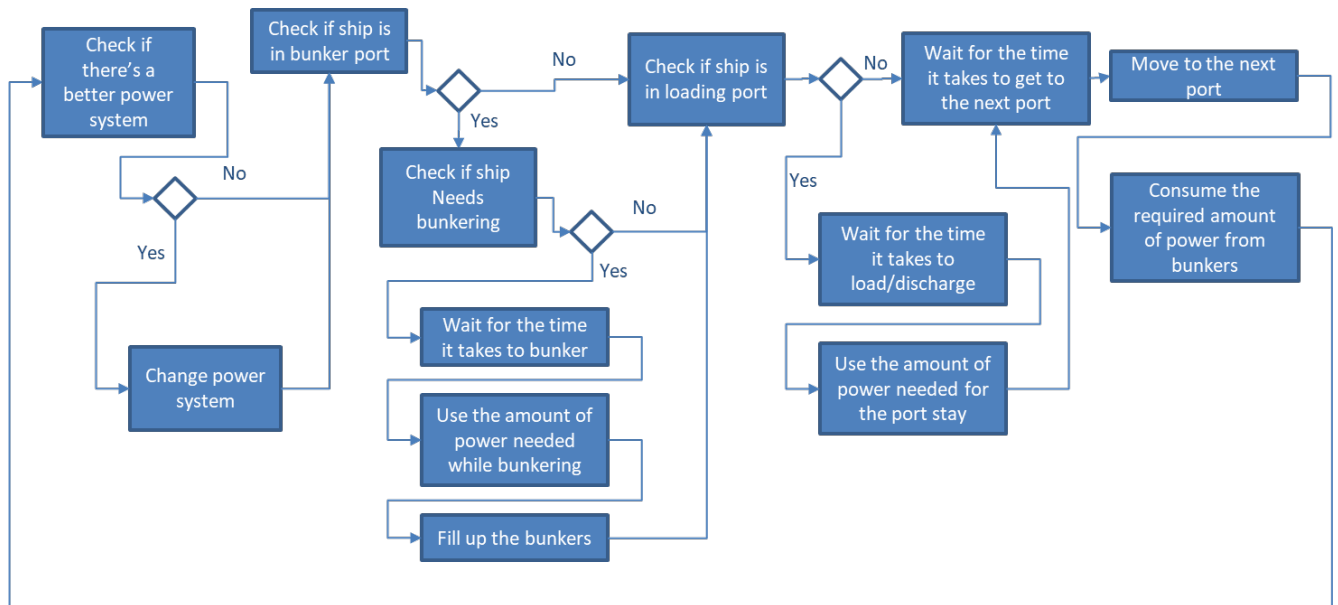


Envelope of the consumption as function of operational parameters



12. Simulation logic

The following diagram details the logic step taken during the time-dependent simulation.





13. Generic Scenarios and first runs

Three types of scenario were created, prior to receive more detailed scenarios for each region. There are so many variables to play with and which can vary in time that the amount of possible scenarios is infinite.

It was then important for us to create those default generic scenarios in order to structure the way variables will be modified and explore cases in a structured way (also to learn ourselves about the possibilities of the tool...):

- A 'switch' scenario where the discrete value of an object attribute is changed "instantly". The change is evenly spread out over the group of object over the change period
 - Example: the change of power system for all the ships.
- A 'continuous' scenario where the value of an object is continuously changing over time. All objects within a group will change over the same time span.
 - Example: the price of MDO is slowly increasing over time
- A 'discrete' scenario where the value of an object is changing over time in discrete steps. All objects within a group will change over the same time span.
 - Example: adding ships to a fleet

As mentioned earlier, the development of the generic framework had to go hand in hand with the input generate by the modelling of the specific region and their fleet. As the same time, discretizing and defining the regions needed the details of the framework.

We originally thought that those 2 steps could be done sequentially but they had to be performed simultaneously.

In the course of the development, there has been also quite some effort to optimize the calculation time. Originally, it tooks several days to simulate a 30 years transition pathways with all elements of a regional framework. We brought it back to about 20 hours on a later stage, then to an incredible 2 hours, with a 2.5 GB output data.

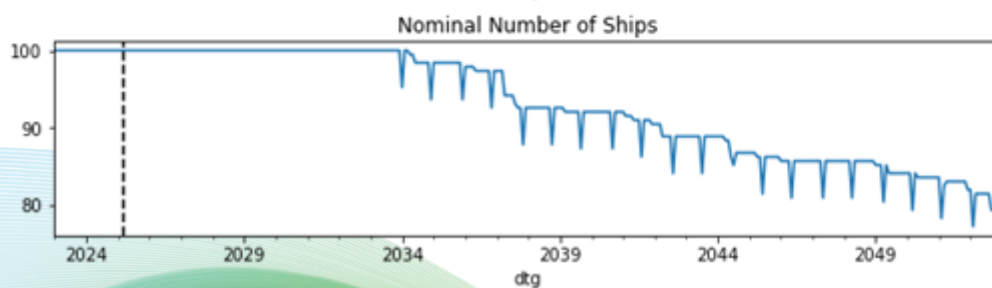
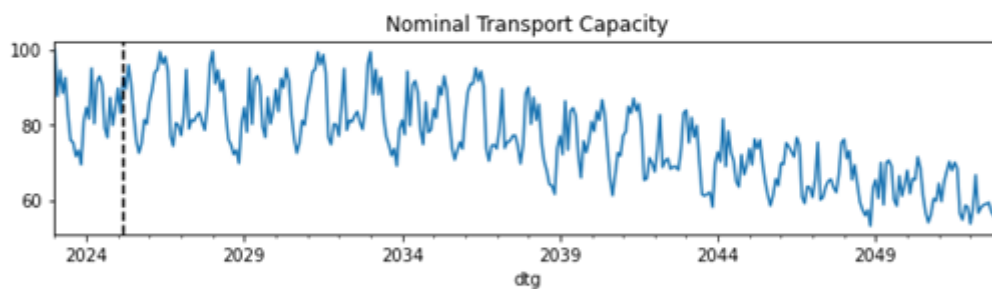
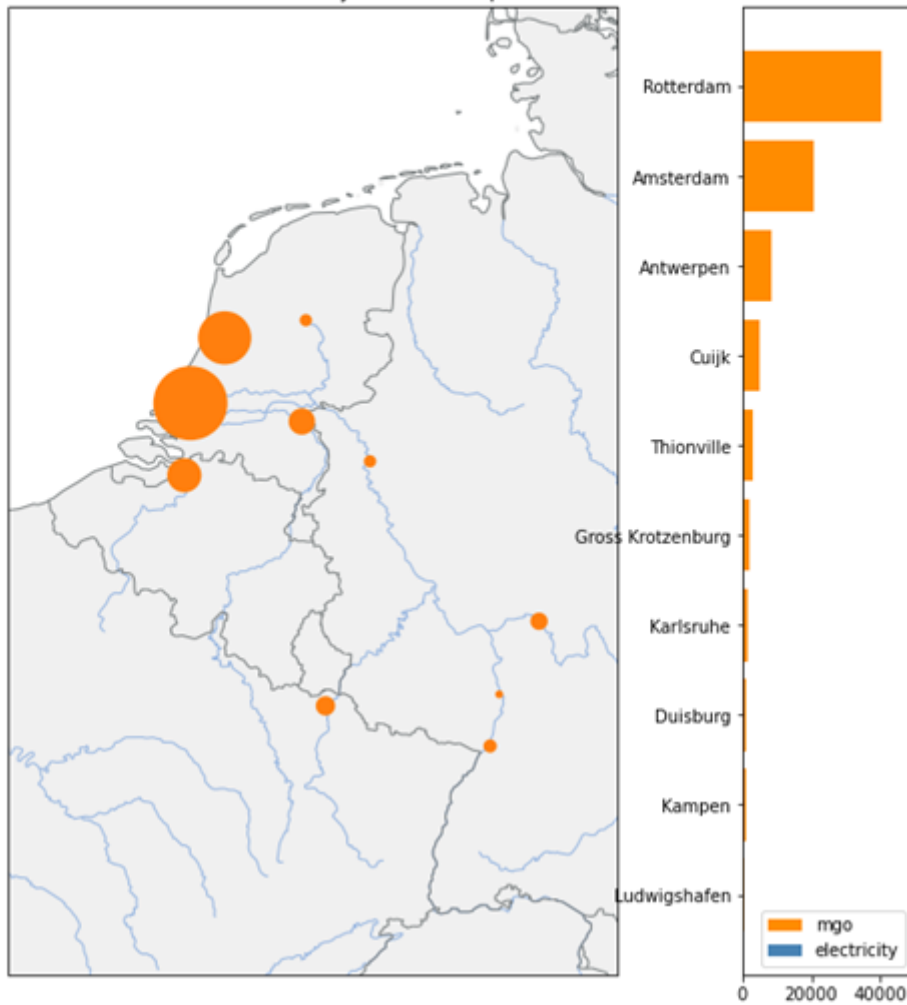
The duration of the computation swill of course depends on the complexity of the scenario and the details of the elements, but monitoring and optimising the velocity of the computation remains a point of attention.

The following pages show an illustration of the first complete simulation performed for the Rhine region. The scenario is a full transition to electric engine for all ships, independent of their operational profile. The simulations, which are concepts ones and draft, shows a clear trend in global energy reduction (direct electric propulsion is more efficient than internal combustion), a reduction of the operational fleet (some ships can not charge on their route and simply stop – there was no additional port made available to supply electricity in that case), and a reduction of the global transport capacity (due to the fact that some ships stopped sailing – battery empty – but also because of the speed reduction imposed by the lower range with battery. Such example is not a realistic one, it is the first fully completed on 30 years basis and we took simple and drastic parameters to try the simulation model.



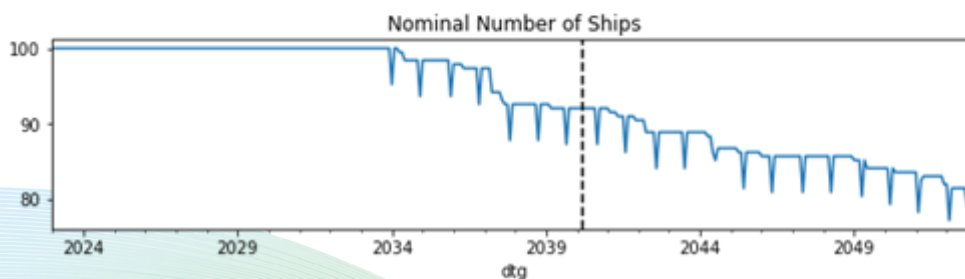
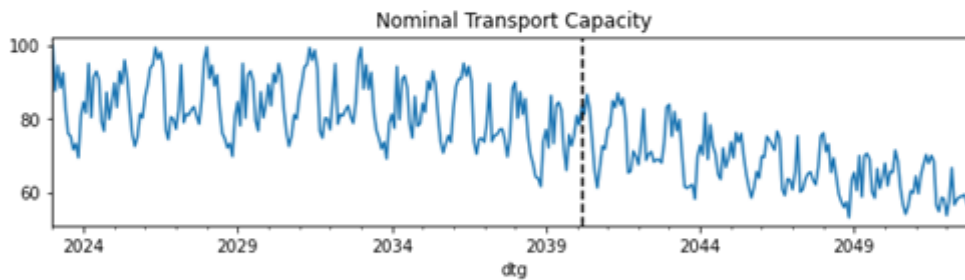
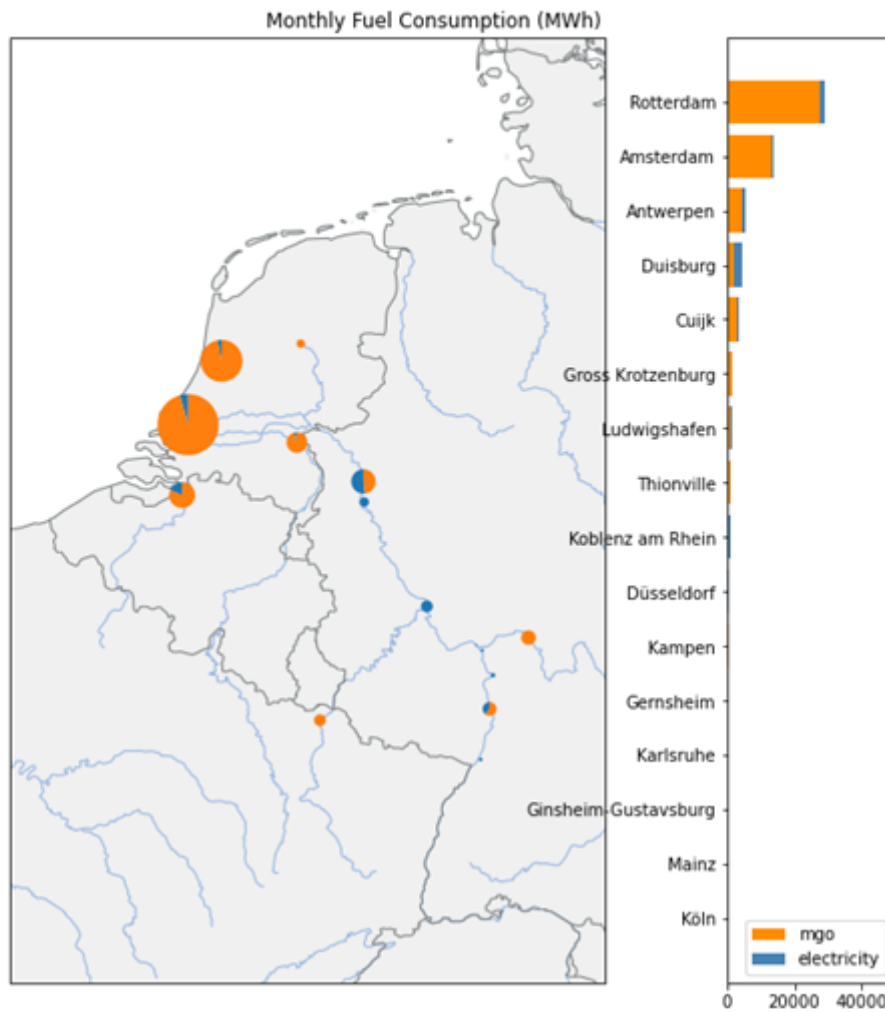
Scenario: To Electric March 2025

Monthly Fuel Consumption (MWh)



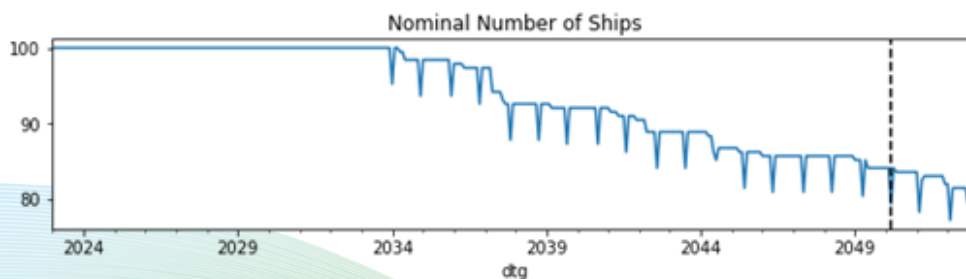
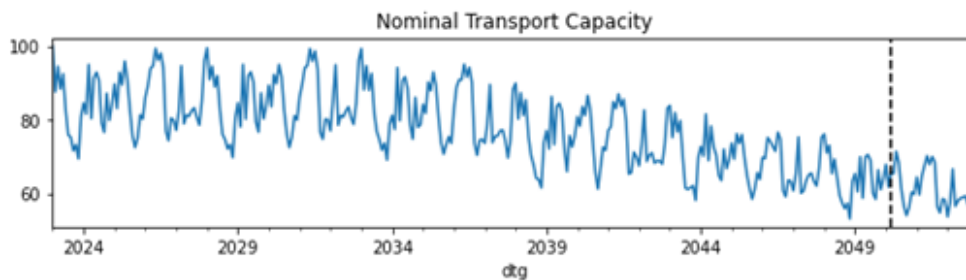
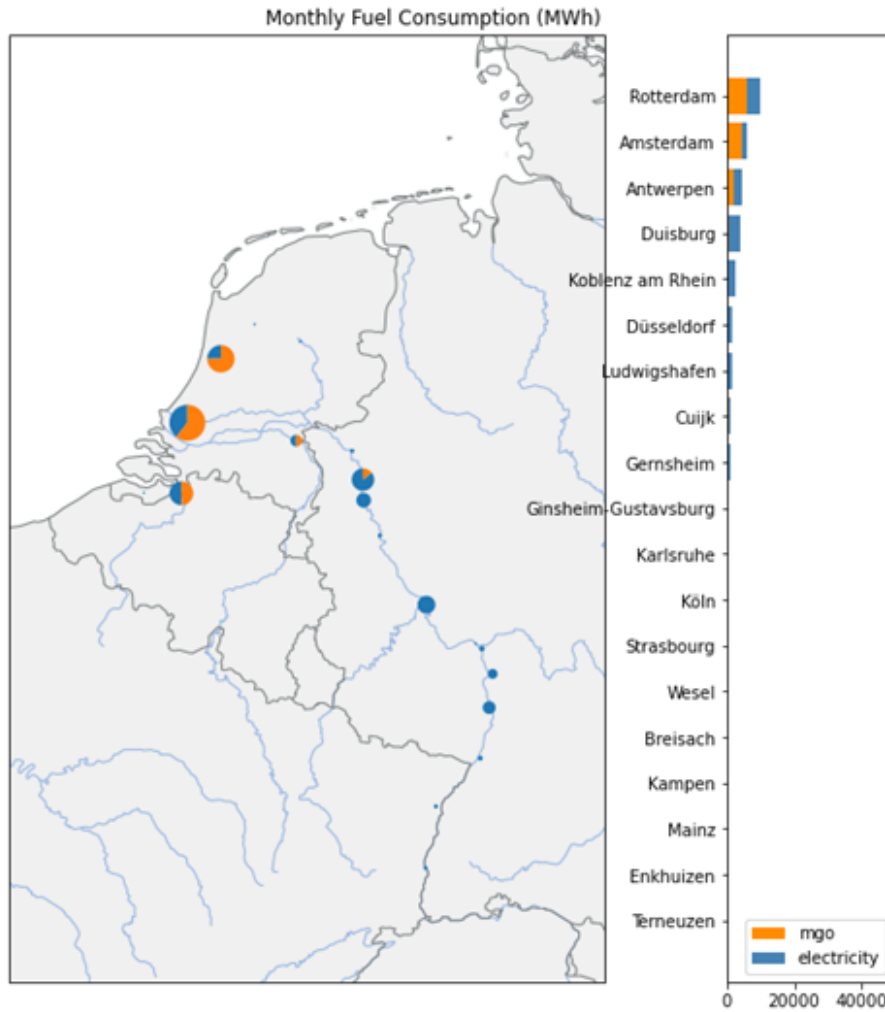


Scenario: To Electric March 2040





Scenario: To Electric March 2050





14. Conclusions

This deliverables illustrates the technical capabilities of the generic framework but also highlights the fact that the characteristics of a given region also affects partly the structure of the framework, in particular the database of fixed or time-dependent parameters.

The joint development of such generic framework, together with the work packages on the regional modelling, has also helped structured this framework. In order to boost the simulation time and allow time-dependent variable to influence the scenario's, it was decided to bring part of the simulations at pre-processing stage (thus region specific), with elements and parameters characterizing the considered region. The type of scenario and the options will still be tunable prior to the simulation or even in post-processing, but a large part of the performance, consumption, emission, energy use or routes are treated in an early phase and saved in databases that can be used on later stage of the simulation.

Overall conclusion is the fact that this simulation framework appears to be able to model any type of regional waterborne transport and including many parameters, fixed in time or varying, or being dependent on each other. This offers great possibilities of variations but will require a good methodology in its use as the number of variations and then scenarios are quite infinite.