Economic analysis - final

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Aegis

Advanced, Efficient and Green Intermodal Systems

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Executive Summary

The present report is deliverable D7.6, Economic analysis-final, in the context of WP7, Cost benefit analysis, and specifically Task 7.2, Economic analysis. It is an evolution of an earlier, preliminary report on the economic analysis, a report which the present document supersedes. It is also the continuation of the work done in Task 7.1, Identification of KPIs, and presented in deliverable D7.2 (Report on KPIs) [1]. Task 7.2 runs parallel to Tasks 7.3 and 7.4, which are the environmental analysis and the social analysis, respectively. All three use cases, A, B, and C are covered in this report.

The following would seem to summarize where we stand as regards the main economic KPIs (cost and time KPIs) for each use case, and particularly on how the AEGIS solution compares to the non-AEGIS baseline solution:

		Cost KPIs	*Time KPIs*
Use case A		After around seven years and a half of operating the AEGIS solution, it will be less expensive than the baseline scenario, in terms of cumulative cost.	AEGIS solution is generally slower than the baseline solution. However, this result is for mother and daughter vessels analysed separately and is expected to be better if they are analysed together.
Use case B		After around four years of operating the AEGIS solution, it will be less expensive than the baseline scenario, again in terms of cumulative cost.	AEGIS solution is generally slower than the baseline solution. But since the AEGIS ships can work daily, there will be no delay or disruption in meeting even daily demands. Therefore, in this case, time would not be a serious challenge.
Use case C	*Aalborg*	After around 8.5 years for the battery system and about seven years for the methanol propulsion system, the AEGIS scenario will have a better cost situation than the baseline scenario.	AEGIS solution is generally slower than the baseline solution. But, since the AEGIS ships can work daily, there will be no delay or disruption in meeting even daily demands. Therefore, in this case, time would not be a serious challenge.
	Vordingborg	AEGIS solution is cheaper.	AEGIS solution is generally slower than the baseline solution.

Among the cost and time KPIs, CAPEX and time KPIs seem to be the only KPIs in which the AEGIS solution is inferior to the non-AEGIS, baseline solution. However, the fact that CAPEX is higher in the AEGIS solution is to be expected due to the advanced nature of the AEGIS solution. It is also expected that the level of CAPEX will get gradually lower in the future, as is common with all advanced technologies. But even with the figures assumed in this analysis, the cumulative (CAPEX+OPEX) cost of operation of the AEGIS system is seen to be lower than the equivalent cost of the non-AEGIS solution after some years of operation.

Regarding time KPIs, whereas the AEGIS solution was generally found to be slower than the non-AEGIS solution, this result is also to be expected given that in many cases AEGIS competes (even partially) with the road mode, which is faster. However, this result is subject to improvement once a better interoperability among the various components of the AEGIS system is achieved, and/or once some key parameters of logistical system design, such as vessel speed, sailing frequency, number of ships, or just-in-time arrival are better adjusted. Such an analysis will be, among other things, the subject of AEGIS Task 7.5, which will deal with the identification of win-win solutions.

Definitions and abbreviations

AEGIS: Advanced, Efficient and Green Intermodal Systems

AG: Advisory Group

AGV: Automated Guided Vehicles

BEP: Breakeven Point

CAPEX: Capital Expenditures

CBA: Cost-Benefit Analysis

CEMT: European Conference of Ministers of Transport

CFD: Computational Fluid Dynamics

EMSA: European Maritime Safety Agency

EU: European Union

GHG: Greenhouse Gases

IWW: Inland Water Way

KPI: Key Performance Indicator

LoLo: Lift-on Lift-off

MRV: Monitoring, Reporting and Verification

OPEX: Operating Expense

RoRo: Roll-on Roll-off

SSS: Short Sea Shipping

TEU: Twenty-foot Equivalent Unit

THC: Terminal Handling Cost

UC: Use Case

WP: Work Package

1 Purpose and structure of this report

Whatever solutions are contemplated in AEGIS, it is imperative to assess them holistically so as to capture the effects of all conceivable cross-linkages and interdependencies and hopefully obtain what we call "win-win" solutions. For that purpose, the main objectives of Work Package 7 (WP7) are to:

- Define Key Performance Indicators (KPIs) to do a quantitative Cost-Benefit Analysis (CBA)
- Perform analyses of economic, environmental, and social effects of AEGIS proposals
- Combine to overall CBA, covering all three factors, and compare it with today's solutions
- Identify "win-win" solutions that give the best overall benefits at the lowest possible cost

The present report is deliverable D7.6, Economic analysis-final. It is the context of Task 7.2 (economic analysis) and is an evolution of an earlier, preliminary report on the economic analysis, report which the present document supersedes. It is also the continuation of the work done in Task 7.1, Identification of KPIs, and presented in deliverable D7.2, Report on KPIs. Task 7.2 (economic analysis) runs parallel to Tasks 7.3 and 7.4, which are the environmental analysis and the social analysis, respectively. All three use cases, A, B, and C are covered in this report.

The rest of this document is organized as follows. Section 2 presents and describes each of the three AEGIS use cases which serve to conduct the CBA. Section 3 presents the methodology for the evaluation of the economic KPIs. Section 4 presents the results of the CBA for the three use cases, and Section 5 presents the conclusions. Finally, Annex A shows the data templates circulated to the AEGIS partners.

A clarifying note is due on other AEGIS deliverables, some of which are cited in this report. Some of these deliverables are classified as "public", hence the reader of this deliverable (which is also public) will have full access to them. For those AEGIS deliverables that are classified as "confidential", a public executive summary will be available, which will also be accessible to the reader of this deliverable.

2 Description of the three use cases

The three AEGIS use cases serve here to compute the predefined KPIs, which represent the criteria under which the set of solutions developed under AEGIS will be evaluated and carry out the cost-benefit analysis (CBA) to assess any solutions further contemplated in AEGIS. The three use cases, including their scenarios and base cases, are presented and described in this section.

An important note is that all three scenarios of use cases (baseline and AEGIS) were continuously evolving during the course of this analysis. The same can be said regarding the data for these scenarios. This section describes the use cases, and associated data, as these were known at the time of the analysis.

A related note is that the degree of completeness of the associated data in the three use cases is by no means uniform as regards the availability of data in these scenarios for the purposes of WP7. Some use cases are more developed than others use cases. In cases data to compute some KPIs were missing, some assumptions and approximations were made, and these are stated in this report.

2.1 Use Case A

This section heavily draws from deliverable D8.2 (Transport system specification– Case A) [2].

Use Case A (UCA) covers transport from the large port of Rotterdam to smaller destinations along a less populated coast of Norway. It will focus on short sea and rural terminals mainly based on a LoLo service. The objectives of UCA are depicted in Figure 1.

The results from the initial cargo volume analysis presented in deliverable D8.1 (Cargo Volume Analysis – Case A) [3] indicate a potential for implementing the AEGIS concepts. Trends that will be important to follow, such as it seems like the volume of 45-feet containers are increasing compared to 40 feet, which again will pose requirements to the vessel design and cargo handling equipment, have been identified. This report points to some of those trends. Based on the results from the logistics studies, the concept has estimated available cargo from the Trondheimsfjord region. The calculations in the report are based on volumes from existing transport routes from the west coast of Norway to the Netherlands, with data from statistics, previous projects, port statistics, and direct input from transporters and cargo owners. The container transport to international regions outside Europe, 60 - 70 % of NCL's international cargo, is mainly carried out by shipping to the big European ports, such as Rotterdam, where it is transshipped to deep-sea vessels. Hence, the NCL sailings are vulnerable to delays in the deep-sea sailing schedules. On average, eight vessels sail out of Rotterdam to the west coast of Norway weekly. The average capacity for the fleet is estimated to be about 750 TEUs per vessel, hence a total weekly capacity of about 6,000 TEUs. The cargo volume for bigger terminals is quite stable, but it varies significantly for the smaller ports. The Trøndelag region in Norway can be served on a weekly basis and include Rørvik and the inner ports of the fjords if introducing feeder lines, such as daughter vessels.

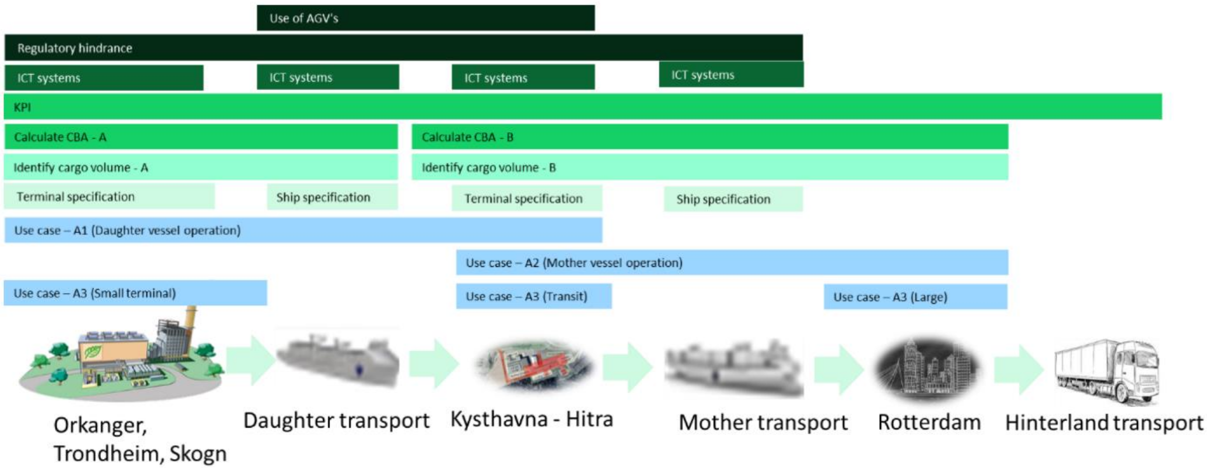


Figure 1: UCA objectives and transport systems (source: Deliverable D8.2 (Transport system specification– Case A) [2].)

According to the cargo analysis carried out in deliverable D8.1 (Cargo Volume Analysis – Case A) [3] has defined two scenarios:

1. The transport between Rotterdam (The Netherlands) and Hitra Kysthavn, Sandstad (Norway). Seen in Figure 1 as region 1.
2. The transport within the Trondheimsfjorden region (Norway). Seen in Figure 2 as region 2.

Figure 2: Use Case A, International and domestic trade.

Furthermore, the use case A transport system will, as indicated in Figure 1 and deliverable D8.2 (Transport system specification– Case A) [2], consist of mother and daughter vessels exchanging cargo at a transshipment terminal and be divided into three segments, A1, A2, and A3:

A1: Transport within the Trondheimsfjorden region, Norway

A2: The transport between Rotterdam, Netherlands, and Hitra Kysthavn (Sandstad), Norway

A3: The terminal activities at the port of Hitra Kysthavn (and Orkanger, Trondheim, Skogn), Norway

The AEGIS concept requires a different operating method than today's practice. The idea behind the concept is to have one or several mother vessels sailing between Rotterdam and Norway with large cargo volumes and a higher level of automation to achieve benefits due to economy of scale. When the mother vessels travel along the west coast of Norway, a number of daughters can accommodate the transport of cargo between a set of regional ports and the mother vessel. In this project, we will focus on the Trondheimsfjord, but the concept can be adapted to other parts of the further route south on the west coast of Norway down to Rotterdam, as well as other regions worldwide. There are several reasons for introducing a mother–daughter concept. The distance between Rotterdam and the Trondheimsfjord and further north will not allow operation by only one vessel with a fixed, regular weekly schedule. The distance is significant, about 800 nm between Rotterdam and Trondheim, which is estimated to be more than two days of sailing one way with a speed of 15 knots. The average loading speed of containers is 30 per hour. The distance from Hitra to Trondheim is 48 nm, which means it takes extra three hours to sail the distance, and to Skogn, it will be about 72 extra nm which means 5 hours extra sailing time with a speed of 15 knots in one direction out of Hitra. This means that the utilization of a mother will be much better if the cargo can be picked up in Hitra, at the same time as it will take too long time to visit smaller and remote ports to pick up a small number of containers.

Additional to the sailing and cargo handling time, we should also consider mooring time, which will be significant. A roundtrip between Hitra Kysthavn and Skogn via Orkanger and Trondheim takes 16 hours at a speed of 12 knots. Mooring, loading, and discharging time will come on top of this. The daily operational cost of a mother is higher than for a daughter, as a larger vessel consumes more energy (among other things). A daughter vessel will be significantly smaller and allowed to operate at a lower speed, which reduces energy consumption. The daughter vessel will not have the same time constraints as the mother, as it only operates within the fjord and transports cargo between the local ports in the region. In the studies, we are also simulating the possibility of having more than one daughter in operation.

A mother vessel must operate with a higher speed due to time and transport constraints with respect to requirements in Rotterdam, such as reaching the deep-sea schedules. Another factor is that some of the smaller ports are too small for a mother vessel, and the quay capacities or infrastructure cannot allow port calls by a bigger vessel. To secure a successful transport system with a mother and daughter vessel, cargo transshipment must be efficient, cost control, and optimized. This requires an efficient transshipment terminal that can provide services for both mothers and daughters, and not least to the cargo owners.

In the rest of this section, the baseline scenario and AEGIS scenario for mother and daughter ships will be explained. Finally, the specification of new ships for both scenarios will be introduced.

2.1.1 Mother vessel case

The mother vessel route is defined as the existing NCL route from Rotterdam along the Norwegian coastline and finally ends in Orkanger, which visits many ports (up to 22). As baseline, Use Case A uses existing vessels operated by NCL for studies regarding the continental transport, region 1 in Figure 2. These are LoLo vessels with a capacity of around 800 TEUs. On the other hand, for this use case, In the AEGIS scenario, the focus is on the limited part of the existing route: Rotterdam – Hitra Kysthavn, as illustrated in Figure 3. The route is 800 nm, and with an average sailing speed of 15 knots, it will take 53.4 hours. The distance from Hitra Kysthavn to Orkanger is 48 nm, and an average sailing speed of 15 knots takes 3.2 hours. If the mother vessel can drop the sailing to Orkanger, it can save around 6.5 hours of sailing. The total saved time can be significant if the mother-daughter concept is implemented in several regions of the coast, resulting in either shorter turnover time for the route or the possibility of sailing further north for more cargo.

Figure 3: The mother ship route (only Rotterdam - Hitra Kysthavn).

The mother vessel use case (A2) is listed in Table 1. It should be noted that in the AEGIS scenario the vessel fleet will consist of four ships, two new concept vessels, and two of the existing (NCL) vessels. On the other hand, the non-AEGIS scenario consists of four NCL vessels that voyage during the week between the route mentioned.

Table 1: Scenario Rotterdam – Hitra Kysthavn (mother vessel).

Element	Description
Scenario title	Rotterdam – Hitra Kysthavn
Distance and sailing time	Rotterdam – Hitra Kysthavn: 800 nm, average sailing speed: 15 knots Sailing time: 800 nm /15 knots = 53.4 hours
Cargo Type (containerized)	Abrasive grain Silicon carbide Hydrogen Peroxide Wastepaper General cargo Paper, silicone, alloys for the foundry industry, carbon and micro silica.
Transport Requirements	Container vessel, LoLo, with own cranes (two), used at Norwegian terminals (in this case, Hitra Kysthavn) Terminals/quays • No cranes or other container handling equipment in Norwegian terminals • For port of Rotterdam, shipboard cranes cannot be used Dependent on deep-sea schedule for carriers out of Rotterdam

2.1.2 Daughter vessel case

The scenario is shown in Figure 4 and is a route that serves the terminals with the biggest cargo volume potential in the Trondheimsfjord. The route goes from Hitra Kysthavn via Orkanger and Trondheim and completes its journey in Skogn. The transport distance is about 100 nm one way. The daughter vessel can serve the mother vessel(s) with cargo originating from ports in the region and, of course, supply the ports in the area with cargo from the mother vessel(s). If, for instance, containers from rail transport are unloaded in Trondheim or Skogn, the containers can be transported by the daughter's vessel to Hitra Kysthavn, where they will be further transported by the mother vessel.

Figure 4: Skog n Trondheim Orkanger Hitra Kysthavn (incl. Holla), map and route from Logistics Analysis tool.

The route in Figure 4 has been further divided into four different routes, as shown in Figures 5 to 8.

It is anticipated that some of the smaller terminals along the route will have to offer self-service, which means that the daughter vessel autonomy level must enable moving a container from the quayside onto the vessel without human involvement at the quayside. It is therefore necessary with a geared daughter vessel that can handle containers at any terminal in the fjord.

In summary, the fleet and corresponding routes have been chosen as follows for the AEGIS scenario:

1. 2 vessels with a capacity of 60 TEUs
2. Daughter vessel 1 sailing route 2 and 3 with corresponding cargo volume
3. Daughter vessel 2 sailing route 1 and 4 (to Orkanger and Holla from Hitra Kysthavn)
4. Sailing speeds: 8 knots for vessel 1 and 5 knots for vessel 2
5. Frequency of sailings: Twice a week for vessel one and three times a week for vessel 2

Figure 5: Route 1: Hitra Kysthavn - Orkanger- Hitra Kysthavn.

Figure 6: Route 2: Hitra Kysthavn – Orkanger – Trondheim – Skogn- Hitra Kysthavn.

Figure 7: Route 3: Hitra Kysthavn – Trondheim - Skogn- Hitra Kysthavn.

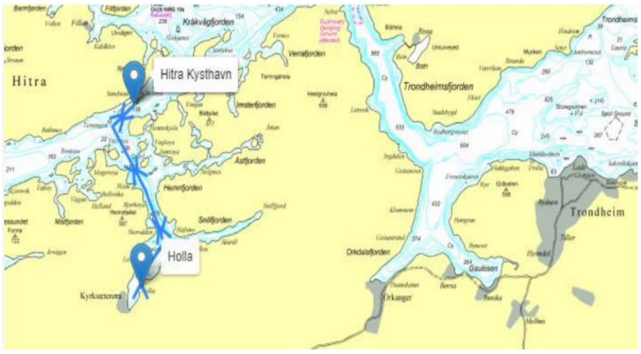


Figure 8: Route 4: Hitra Kysthavn – Holla- Hitra Kysthavn.

It should be mentioned that the baseline scenario in this case (region 2 in Figure 2) is trucks that serve the region today. Based on deliverable D8.2 (Transport system specification– Case A) [2], the (one way) distance for these four routes in both scenarios is addressed in Table 2.

Table 2: Distances for the daughter case (sea and road).

Number of routes	AEGIS (vessels)	Baseline (trucks)
Route 1	96 nm	138 km
Route 2	183 nm	368 km
Route 3	162 nm	361 km
Route 4	28 nm	154 km

2.1.3 Ships specification

In WP4 (Green advanced vessels), low-energy, low-emission, and logistics-adapted advanced vessel concepts are investigated and developed with the aim of enabling more efficient and green waterborne transport. Its most recent deliverable is D4.2 (Specification of vessel types for use cases) [4]. Its main objective is the development of advanced green vessel concepts which fulfill the requirements of the three different use cases. For the report state of concept development, several vessel types for each use case are presented in detail, for example, in propulsion specification and onboard handling systems.

The actual envisioned vessel concepts for Use Case A are presented in Tables 3 and 4. A mother-daughter concept was identified as a feasible solution for this use case. Hitra, an island outside the

Trondheim fjord, was chosen as the hub for the transshipment between the mother and the daughter vessels.

For the mother vessels, we considered a new short-sea shipping from Rotterdam to the Trondheim region with a capacity of approx. 1100 TEU. Also, the propulsion system of this conceptual ship would be a hybrid of methanol and battery (the main fuel is methanol). ,

For the daughter vessel in use case A, we considered a self-propelled (fully electric) shuttle with a capacity of approx. 60 TEU. For this case we have two ships that can run inside the Trondheim fjord, collecting cargo at different smaller ports or industry sites.

Table 3: Use Case A mother vessels.

Data	Mother Vessel
Vessel Description	1100 TEU Container Ship, incl. places for 20, 40, 45 foot and reefer containers
Vessel Type	Container SSS vessel
Route deployed in	Rotterdam - Hitra
Length Overall, Loa	143.90 m
Length Waterline, Lwl	142.20 m
Length between perpendiculars, Lbp	133.20 m
Beam Overall, Boa	25.50 m
Beam Waterline, Bwl	25.50 m
Design Draft, T	8.16 m
Depth to main deck, D	14.10 m
Displacement	18,997 tonnes
Gross Tonnage	10,890 GT
Wetted Surface	4422.50 m^2
Waterplane Area	2797 m^2
Bulb Area	15.40m^2
Half Entrance Angle	19.76°
Stern Type Coefficient	-25
Main Engine Type	Methanol combustion engine (“methanol ready”) and battery support for Norwegian Fjords
Main Engine Fuel Type	Methanol and battery
Design Speed	15 knots
Vessel capacity	1100 TEU
Cargo Handling Equipment	2 triple-joint cranes (CT/MCG), reach 32m and SWL of 45t
Autonomy Level	Medium autonomy level (2)

Table 4: Use Case A daughter vessels.

Data	Daughter Vessel
Vessel Description	60 TEU, incl. places for 20, 40 feet containers
Vessel Type	Container vessel for TA1-2, maybe up to TA3
Route deployed in	Daughter 1: Hitra Kysthavn – Orkanger – Trondheim – Skogn & Kysthavn – Trondheim - Skogn Daughter 2: Hitra Kysthavn – Orkanger & Hitra Kysthavn – Holla
Length Overall, Loa	65.00 m
Length Waterline, Lwl	65.00 m
Length between perpendiculars, Lbp	62.70 m
Beam Overall, Boa	11.45 m
Beam Waterline, Bwl	11.45 m
Design Draft, T	2.20 m
Depth to main deck, D	5.00 m
Displacement	1,270 tonnes
Gross Tonnage	895 GT
Wetted Surface	843 m^2
Waterplane Area	670 m^2
Half Entrance Angle	30.8°
Stern Type Coefficient	-22
Main Engine Type	Fully electric
Main Engine Fuel Type	Battery
Design Speed	Daughter 1: 8 knots Daughter 2: 5 knots
Vessel capacity	60 TEU
Cargo Handling Equipment	On-board Reach Stacker (placed on lift + ramp)
Autonomy Level	High autonomy level (3-4)

Furthermore, based on information provided by ISE, the speed-power diagram for the mother and daughter vessels is shown in Figures 9 and 10, respectively.

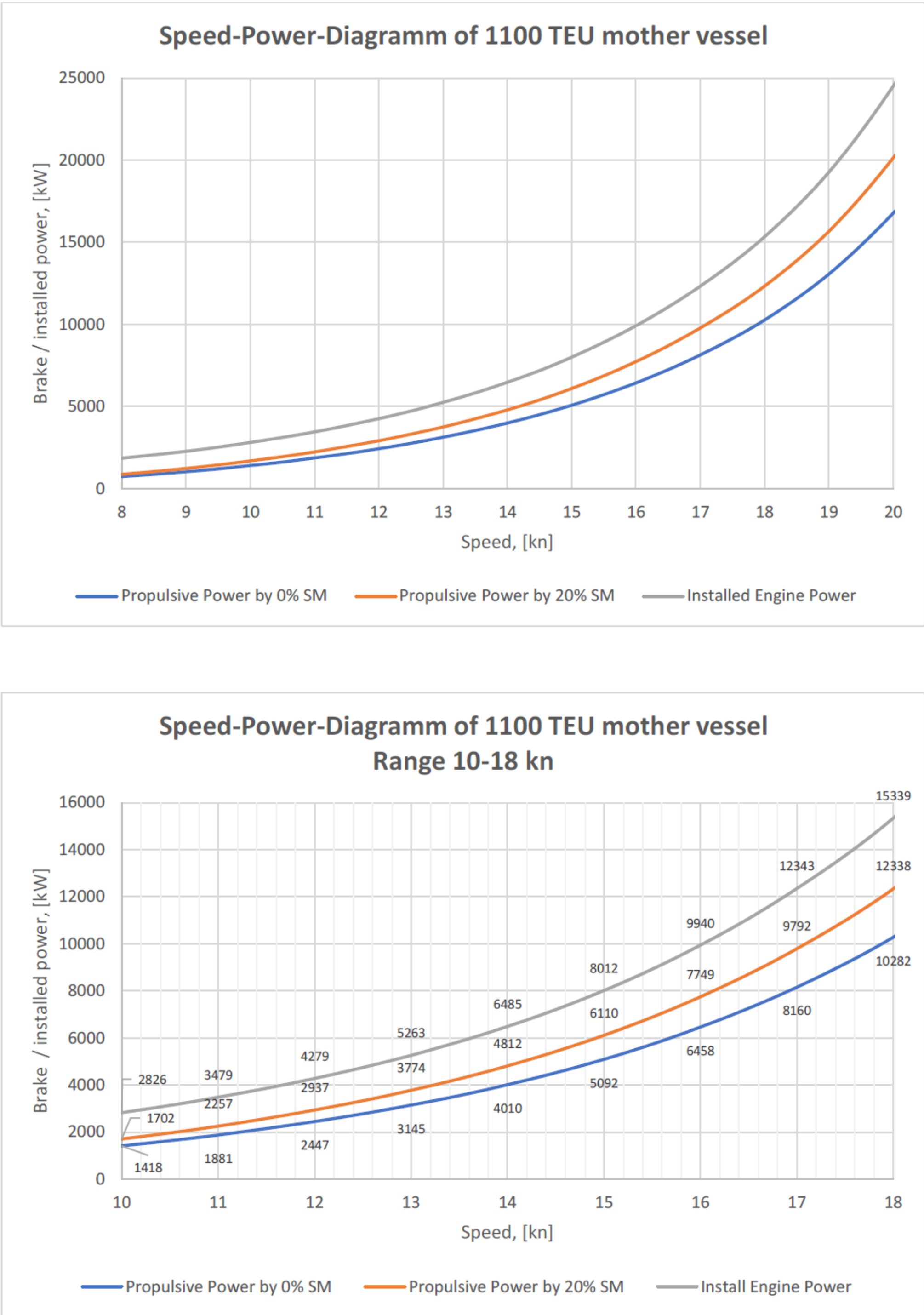


Figure 9: Use Case A, speed-power diagram of mother vessel. Source: ISE.

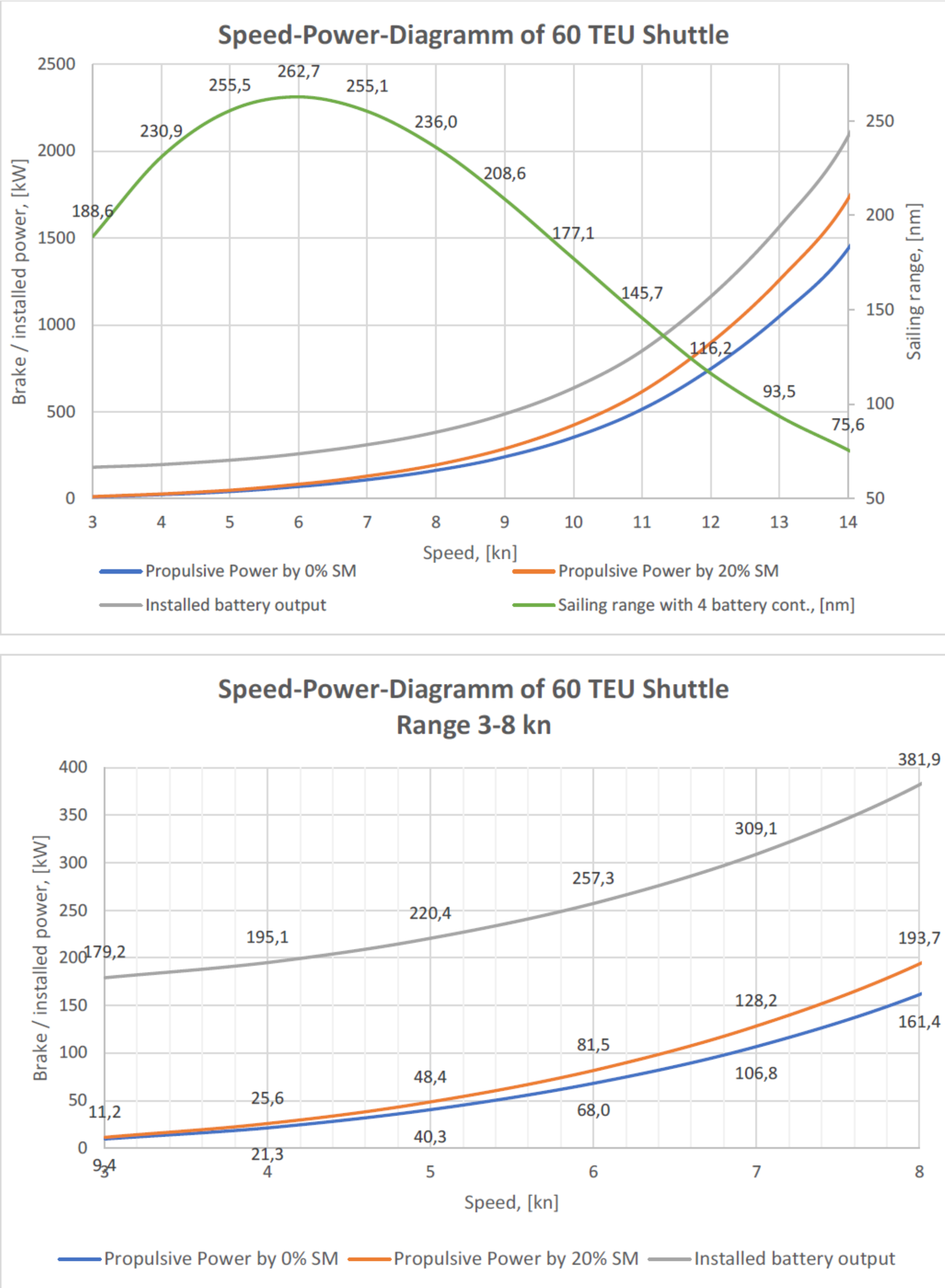


Figure 10: Use Case A, speed-power diagram of daughter vessel. Source: ISE.

2.2 Use Case B

Use Case B examines Belgium and Netherlands's short sea and inland interface. The two countries are significant hubs for cargo transportation from and to Europe. Rotterdam, located in the Netherlands, is the largest port in Europe and one of the largest ports in the world, with shipping lines established to all corners of the globe. Everything from dry bulk to liquid bulk, containers, and breakbulk, in which category one finds RoRo cargo, is passing through the port, constituting a total of 436,800,000 tonnes of cargo in 2020. The second busiest European port is Antwerp, in Belgium. Furthermore, the port of Ghent is part of the so-called North Sea Port – a conglomeration of Vlissingen, Terneuzen, and Ghent (see Figure 11). Consequently, the port extends over 60 kilometers, 9.100 hectares (ha), across two countries: Belgium and the Netherlands. It is ranked number 9 of all European seaports measured in the volume of goods and number 6 of seaports in the Hamburg – Le Havre range also measured in the volume of goods. Freight transportation through the inland waterways is already well developed, but there is still space for more cargo to be distributed via waterways. This region is ideal for the purposes of AEGIS, and this is why it was chosen for this Use Case B.

Figure 11: The ports within North Sea Port (Source: Deliverable D9.1 (Analysis of transport needs – Case B) [5]).

In summary, the objectives of UCB are to:

- Apply and validate the results from WPs 2-7 into use-case B, which examines the short sea and inland interface in Belgium and Netherlands, with partner DFDS being involved as a WP leader. The area under examination involves the ports of Rotterdam, Antwerp, Ghent, and Zeebrugge.
- Use the above results to bring cargo as close to the end destination as possible with small vessels with zero emission propulsion (battery, fuel cells, etc.).
- Address possible administrative and regulatory challenges and bottlenecks that should be tackled for efficient and environment-friendly solutions.

The main objective of the transport system for use case B is to shift cargo from the road to an inland waterway barge service, as illustrated in Figure 12. With this goal in mind, the transport system for use case B was understood as an interaction of advanced inland navigation vessels serving two specific flows in the region of Belgium and the Netherlands, of routes within these flows, of the ports along these routes, and of the transshipment from vessel to port.

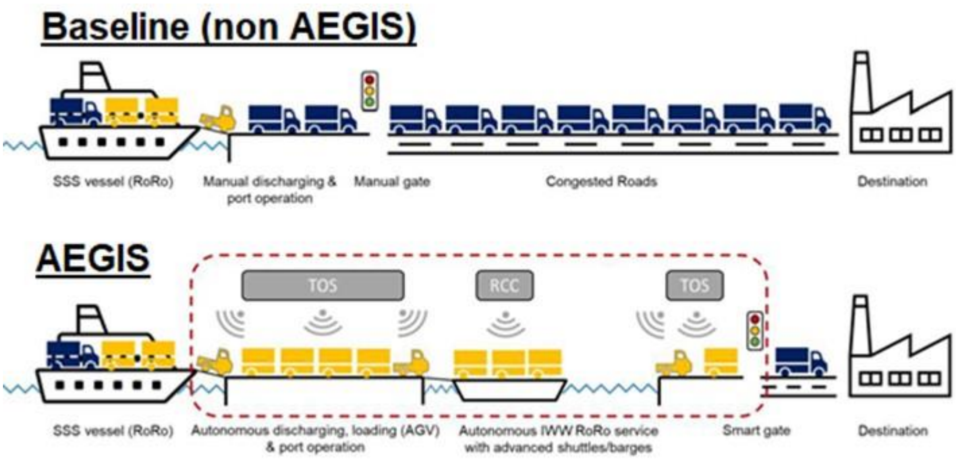


Figure 12: Baseline vs AEGIS scenarios. Source: DFDS.

Use case B involves two scenarios (Figure 12):

a) The baseline (non-AEGIS) scenario, which involves shipping cargo from Ghent to Rotterdam (and vice versa) by truck.
b) The AEGIS scenario, in which cargo is moved from Ghent to Rotterdam (and vice versa) via a canal onboard an AEGIS vessel (Figure 13).

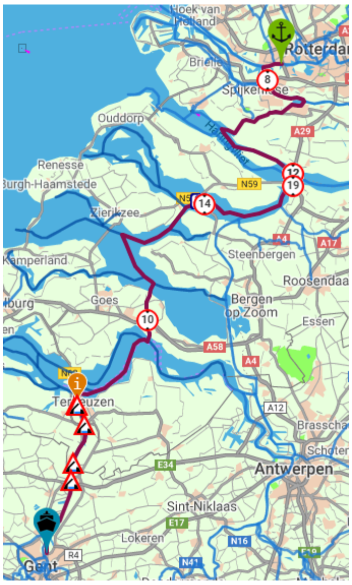


Figure 13: Rotterdam – Ghent route scenario for UCB

A main reason for selecting this route is because DFDS has terminals both in Rotterdam and Ghent – terminals which both are experiencing increasing cargo volumes and expansion projects in order to keep up with this cargo volume. Therefore, potentially redirecting cargo between the terminals into the short sea shipping, especially from Rotterdam to Ghent, would help alleviate these issues and could potentially have a broader, positive influence on the general flow overseas of cargo in and out of the terminals.

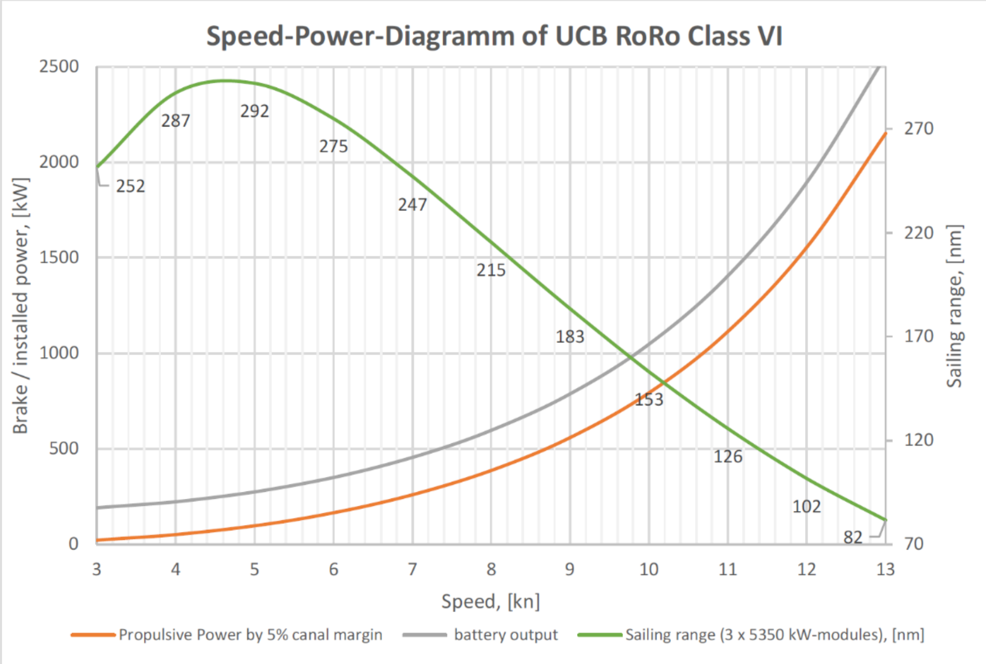
2.2.1 Ships specification

The envisioned vessel concepts for Use Case B are presented in Table 5. RoRo vessel concepts, i.e. for trucks, trailers, or other "rollable" cargo units, of the CEMT class VI concept w/transversal loading (double deck) was developed for this use case. It was tried to keep the draught as low as possible (in the range of 4.5 m) to be able to sail even on low water levels during summer periods. For CEMT class IV+, a transversal loading of trucks or trailers can be realized. Therefore, a RoRo concept with a capacity of 69 trucks/trailers was designed with a resulting vessel breadth of 18.1 and 15 m for trucks and trailers, respectively.

Table 5: Use Case B vessel.

Data	Vessel
Vessel Description	IWW CEMT Class VI
Vessel Type	RoRo IWW vessel
Route deployed in	Rotterdam - Ghent
Length Overall, Loa	139.20 m
Length Waterline, Lwl	125.50 m
Length between perpendiculars, Lbp	124.30 m
Beam Overall, Boa	15.00 m
Beam Waterline, Bwl	15.00 m
Design Draft, T	4.50 m
Depth to main deck, D	9.35 m
Displacement	6,716 tonnes
Gross Tonnage	4,630 GT
Wetted Surface	2,569 m^2
Waterplane Area	1794 m^2
Half Entrance Angle	43.60°
Stern Type Coefficient	-23
Main Engine Type	Fully electric, swappable batteries
Main Engine Fuel Type	battery
Design Speed	7- 8 knots
Vessel capacity	69 trailers/trucks (incl. 2–3 battery trailers/containers)
Cargo Handling Equipment	Lift and ramp; optional AGV (if only trailer)
Autonomy Level	high autonomy level (3-4)

Furthermore, based on information provided by ISE, the speed-power diagram for the vessel is shown in Figure 14.



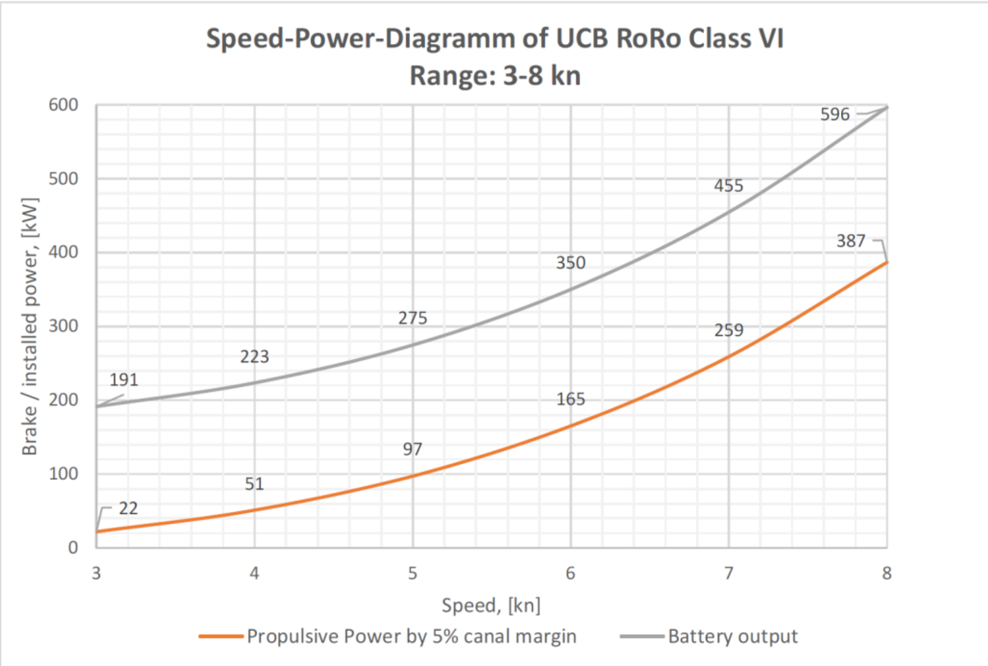


Figure 14: Use Case B, speed-power diagram of CEMT class VI vessel. Source: ISE.

2.3 Use Case C

Use Case C examines cargo traffic in the areas around Vordingborg and Aalborg and looks at possibilities to increase the use of waterborne transport by increasing automation of cargo handling and some types of ships. It will also look at possibilities for restructuring the terminal network and also increase inbound and outbound transport to the rest of Europe, in particular, Germany and possibly the Baltic states.

The objectives of UCC are to:

- To validate outputs from WPs 2-7 in two Danish ports, the Port of Vordingborg and the Port of Aalborg.

- To use the ports of Vordingborg and Aalborg as practical test sites for the application of the technical developments of AEGIS in redesigning logistic systems, developing new terminal concepts, applying automatic cargo handling, and improving digital connectivity.
- To use the ports of Vordingborg and Aalborg to address regulatory challenges and constraints to enhance new waterborne logistics solutions.

In the first Use Case C deliverable, D10.1 (Potential transfer from road transport to short-sea-shipping in Denmark) [6], the potential gross volume that can be shifted from road transport to short-sea shipping in Denmark, categorized by different goods types, was examined. This encompasses analyses of the price structure for transportation of the goods by both road transport and short-sea shipping, including an analysis of last mile delivery. The report analyses all relevant goods in Denmark, including national and international goods. To have a comparable price structure baseline, it was found that any road transport would need to be more than 150 km in order for a shift to short-sea shipping would be economically viable. This included a last-mile analysis. For national goods, emphasis is put on the region of Northern Jutland as well as the Capital Region and Zealand, due to the case focus of the ports of Aalborg and Vordingborg, as well as the distance between these regions. Approximately 1 million tonnes of goods are transported to/from Northern Jutland (mostly of relevance to Port of Aalborg) and Zealand (mostly of relevance to Port of Vordingborg). Applying a scenario-based analysis, it was estimated that 177,540 tonnes of national goods, covered by 9,899 truck movements, could be shifted to sea yearly in Denmark.

Moreover, it was estimated that the potential gross volume of goods that can be shifted from road transport to short sea shipping (SSS) in Denmark is approximately 5 million tonnes yearly, or about 18% of the relevant goods by truck. It is again important to note that any short-sea shipping solution would be on par or cheaper than a competing direct road solution.

Deliverable D10.2 (SWOT analysis for Port of Vordingborg and Aalborg) [7] conducted a SWOT analysis for the Port of Aalborg and the Port of Vordingborg. The report concluded that Port of Aalborg has a strong financial position compared to its closest competitors. This provides great long-term opportunities to invest in new, autonomous port solutions. Short-term, it can be expected that the closest geographical competitors (the Port of Hirtshals and the Port of Frederikshavn) on RoRo would have a solid counter-reaction for a potential RoRo route. However, due to the CAPEX bindings of these two ports, it is assessed that the Port of Aalborg would have better long-term maneuverability for RoRo and overall terminal investments. Furthermore, the Port of Vordingborg has recently undergone vast development, including a large port expansion. This provides great opportunities yet simultaneously gives financial constraints in terms of investment capacity in the coming years. Possible short-term solutions would be to capitalize on goods that can be overtaken by decommissioned ports in the vicinity and carefully analyze a “virtual terminal» concept for possible RoRo activities.

After several discussions with the partners of this project and examination of several scenarios, the following scenarios for both ports were considered.

<u>*For Aalborg:*</u>

a) a) The baseline (non-AEGIS) scenario involves shipping cargo from the port of Gothenburg to the port of Hamburg (and vice versa) by truck. Specifically, this route consists of Gothenburg to Malmö, Malmö to Copenhagen, and Copenhagen to Hamburg and would be around 644 km.

b) In the AEGIS scenario, cargo is moved from the port of Gothenburg to the port of Aalborg (and vice versa) via an AEGIS vessel and then from the port of Aalborg to the port of Hamburg by trucks. The distance of the sea route is 160 km, and the land-based route is nearly 458 km.

For Vordingborg:

a) a) The baseline (non-AEGIS) scenario involves shipping cargo from the port of Vordingborg to the port of Rostock in Poland by ships and then from the port of Rostock to the port of Elblag in Poland (and vice versa) by trucks. The distance of the sea route is around 49 km, and the land-based route is 750 km.

b) In the AEGIS scenario, cargo is moved from the port of Vordingborg to the port of Elbląg (and vice versa) via an AEGIS vessel (the one specified for use case C- Vordingborg scenario). The distance of the route is 573 km.

2.3.1 Ships specification

According to deliverable D4.2 (Logistics analysis tool initial version) [4], the envisioned vessel concepts for Use Case C are presented in Tables 6 and 7. The diverse cargo and route options lead to the development of different vessel concepts for Use Case C. For the Aalborg case, a RoRo short-sea shipping vessel was studied using Use Case B synergies. A truck/trailer vessel can be adopted from a design for inland waterway conditions to be feasible for short-sea shipping between Denmark and South Sweden. As for use case B, a double-decker solution (combined with a lift system) is used to achieve a capacity of 50 – 60 trucks or trailers. For the Vordingborg case, a mixed container and bulk vessel concept with approx. 3500 tonnes were considered.

Table 6: Use Case C Aalborg case vessels.

Data	Vessel
Vessel description	AHL-case: 55 units SSS RoRo vessel
Vessel Type	SSS RoRo
Route deployed in	Aalborg - Hamburg
Length Overall, Loa	127.47 m
Length Waterline, Lwl	127.42 m
Length between perpendiculars, Lbp	123.40 m
Beam Overall, Boa	16.90 m
Beam Waterline, Bwl	16.90 m
Design Draft, T	4.50 m
Depth to main deck, D	6.35 m
Displacement	8,394 tonnes
Gross Tonnage	5,700 GT
Wetted Surface	2876.21 m^2
Waterplane Area	1919.48 m^2
Half Entrance Angle	19.76°
Stern Type Coefficient	-25

Main Engine Type	Fully electric or Methanol propulsion system
Main Engine Fuel Type	Battery or Methanol
Design Speed	8 knots
Vessel capacity	55 trailers/trucks (37 main deck + 18 tank top)
Cargo Handling Equipment	Lift and ramp; optional AGV (if only trailer)
Autonomy Level	Medium autonomy level (2-3)

Table 7: Use Case C Vordingborg case vessels.

Data	Vessel
Vessel Name	VH-case: Combined SSS/IWW LoLo concepts for bulk & containers
Vessel Type	SSS/IWW LoLo
Route deployed in	Vordingborg - Elbląg
Length (max)	99.00 m
Breadth	15.00 m
Design Draft, T	3.90 m
Max airdraft	9.10 m
Main Engine Type	Methanol propulsion system
Main Engine Fuel Type	Methanol
Design Speed	10 knots
Vessel capacity	3500 tonnes (170 containers)
Cargo Handling Equipment	crane
Autonomy Level	2

Furthermore, based on information provided by ISE, the speed-power diagram for the vessels of Aalborg case for battery and methanol are shown in 15 and 16, respectively. For the Vordingborg case this is shown in Figure 17.

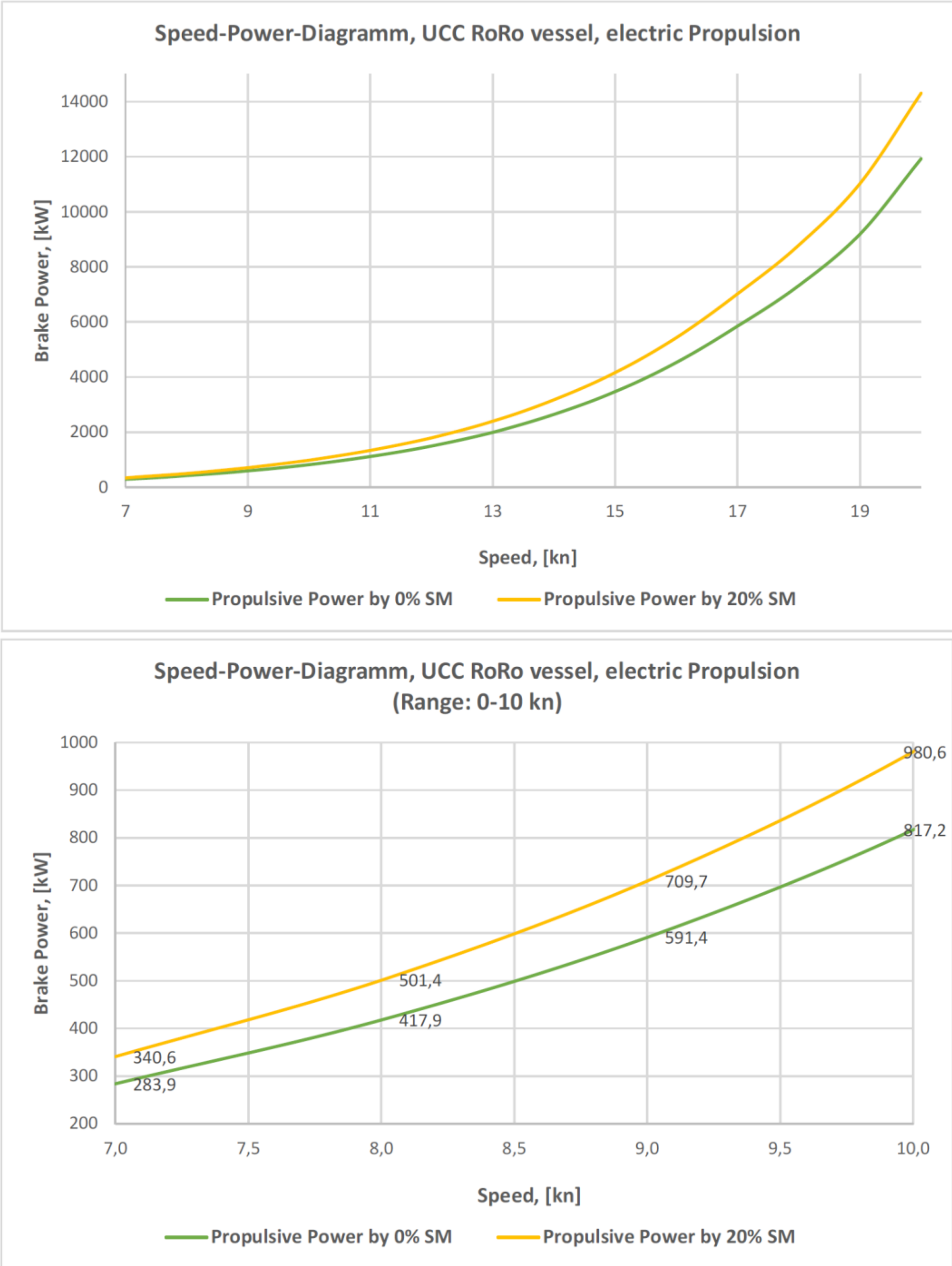


Figure 15: Use Case C, speed-power diagram of Aalborg case vessels (Electric system). Source: ISE.

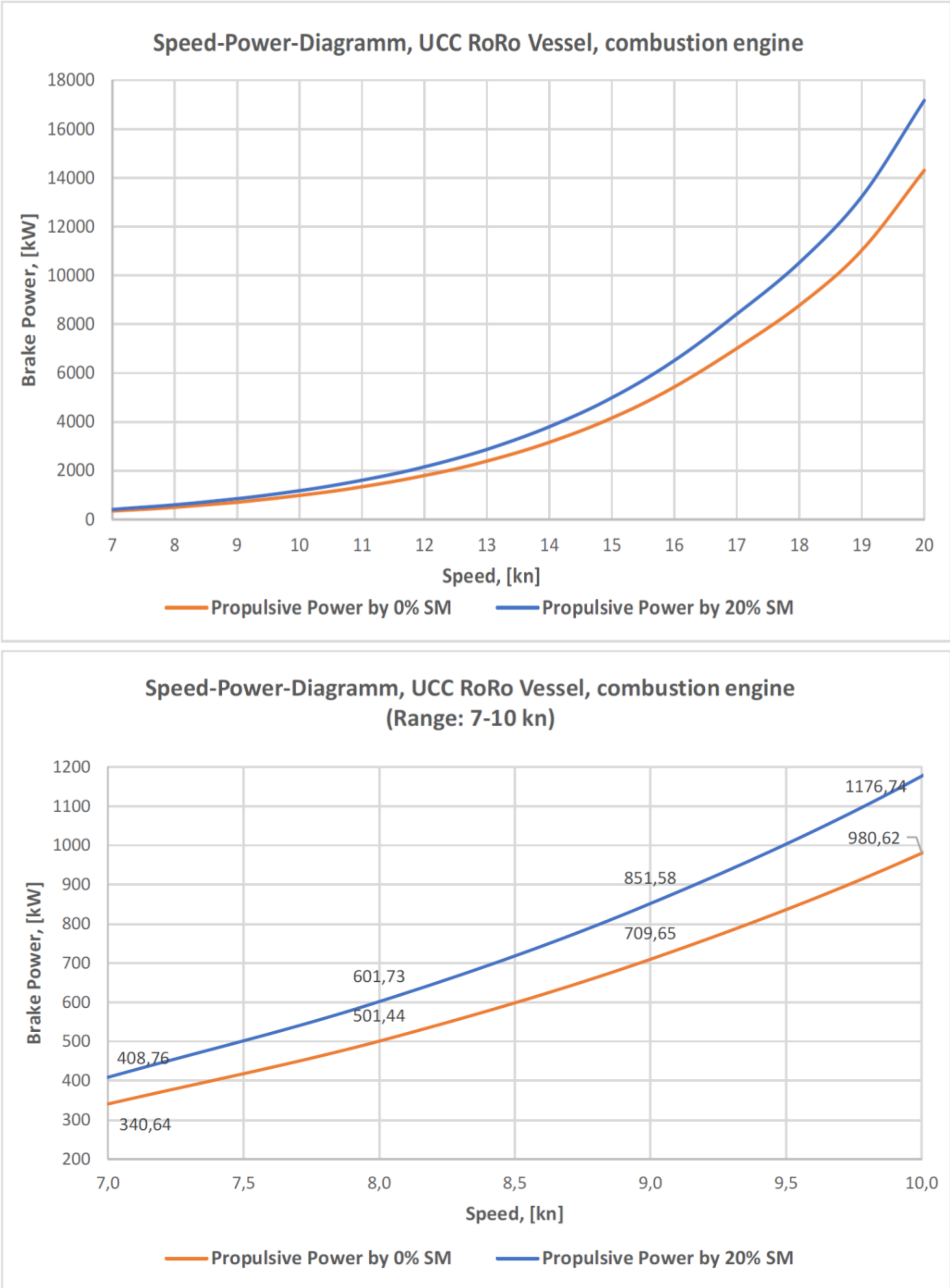


Figure 16: Use Case C, speed-power diagram of Aalborg case vessels (Methanol system). Source: ISE.

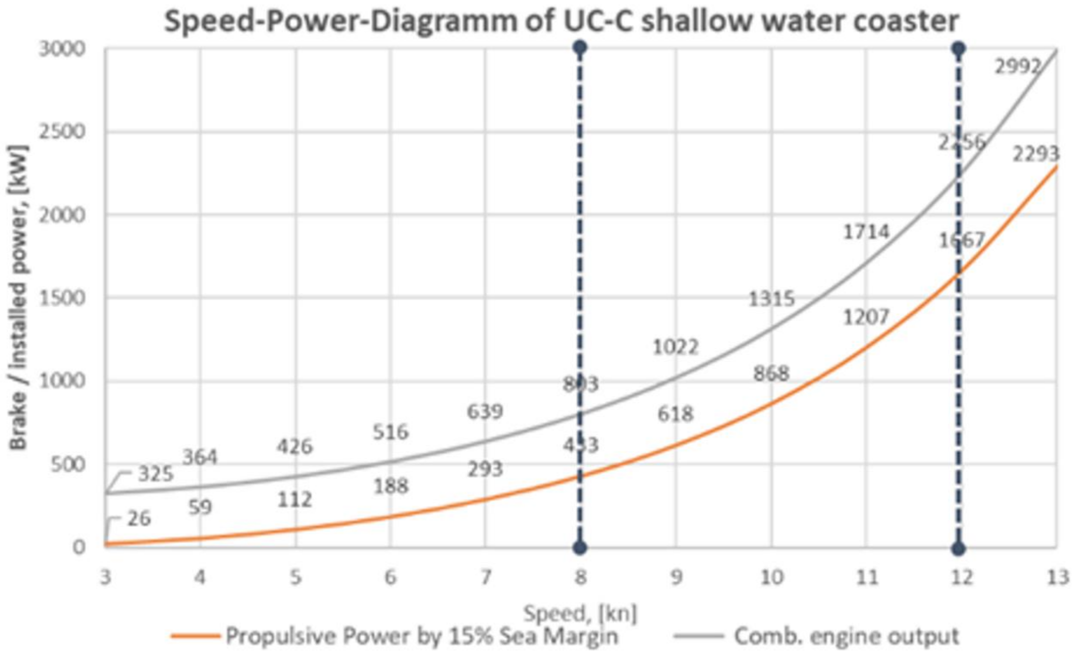


Figure 17: Use Case C, speed-power diagram of Vordingborg case vessel. Source: ISE.

3 Methodolody: evaluation of economic KPIs

3.1 Preamble

The purpose of this section is to present the methodology for evaluating economic KPIs. The methodology describes how the data assembled for each use case scenario are used to perform the economic CBA and assess the economic KPIs.

It is to be understood that any such methodology has two main components or parts:

(a) A general part, which is more or less independent of the use case under consideration.

(b) A specific part, which depends on the use case under consideration.

The above distinction is important, as it is conceivable that the data that is assembled for each use case may ultimately influence and customize the method to conduct the CBA.

The rest of this section first presents how the economic KPIs are calculated based on the data template input that we requested from AEGIS partners. We start by introducing the quantitative modelling framework and the equations that link data input with the required KPIs.

It should be noted that, although in this research a maximum effort has been given to collect as much data as possible, some data were still unavailable by the time this report was being finalized. Also, for some KPIs, precise data would only be available after the real-world implementation of the AEGIS project. For several data, where uncertain, we have made some assumptions and approximations on the missing values and data.

3.2 Framework for the estimation of economic KPIs

Deliverable D7.2 (Report on KPIs) [1] pertaining to the outcome of Task 7.1, presented the different KPIs for evaluating the AEGIS solutions and their comparison with existing transportation options. The process concerned several rounds of discussions, work between the consortium partners and Advisory Group (AG) members, and prioritization of retrieved KPIs. Table 8 is adapted from the above deliverable and presents the finalized economic KPIs that we aim to analyze in this document. It is recalled that the above deliverable stated that these KPIs might be adjusted in the CBA, depending on the availability and quality of data.

Table 8: Economic KPIs (adapted from Table 6 of deliverable D7.2 (Report on KPIs) [1]).

KPI Level	KPI Sublevel	KPI Name	KPI Measurement	KPI Description
Economic	Cost	CAPEX	€	Capital expense
Economic	Cost	OPEX	€	Operating expense
Economic	Cost	Maintenance costs	€	All expenses to ensure the correct operation of an asset and keep reliability high
Economic	Cost	Port charges	€	Fees paid to port authorities for the use of its facilities and services

Economic	Cost	Fuel cost	€/NM	Total amount of money spends in fuel
Economic	Cost	Wages	€	Total amount of money spent on salaries. This includes salaries to personnel employed in the AEGIS control centre.
Economic	Cost	Cargo unit cost	OPEX/TEUs	OPEX divided by the number of cargo units
Economic	Time	Loading time	H	Duration of the loading process
Economic	Time	Sailing time	H	Duration of the vessel voyage
Economic	Time	Unloading time	H	Duration of the discharging process
Economic	Time	Waiting time	H	Time during which cargo is idle or delayed
Economic	Time	Drive time	H	Duration of the trip of the cargo from to its final inland destination, and vice versa
Economic	Time	Punctuality rate	% Of port calls	Mean deviation from expected arrival/departing time.
Economic	Time	Recovery time	H	Time from the detection of a disruption to when full level of performance is restored
Economic	Time	Cargo handling time	TEUs/h	Time to move goods on and off ships plus the terminal handling time
Economic	Others	Energy consumption	kWh	Total energy needed
Economic	Others	Cargo carried	TEUs/ship	Cargo carried from loading to discharging
Economic	Others	Percentage of load	Cargo car/max cap.	Actual cargo carried compared to vessel maximum loading capacity
Economic	Others	Cargo lost	% Total cargo	Cargo unable to be found
Economic	Others	Number of Cyber-attacks	#	Quantity of cyber-attacks suffered
Economic	Others	Restored level of performance	%	How fully performance is restored after a disruption occurs
Economic	Others	Frequency of service	Shipments/week	Number of available sailings per week
Economic	Others	Energy efficiency	%	Energy-expenditure required to achieve a target

Economic	Others	Number of container moves	#TEU/route	Amount of goods shipped per route

Some clarifications are due here, first with respect to wages. With the exception of use case C (Vordingborg sub-case), in which the AEGIS ship is manned by two people, all other AEGIS vessels are considered unmanned. As a consequence, and again with the above sub-case excepted, no wages will be spent on AEGIS crew. However, some wages will be spent on the AEGIS control centre, which in all use cases is assumed to consist of personnel who are assumed to be fully employed in that capacity. In all these cases an estimate of the salaries of this dedicated personnel has been made, the same in all cases. It is assumed that such a control centre will be available for each of the use cases (and in use case C, for each of the two sub-cases).

A second clarification is that in all the wage calculations, wages to any port personnel handling the cargoes loaded to and unloaded from AEGIS ships have been omitted, as this would involve double counting. As terminal handling charges (THC) are typically included in OPEX calculations, it is assumed that these charges cover the salaries paid by the terminal operator to terminal cargo handling personnel, and therefore they implicitly account for port personnel wages.

A third clarification is that we have been unable to estimate the CAPEX of the AEGIS control centre, as this was outside the scope of WP7 and of the AEGIS project. One would imagine that this would depend on where that control centre would be hosted, and on the speficications of the hardware and other equipment that would need to be used. In the best case, such a control centre would be hosted in the premises of the shipping company operating the AEGIS ships, or in the premises of one of the associated ports, and associated on-shore equipment CAPEX would be accounted for as part of the CAPEX of the AEGIS ships. It might also be outsourced to a specialized company.

A final clarification is due with respect to maintenance cost data, which are part of OPEX. These proved elusive to acquire, particularly for the AEGIS solution. In their absence, we have used some estimates (to be further explained later). We conjecture that these estimates probably overestimate the respective costs. In that sense, we believe that the OPEX costs of the AEGIS solution are probably lower than those shown in this document.

3.3 Data templates

To conduct the analysis, it was essential to solicit information on the routes of each case study, as well as the ship concepts developed in WP4 and their technical specifications. To do so, a data template was sent in the spring of 2021 to WP7 partners, which included the leaders of all other technical WPs and the leaders of all three use cases to collect the necessary information. The template format was a spreadsheet file with data requirements on Ship, Route, Cargo, Port, and Others. The full template contains 75 fields to be filled with information. Figure 18 shows a snapshot of the “Route” spreadsheet. Annex A presents the rest of the data template. After this stage, to collect data during this research, we provided several questionnaires and sent them to our partners, such as ISE, SINTEF, Port of Vordingborg, and DFDS, to get more information. To do this, we also had several meetings to get more precise data and made clear our need for them.

Data	Units	ENTER INPUT HERE	COMMENT
Route Length	NM		
Route description including transshipment nodes (ports, other)	Names		
Number of transshipment nodes	#		
Route Cargo Volume A to B	Lane meters/year or TEUs/year		
Route Cargo Volume B to A	Lane meters/year or TEUs/year		
Ship Speed (average)	Kn		
Total Sailing Time	hours		
Total Loading Time	hours		
Total Unloading Time	hours		
Total Terminal Cargo Residence Time	hours		
Other waiting time	hours		
Number of ships on route	#		
Punctuality	%		
Frequency of Service	shipments/week		
Bunkering Possibilities and Availabilities (LNG, Hydrogen, Battery…)	-		
Competing services on route and their shares			
Non-maritime leg of route- type of vehicle	name		
Non-maritime leg of route- total distance	km		
Non-maritime leg of route- total transit time	hours		
Non-maritime leg of route- total cost (last mile)	€		
Any other relevant info.			

Figure 18: The data template circulated to the AEGIS use case leaders ("Route" component).

3.4 Mapping KPIs in terms of use case relevance and context

The complete list of economic KPIs, as seen in Table 8, should be seen as generic for the overall AEGIS project. Some of the KPIs may be more or less relevant for each use case, depending on the overall objective of the use case and the involved stakeholders (and potential decision makers). In addition, the required input data needed to calculate each KPI may not be available in all use cases. This is because we are working with concepts and not actual operations. The latter is most evident when assessing the "to-be solutions" but also for the various "as-is solutions." A lack of reliable and valid input data may pose a challenge. Figure 19 shows this procedure.

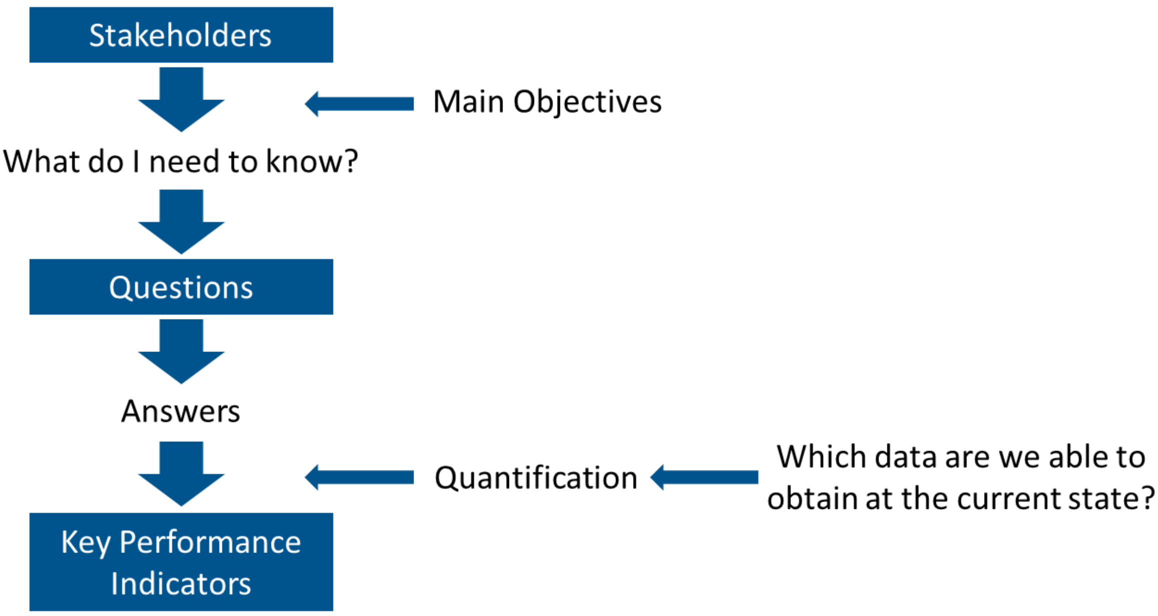


Figure 19: Mapping KPIs in terms of use case relevance and context.

For each use case, the stakeholders assessed each KPI in terms of validity. In addition, all KPIs were evaluated in terms of overall AEGIS validity by AEGIS partners and the AEGIS advisory group. In addition, for each use case, the KPIs were assessed in terms of data availability and accuracy. Finally, for each use case, the KPIs were assessed in terms of interested stakeholders, data input source, and required assumptions (KPI context). In addition to the previously presented Table 8, three extra columns were added:

- Data availability/accuracy was categorized as “yes,” “no,” and “maybe.”
- Prioritization by the AEGIS partners, the AEGIS advisory group, and the specific use case.
- KPIs capture and usage include the interested stakeholder, KPI usage, required data input, input data source, and required assumptions.

In sections section 4, where the KPIs are applied to each use case, we present the final list of KPIs which are relevant and obtainable for the specific use case.

3.5 KPIs calculation

The most critical data for estimating the KPIs pertain to the sailing route (sea distance, voyage duration, ports of call) and the deployed vessels (fuel consumption at service speed, operating costs). From these, most of the KPIs can be calculated. In this subsection, we will show the methodological framework and equations we developed to calculate the economic KPIs shown in Table 8.

3.5.1 Cost KPIs

The first KPIs refer to each ship's cost elements (capital investment, operating expenses excluding fuel, and maintenance). These are planned to be taken as input from the ship operator (actual cost of acquiring the ship, operating costs per year, cost of maintenance). The port charge KPI refers to the port costs for using the facility. Full information on actual port costs in all ports was not available. Each port has its pricing mechanism for its visiting vessels. Cargo handling tariffs for containerized cargo typically depend on the size and type of the container (20ft, 40ft, laden, empty, import, export, transshipped, etc.) and vary among ports. For RoRo cargo, tariffs typically depend on trailer size. Some tariffs are confidential between the port and the shipping company.

A major cost element is the actual fuel consumption per voyage leg, including the fuel consumption at each port. We consider the set of all sailing legs and port visits by voyage during one iteration of a repeating sailing schedule. For example, in the case of a simple service calling only between two ports, we would consider an entire voyage the return trip (sailing from port A to port B, staying at port B, and then sailing back from port B to port A, visiting at port A). For a more complicated voyage with multiple port calls, consider all sailing legs (e.g., from port A to port B, port B to port C, etc.) and stays at each port. In addition, in some cases, we just estimated one way of sailing for baseline and AEGIS scenarios because the cost of going and returning was the same.

This information can be provided by the ship operator directly (for the non-AEGIS solution) or estimated using different modelling approaches. For the latter, we consider the following simplistic approach, with equation 1 calculating the fuel consumption during sailing ($FC_{sailing}$) in per kWh of fuel (note the units):

$$FC_{sailing} = \{EP_{main} + EP_{aux}\} \cdot (sailing\ time) \tag{1}$$

Where EP_{main} and EP_{aux} refer to power (kW) for the main and auxiliary engine that comes from the ISE report (see section 2), respectively. The previous equation assumes that during sailing both the main (for propulsion) and auxiliary (for electricity and onboard energy demand) are operating. However, there might be ships that only use one engine type (for propulsion). To calculate the actual fuel cost $Fuel\ Cost_{sailing}$ (in € per voyage) for the cruise segment, the fuel price is multiplied by the fuel consumption of each machinery operating onboard the vessel during sailing. In case there is different fuel used by the propulsion and auxiliary engines, we respectively use two different terms as FP_{main} and FP_{aux} to signify the price in € per kWh of fuel. The calculation for the total fuel cost is shown equation 2:

$$Fuel\ Cost\ _{sailing} = \{EP_{main}.FP_{main} + EP_{aux}.FP_{aux}\} \cdot (sailing\ time) \quad (2)$$

Equation 2 can be further simplified if all machinery is using the same fuel type (with the same fuel price), with a simple multiplication between *FP* and $FC_{sailing}$.

The fuel consumption at a port in kWh per call (where only the auxiliary engines are operating to cover hoteling demands, including the ship boilers) can be estimated using a similar activity-based approach as follows in equation 3:

$$FC_{port} = EP_{aux} \cdot (time\ at\ berth) \quad (3)$$

With fuel cost shown in equation 4:

$$Fuel\ Cost_{port} = FC_{port} \cdot FP_{aux} \quad (4)$$

Summing the fuel consumption at each leg and each port stay and subsequently multiplying each fuel consumption with the respective fuel price (as different engines may be using various fuel types) can lead to the estimation of the total fuel cost per voyage in equation 5.

$$Fuel\ Cost_{voyage} = Fuel\ Cost_{sailing} + Fuel\ Cost_{port} \quad (5)$$

At this point, it is noteworthy that the total operating costs will need to be compared for the different transportation alternatives. It might be that the use of alternative fuel is more expensive compared to the use of conventional fuel, depending on the prevailing fuel and energy prices. Some of the technologies envisioned in AEGIS are environmentally friendlier but, at the same time, might be more expensive (for example, if hydrogen as a fuel is considered, or battery-powered propulsion that will require significant capital costs).

Alternatively to the above formulas, fuel consumption at sea and/or at berth may be provided:

a. directly via fuel consumption data from the shipping company[1]
b. via use of model tests in towing tanks

[1] EU's MRV (for Monitoring, Reporting and Verification) system for ships of 5,000 GT and above is a mechanism for collecting such data in EU ports, and the data is available via EMSA's THETIS platform. https://mrv.emsa.europa.eu/#public/eumrv

c. via use of computational fluid dynamic (CFD) models

The provision of the speed-power diagram of most AEGIS ships (section 2) by ISE facilitates these calculations. Also, it should also be noted that in some use cases, € per tonne kilometer or € per kilometer should also be calculated. In that case, we have used data that enables the conversion of € per kWh to these other units.

For the trucks in the baseline scenarios, we used the data as per Table 9. Indeed, this type of truck was selected for examination because it is used by DFDS. Like the ship part, we can calculate the total energy consumption of land-based systems by multiplying daily fuel consumption by the duration of travel.

Table 9: The specification and energy consumption of selected truck (source: Podiotis and Daskalaki, 2021 [8]).

Volvo truck name	Volvo FH
Engine	D13k500 Euro 6 Diesel Engine
Max power output at 1530-1800 r/min	500 hp (368 kw)
Fuel	Diesel EN590
Consumption	26 Liters/100 km
Emission standards	Euro 6

We finally note that future fuel prices in Europe may include a fuel, carbon tax, or a carbon price traded in the EU carbon market. The impending inclusion of shipping in the EU Emissions Trading System (ETS) might make such an inclusion a reality. No such carbon prices, and their associated costs, have been considered in the present economic analysis, as none are currently applicable. However, and for the reason stated above, the environmental KPIs that will be calculated in the context of Task 7.3 (Environmental analysis), under the proper circumstances, also have economic repercussions and might have important policy ramifications. It is expected that in the final Task of WP7, Task 7.5 (Identification of win-win solutions), this issue will be addressed.

3.5.2 Time KPIs

The second group of economic KPIs focuses on time. The first two KPIs concern the loading and unloading time of the vessel (measured in hours) while at the port, respectively. This time depends on the terminal's productivity in handling the vessel, as well as the vessel’s own productivity, the total cargo that is onboard the ship (for unloading), and the cargo volumes to be loaded. The total loading and unloading times vary across different ship sizes and types. This depends on the number of cranes assigned to the vessel for container terminals and the productivity (TEU moves per hour). For Ro-Ro ships, the efficiency of the loading and unloading operations depends on the vessel's layout, the width of the ramp, and the sequence the operators follow. In most SSS routes, this time is estimated based on the number of vehicles and unaccompanied trailers to be loaded on the vessel. An upper bound on the total loading and unloading time can be evaluated based on the published schedule of the service (e.g., the difference between arrival time and next departure at the port of call). In our work, we use the following relationship to estimate the composite cargo handling time (CHT) KPI:

$$CHT_j = \frac{Nmoves_j}{Cargo\ handling\ rate} \quad (6)$$

where $Nmoves_j$ is the total number of moves for each port call j.

It should be noted that the cargo handling rate depends on many features, such as the number of cranes, the type of equipment, the degree of automation of equipment, and the skill level of manpower which could be different based on the type of ships and ports.

For sailings between two ports (for example the mother vessels in Use Case A) the total number of moves $Nmoves_j$ depends on the nominal capacity of the vessel (in TEU or lanemeters depending on the ship type), and the cargo capacity utilization rate of the vessel that is expressed as a percentage, and shown in equation 7.

$$Nmoves_j = Vessel\ capacity\ \cdot cargo\ capacity\ utilization \quad (7)$$

For the case of daughter vessels with multiple port calls, the number of moves (and thus the loading/unloading time) must be estimated based on the cargo to be loaded on the ship and cargo to be discharged to the port at each node j, and a summation over each node to estimate the total number of moves in the voyage. It is to be understood that in the multiple port case the number of moves in each port may be well below the capacity of the vessel.

The sailing time (expressed in hours) KPI can be retrieved either from the published schedule of service or by considering the route's sailing distance (typically expressed in Nautical Miles – NM) and the planned service speed (expressed in knots). Thus, we use equation 8:

$$Sailing\ time\ = \frac{Sailing\ distance}{service\ speed} \quad (8)$$

A note here is that in our analysis service speed is assumed a fixed and known input, and not a decision variable. Allowing service speed to change would have ramifications on a number of KPIs, including economic KPIs such as OPEX, fuel cost, time, frequency and others, and environmental KPIs such as emissions. It may also impact the number of ships necessary for the service.

Adding the sailing time with the terminal time (at port of origin and port of destination) with the waiting time at the port provides the total transportation time at each leg of the voyage. The waiting time could be due to idling during intermodal changes (for example until the truck or rail car picks up the cargo), or until the transshipment (from mother vessel to daughter or vice versa) takes place. Considering also the potential delays in sailing (for example due to rough weather or any other unexpected event during sailing), it is possible to estimate the total transportation time. The total transportation time (in hours) is retrieved by summing across all *N* voyages where index *i* denotes each leg, and adding the driving time KPI (for cargo that is at some point moved via road), and any delays during each sailing leg.

$$Transportation\ time = \sum_{i}^{N} (Sailing\ time_i + waiting\ time_i + \ delay\ time_i + CHT_j) + drive\ time \tag{9}$$

3.5.3 Other KPIs

The last group of KPIs contains somewhat more diverse KPIs with some economic repercussions but are not directly translated into measuring efficiency in monetary or time units. For example, the first KPI is energy consumption. For ships that use electricity at part of the voyage (for example, when powered by batteries or for shore power applications at berth), reduced energy consumption will translate to reduced cost (for purchasing electricity at the grid or charging the batteries) and reduced emissions. Other KPIs also include those relevant to the actual cargo that is carried. The first is the quantity of cargo (in TEUs or lane meters, depending on the ship type). This is linked with the capacity utilization KPI through the following equation:

$$Cargo\ carried = Capacity\ utilization\ \cdot Vessel\ capacity \tag{10}$$

Two KPIs refer to cyber-attacks and the recovery time for the restored level of performance following an attack.

The last economic KPI is the frequency of service (sailings per week), which can be used to estimate the revenue generated by the deployed services. The frequency of service is linked with other route data: cargo carried in TEU or lane meters per sailing and total cargo throughput in TEU or lane meters per week between the origin and destination of the cargo. This is shown in equation 12:

$$frequency\ of\ service = \frac{total\ cargo\ throughput}{Cargo\ carried} \tag{11}$$

4 Application of economic KPIs on Use Cases

In this section we have calculated the KPIs relevant to each Use Case in baseline and AEGIS scenarios. Also, we have compared these scenarios to investigate the advantages of each of them.

4.1 Use Case A

The final list of relevant and obtainable KPIs for the specific UCA for the mother and daughter cases are presented in Tables 10 and 11, respectively. This is the result of the mapping of the KPIs in terms of use case relevance and context, as previously described.

Table 10: Economic KPIs for Use Case A- Mother Vessel.

KPI Level	KPI Sublevel	KPI Name	KPI Measurement
Economic	Cost	CAPEX	€
Economic	Cost	OPEX	€/week
Economic	Cost	Maintenance costs	€/week
Economic	Cost	Port charges	€
Economic	Cost	Fuel cost	€/week
Economic	Cost	Fuel cost	€/kWh
Economic	Cost	Wages	€/week
Economic	Cost	Total Cost Per Unit Cargo	€
Economic	Time	Loading time	H
Economic	Time	Sailing time	H
Economic	Time	Unloading time	H
Economic	Time	Waiting time	H
Economic	Time	Cargo handling time	Number of Cargo/H
Economic	Others	Energy consumption	kWh/week
Economic	Others	Cargo carried	Number of Cargo/Ship
Economic	Others	Percentage of load	Cargo Car/Max Capacity
Economic	Others	Frequency of service	Shipments/week
Economic	Others	Energy efficiency	%
Economic	Others	Number of container moves	Number of Cargo /Routes

Table 11: Economic KPIs for Use Case A- Daughter Vessel (adapted from Table 6 of deliverable D7.2: (Report on KPIS) [1].

KPI Level	KPI Sublevel	KPI Name	KPI Measurement
Economic	Cost	CAPEX	€

Economic	Cost	OPEX	€/week
Economic	Cost	Maintenance costs	€/week
Economic	Cost	Port charges	€
Economic	Cost	Fuel cost	€/Per week
Economic	Cost	Fuel cost	€/km
Economic	Cost	Fuel cost	€/tkm
Economic	Cost	Wages	€/week
Economic	Cost	Total Cost Per Unit	€
Economic	Time	Loading time	H
Economic	Time	Sailing time	H
Economic	Time	Unloading time	H
Economic	Time	Waiting time	H
Economic	Time	Cargo handling time	Number of Cargo/h
Economic	Others	Energy consumption	kWh/week
Economic	Others	Cargo carried	Number of Cargo/Ship
Economic	Others	Percentage of load	Cargo Car/Max Capacity
Economic	Others	Frequency of service	Shipments/week
Economic	Others	Energy efficiency	%
Economic	Others	Number of container moves	Number of Cargo /Routes

Based on the questionnaires shown in Annex A, we have made efforts to collect data from our partners and stakeholders. For missing data, we made some approximations to estimate them. These KPIs are explained in Table 12, and the associated approximations to circumvent the lack of data are also explained in that table.

Some clarifications follow.

Vessels have two types of energy consumption: one is related to sailing (at sea) consumption, and the next is relevant to port (at berth) consumption. For the sailing consumption, we used the data that comes from ISE, which was addressed in Section 2. On the other hand, for the estimation of port consumption based on a discussion with SINTEF, we decided to use two new VFD generation cranes for the mother case (see Table 17).

Since the propulsion system of the mother vessel is a hybrid fuel system of methanol and battery, to calculate the energy consumption, we need the percentage of each of them. In accord with SINTEF Ocean, since methanol fuel will be the ship's main fuel, 90% of the consumed energy is allocated to methanol and 10 % to the battery.

As stated in this section, we did not have sufficient data to estimate OPEX for UCA, and to deal with this issue, we used the approximations listed in Table 12.

Also, fuel price in a week was estimated based on equation 12.

$$\text{Fuel Cost } (€/week) = Energy\ efficiency\ (KWh/week) * Fuel\ Cost\ (€/KWh) \quad (12)$$

Table 12: Lack of data and associated approximations in UCA.

KPIS	Explanation
OPEX	For the mother vessels, we calculate this KPI for both kinds of ships by a summation of maintenance cost, fuel cost, wages, and THC. For the daughter vessels, based on the data from ISE, OPEX cost without considering THC is around €9600 per week. So, we add this number by THC to calculate the OPEX cost of this type of ship.
Maintenance costs	For the AEGIS mother ship, the maintenance costs, according to ISE data are €29,000 per ship (plus taking into account the crew on deck due to autonomy level 2, which also requires a small number of crew on deck). It is important to mention that the share of this cost in the total OPEX cost is insignificant, and therefore it will not have a significant impact on the results. For the daughter vessels, as we know the wages, THC, and fuel cost, we can calculate the maintenance cost by subtracting the OPEX cost from the sum of these numbers.
Port charges	We did not have detailed specific data for terminal handling costs for the mother and daughter vessels. However, we assumed 60 Euros per TEU based on deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0, which is a kind of average cost price.
Wages	As stated earlier, for the AEGIS solution, wages will have to be estimated for personnel in the control centre. At least six employees with a rotating schedule are necessary to operate that control room[2], and DFDS estimated that salary costs are estimated at around €50,000 per month, which means it should be around €8400 per person per month. Also, because this expense will be applied to both the daughter ship case and the mother ships case, for accounting purposes we have equally split these wages among the mother and daughter vessels. We have also assumed that 15 crew members[3] are needed for the conventional container ships, with a yearly salary per person is 460,774 NOK (€41,900) in Norway[4] and €44,600 in the Netherlands[5].
Waiting time	We did not have any specific data for this KPI. This issue is less important for the mother vessel because both the base scenario and AEGIS are ships and visit the same ports. Also, for the daughter vessel, since we have a calculation for

[2] http://www.unmanned-ship.org/munin/wp-content/uploads/2015/09/MUNIN-D8-8-Final-Report-Shore-Control-Centre-CTH-final.pdf

[3] https://products.damen.com/-/media/products/images/clusters-groups/shipping/container-feeder/cfe-800/deliveries/container-feeder-800-johanna-schepers/damen_container_feeder_800_568309_johanna_schepersr.pdf?la=en&rev=dc1bf3c027a940f79dc4ebcfaded8706

[4] https://www.salaryexpert.com/salary/job/seaman-able/norway#:~:text=The%20average%20seaman%20able%20gross,and%20anonymous%20employees%20in%20Norway.

[5] https://www.salaryexpert.com/salary/job/seaman-able/netherlands#:~:text=The%20average%20seaman%20able%20gross,and%20anonymous%20employees%20in%20Norway.

	Loading/Unloading and Sailing time and because the time difference between the truck and the ship is very high, calculating the waiting time does not affect the result and determining the superiority of one of the scenarios.

In the following, according to the routes explained in section 2.1, the results obtained in both scenarios (basic and AEGIS) for the mother, daughter 1 and daughter 2 are respectively in tables 13 to 15.

Table 13: Result of mother vessel in UCA.

<table>
<tr><th rowspan="3">KPI</th><th rowspan="3">KPI Name</th><th rowspan="3">KPI Measurement</th><th colspan="4">Result</th><th rowspan="3">Description</th></tr>
<tr><th colspan="2">AEGIS
(Rotterdam-Hitra)</th><th colspan="2">Baseline
(Rotterdam-Orkanger)</th></tr>
<tr><th>New Vessel
(Methanol+Battery)</th><th>NCL</th><th colspan="2"></th></tr>
<tr><td>Cost</td><td>CAPEX</td><td>€</td><td>66,000,000</td><td>48,000,000</td><td colspan="2">96,000,000</td><td></td></tr>
<tr><td>Cost</td><td>OPEX</td><td>€/week</td><td>272,000</td><td>280,240</td><td colspan="2">599,940</td><td></td></tr>
<tr><td>Cost</td><td>Maintenance Cost</td><td>€/week</td><td>58,000</td><td>58,000</td><td colspan="2">116,000</td><td></td></tr>
<tr><td>Cost</td><td>Port Charges or THC</td><td>€/TEU</td><td>60</td><td>60</td><td colspan="2">60</td><td></td></tr>
<tr><td>Cost</td><td>Port Charges or THC</td><td>€/week</td><td>132,000</td><td>103,440</td><td colspan="2">235,440</td><td></td></tr>
<tr><td>Cost</td><td>Fuel Cost</td><td>€/week</td><td>76,000</td><td>93,000</td><td colspan="2">197,000</td><td></td></tr>
<tr><td>Cost</td><td>Fuel Cost</td><td>€/KWh</td><td>(0.094;0.116)</td><td>0.119</td><td colspan="2">0.119</td><td>In the new vessel part, the first element is related to the battery and the second term to methanol.</td></tr>
<tr><td>Cost</td><td>Wages</td><td>€/week</td><td>6,000</td><td>25,800</td><td colspan="2">51,500</td><td></td></tr>
<tr><td>Cost</td><td>Total Cost Per Unit</td><td>€</td><td>75</td><td>141</td><td colspan="2">147</td><td></td></tr>
<tr><td>Time</td><td>Sailing or Drive Time</td><td>H</td><td colspan="2">53.33</td><td colspan="2">56.53</td><td>The speed of ship is 15 Kn.
(One way)</td></tr>
<tr><td>Time</td><td>Loading + Unloading time</td><td>H</td><td colspan="2">(26;35)</td><td>(22;29)</td><td>(22;29)</td><td>The first element is related to the port of Rotterdam. The second terms belong to the ports of Hitra and Orkanger, respectively.</td></tr>
</table>

Time	***Cargo Handling Time***	Number of Cargo/H	(20;15)			The first element is related to the port of Rotterdam. The second terms belong to the ports of Hitra and Orkanger. Also, these numbers are for one crane and there are two cranes.
Others	***Energy consumption***	kWh/week	667,000	781,000	1,654,000	
Others	***Cargo carried***	Number of Cargo/Ship	1,100	862		
Others	***Percentage of load***	Number of Cargo/Max Capacity	100%	100%	100%	
Others	***Frequency of service (one way)***	Shipments/week	2	2	4	Based on data from deliverable D8.2 (Transport system specification– Case A) [2]. There would be two new vessels and 2 NCL vessels between Rotterdam and Hitra.
Others	***Energy efficiency***	%	50	40	40	
Others	***Number of container moves (round trip)***	Number of Cargo/Route per week	2200	1724	1724	

Table 14: Result of daughter vessel 1 in UCA.

KPI	KPI Name	KPI Measurement	Result		Description
			AEGIS	Baseline-Truck	
Cost	***CAPEX***	€	8,000,000	1,628,000	11 trucks are enough for this route.
Cost	***OPEX***	€/week	16,800	113,724	One ship vs. 30 trucks

Cost	***Maintenance Cost***	€/week	5,150	22,744	One ship vs. 30 trucks
Cost	***Port Charges or THC***	€/TEU	60	0	
Cost	***Port Charges or THC***	€/week	7,200	---	
Cost	***Fuel Cost***	€/week	1,450	34,118	One ship vs. 30 trucks
Cost	***Fuel Cost***	€/Km	0.99	0.78	
Cost	***Fuel Cost***	€/tKm	0.0006	0.026	
Cost	***Wages***	€/week	3,000	56,862	One ship vs. 30 trucks
Cost	***Cost Per Unit Cargo in a week***	€	74	945	
Time	***Loading Time***	H	2	0.03	One round trip
Time	***Sailing or Drive Time***	H	43.1	9.1	One round trip
Time	***Unloading Time***	H	2	0.03	One round trip
Time	***Waiting Time***	H		0	One round trip
Time	***Cargo Handling Time***	Number of Cargo/H	15	---	These numbers are for one crane and there are two cranes.
Others	***Energy consumption***	KWh/week	17,689	200,928	One ship vs. 30 trucks by considering the frequency of services.
Others	***Cargo carried***	Number of Cargo/Ship or truck	60	2	Based on TEU measurement
Others	***Percentage of load***	Number of Cargo/Max Capacity	Almost 100	---	
Others	***Frequency of service***	Shipments or Truck/week	2	60	
Others	***Energy efficiency***	%	60	40	
Others	***Number of container moves***	Number of Cargo/Route per week	120	120	Based on TEU measurement (Round trip)

Table 15: Result of daughter vessel 2 in UCA.

KPI	KPI Name	KPI Measurement	Result		Description
			AEGIS	Baseline-Truck	
Cost	***CAPEX***	€	8,000,000	1,184,000	8 trucks are enough for this route.

Cost	***OPEX***	€/week	19,320	61,497	One ship vs. 27 trucks. For each truck would be 1895.4 Euros.
Cost	***Maintenance Cost***	€/week	6,200	12,300	One ship vs. 27 trucks
Cost	***Port Charges or THC***	€/TEU	60	0	
Cost	***Port Charges or THC***	€/week	9,720	---	
Cost	***Fuel Cost***	€/week	405	18,450	One ship vs. 27 trucks Norway Battery (€/Kwh): 0,082€/KWh Source: deliverable D7.3 (Economic Analysis – Preliminary) [10]
Cost	***Fuel Cost***	€/Km	0.46	0.78	
Cost	***Fuel Cost***	€/tKm	0.0003	0.026	
Cost	***Wages***	€/week	3,000	30,750	One ship vs. 27 trucks
Cost	***Cost Per Unit Cargo in a week***	€	42	379.7	
Time	***Loading Time***	H	1.8	0.03	One round trip
Time	***Sailing or Drive Time***	H	24.8	3.7	One round trip
Time	***Unloading Time***	H	1.8	0.03	One round trip
Time	***Waiting Time***	H		0	One round trip
Time	***Cargo Handling Time***	Number of Cargo/H	15	---	These numbers are for one crane and there are two cranes.
Others	***Energy consumption***	KWh/week	4,940	110,290	One ship vs. 27 trucks by considering the frequency of services.
Others	***Cargo carried***	Number of Cargo/Ship or truck	54	2	Based on TEU measurement
Others	***Percentage of load***	Number of Cargo/Max Capacity	0.9	---	
Others	***Frequency of service***	Shipments or Truck/week	3	81	
Others	***Energy efficiency***	%	60	40	
Others	***Number of container moves***	Number of Cargo/Route per week	162	162	Based on TEU measurement (Round trip)

For the mother vessel, as one can see in Table 13, the calculation has been done for one way route (like Rotterdam to Hitra and Rotterdam to Orkanger). Also, calculations have been done based on four conventional ships for the base scenario and four ships for the AEGIS scenario, two of which have a new design. According to the data we have received from SINTEF Ocean, two cranes have been considered for loading and unloading the ship. The speed of each of them which is stated in Table 16. The speed of cargo handling in the port of Rotterdam is higher than others due to more advanced facilities. The types of these cranes and their energy consumption are shown in Table 17.

Table 16 - Cargo handling equipment

	Loading (Units/h)	Offloading (Units/h)
Mother case	30	30
Daughter case	15	15
Rotterdam	40	40

Table 17 – Power consumption of crane

Type of drive system	Crane type	Average power
Closed-loop hydraulic	LC45 Cylinder	137 KW
Closed-loop hydraulic	GL45 Rope	126 KW
VFD new generation	GLE45 Rope	62 KW

Methanol has a lower heat value than diesel fuels, and more fuel is consumed to provide the same power. The specific fuel consumption of a (fully) methanol-powered marine engine will be in the range of 322 to 350 g of methanol per kWh. With a current trading price of €350 per tonne, the cost would be €0.116/kWh. For MDO, the typical SFOC is in the range of 170 to 190 g/kWh, and the price is at €630 per tonne; thus, a cost per kWh would be similar at 0.107-0.119, which we assumed is 0.119.

For the electric case, the actual energy cost will depend on where the vessels would be charging because the price is different in the country of Netherlands and Norway (see Table 18). However, since we have a round trip and we should use the electricity of two countries, we assumed the arithmetic average price of these two countries.

Table 18 – Energy cost when powered by batteries for UCA

Charger at	Cost (€/kWh)
Norway	0.082
Netherlands	0.105

For the daughter vessels, the AEGIS solution will compete mainly with existing road infrastructure, as the expected shipments in both cases are on-demand services. As you can see in Tables 14 and 15, the calculation has been done for round trip and considered the frequency of services in a week. To compare the baseline scenario with the AEGIS, the number of trucks/trips required to equal the ship load is considered. However, for the KPI of CAPEX, due to the shorter travel time of the trucks, it is not necessary to purchase the same number of trucks, and a smaller number of trucks is needed, which was calculated in the following equations for both cases. Also, the price of the truck considered is now 148,000 euros[6].

$$Daughter\ 1 := \frac{\frac{120}{2} * 2}{\frac{24 * 7}{9.16 * 2}} = 7.25 \sim 8\ trucks \quad (13)$$

$$Daughter\ 2 := \frac{\frac{162}{2} * 2}{\frac{24 * 7}{3.76 * 2}} = 10.87 \sim 11\ trucks \quad (14)$$

For the OPEX part of the baseline scenario, we have used the data that comes from deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0, which can be seen in Table 19.

Table 19 – The breakdown of OPEX cost for truck of UCA (source: Deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0)

Cost Type	Percentage (%)	Cost Value (€/km)	Cargo unit cost (€/t-km)
Labor	50	1.3	0.044
Fuel	30	0.78	0.026
Other expenses	20	0.52	0.0173
Total	100	2.6	0.087

It should be noted that, like the mother case, to calculate OPEX for the AEGIS scenario, we have used the procedure of Table 12 and equation 15. Also, we have considered two cranes for cargo handling, which Table 16 shows their speed rate in an hour. The type of cranes and their energy consumption of them are also like the mother case.

4.1.1 Analysis of UCA

In this section, we analyze the result obtained from UCA. First, a simple analysis has been made according to the results separately obtained for the cases of mother and daughter vessels in Tables 20 and 21, respectively. In these tables, the green and red cells show the advantages of the AEGIS and baseline scenarios on that KPIs, respectively. Also, orange cells represent there is no significant difference between the two scenarios.

Table 20 – Comparing the superiority of the base scenario and AEGIS in the mother case in UCA.

KPI Name	Mother	
	AEGIS	Baseline
CAPEX		
OPEX		
Maintenance Cost		
Port Charges or THC		
Fuel Cost		

[6] Source: https://autoline.info/-/sale/truck-tractors/VOLVO/FH-500--22120814404825303300

Wages		
Cost Per Unit Cargo in a week		
Loading Time		
Sailing or Drive Time		
Unloading Time		
Cargo carried		
Energy consumption		
Energy efficiency		
Number of container moves		

As can be seen in Table 20, the AEGIS scenario in most KPIs has privileges except on CAPEX, and loading and unloading time. However, energy consumption, sailing time, OPEX cost, and fuel cost, which are essential economic KPIs, have considerable merits. Also, it is worth mentioning that the time of loading and unloading for the AEGIS is higher than baseline because the capacity of the AEGIS ship is higher than conventional ships. Hence, although the loading time is longer, ultimately more cargo is transferred in a sea voyage which itself has many advantages in the environmental and social areas.

Table 21 – Comparing the superiority of the base scenario and AEGIS in the daughter cases in UCA.

KPI Name	Daughter 1		Daughter 2	
	AEGIS	Baseline-Truck	AEGIS	Baseline-Truck
CAPEX				
OPEX				
Maintenance Cost				
Port Charges or THC				
Fuel Cost				
Wages				
Cost Per Unit Cargo in a week				
Loading Time				
Sailing or Drive Time				
Unloading Time				
Energy consumption				
Frequency of service				
Energy efficiency				

As can be seen in Table 21, the sea transport in terms of OPEX, fuel cost, energy consumption acted better than land-based system. However, from the point of view of the time KPIs, the land route has a noticeable superiority. Also, like the mother case, the CAPEX of the baseline scenario is cheaper than AEGIS.

An important clarification here that the time KPIs have been examined separately for the mother and daughter vessels. We speculate that these KPIs would likely improve if they are examined together as a collaborative system. Doing so would involve some assumptions on the timing and interoperability of the logistical operation, and probably adjustment of some key parameters of logistical system design, such as frequency of service, vessel speed, number of ships, and just-in-time arrival of cargo. This is beyond the scope of this report but will be examined, among other things, in the context of AEGIS Task 7.5, the identification of win-win solutions.

In the rest of this part, we are looking to determine the Breakeven Point (BEP) for each of the scenarios. To be more precise, we seek to determine when the CAPEX and OPEX costs of the AEGIS scenario will be superior to the base scenario.

Equation 15 and Figure 20 show the BEP of the mother case and declare that after around seven years and a half in terms of cost KPI, the AEGIS scenario will more cost efficient than the base scenario.

$$(66.000.000 + 48.000.000) + (272.000 + 280.240) * x = 96.000.000 + 599.940 * x$$
$$\Longrightarrow \; x = 377.35 \text{ weeks} \sim 90 \; months \qquad (15)$$

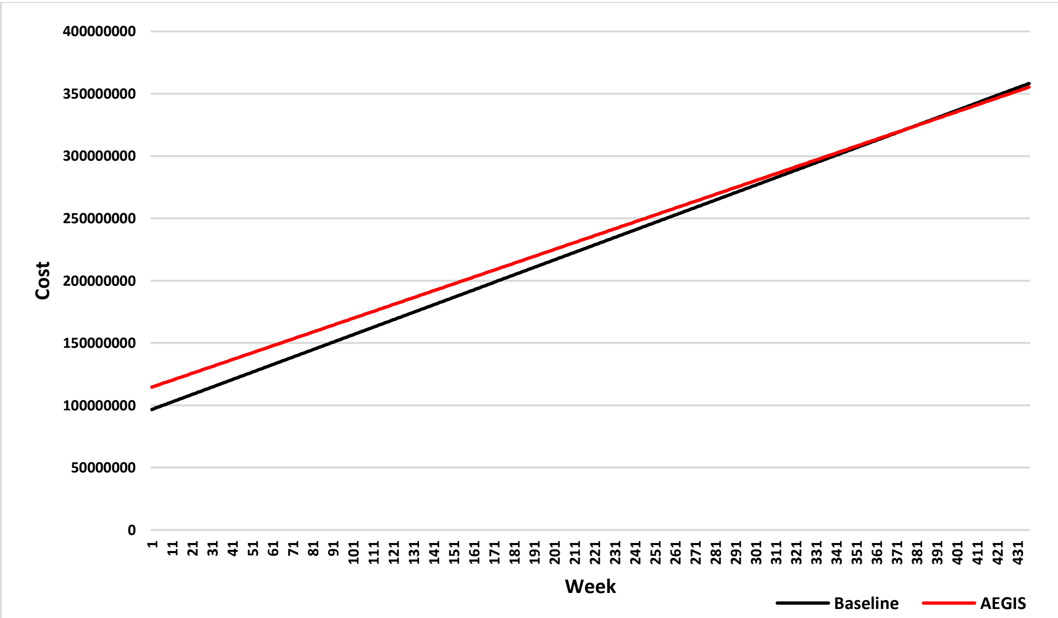


Figure 20: The BEP of mother scenario in UCA.

This BEP is about 1 year and 4 months and 3 years and 2 months for the two daughter ships respectively. How these are calculated can be seen in equations 16 and 17 and Figures 21 and 22 for vessels 1 and 2, respectively.

$$8.000.000 + 16.800 * x = 1.628.000 + 113.724 * x$$
$$\Longrightarrow \; x = 65.8 \text{ weeks} \sim 16 \; months \qquad (16)$$

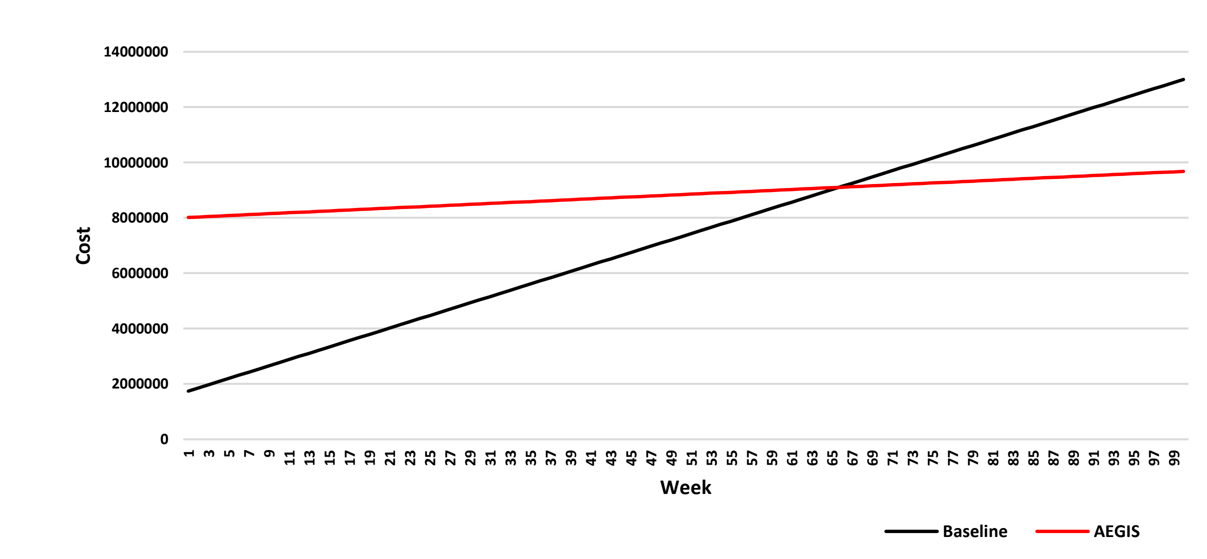


Figure 21: The BEP of daughter 1 scenario in UCA.

$$8.000.000 + 19.320 * x = 1.184.000 + 61.497 * x \\ \Longrightarrow\ x = 161.6 \text{ weeks} \sim 38\ months \tag{17}$$

Thus, the calculation of the BEP for UCA shows that although the CAPEX cost for the AEGIS scenario is much higher than the base scenario, due to its superiority in the OPEX part, this cost can be recovered in less than three and a half years. It should also be noted that this breakpoint calculation was a simplified calculation. And if assumptions such as the useful life of trucks and ships are considered, the weight of the preference of the AEGIS scenario will be even better in terms of economics.

We should also note that we believe that these results are conservative, since as mentioned earlier we believe that our estimates of the maintenance costs, and hence of OPEX, are likely to be higher than their respective real values.

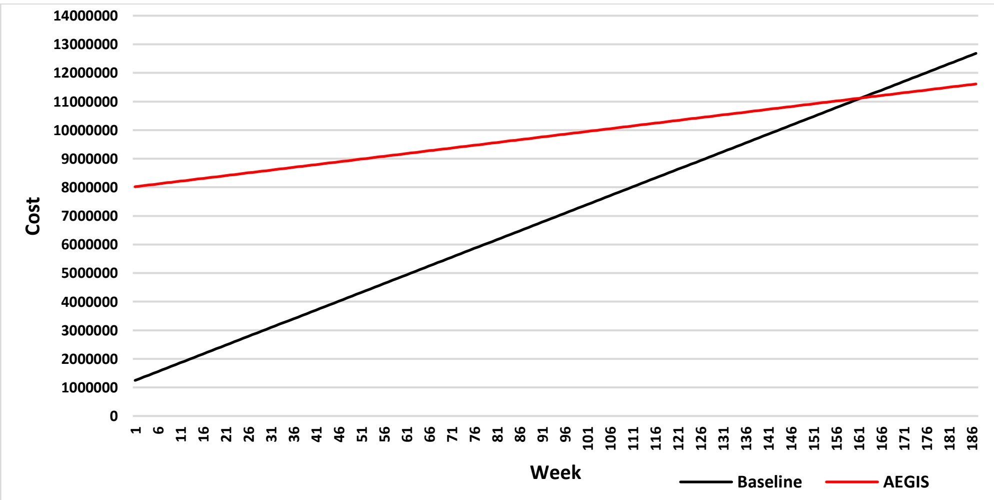


Figure 22: The BFP of daughter 2 scenario in UCA.

Finally, if we want to see the whole UCA as a unit, we will see the conclusion that a weak point of AEGIS is in the issue of transportation time, and this will be very important if the transported goods are time sensitive. However, AEGIS has significant advantages in terms of energy consumption and OPEX costs.

4.2 Use Case B

The final list of relevant and obtainable KPIs for the specific use case is presented in Table 22. This is the end result of the Mapping of the KPIs in terms of use case relevance and context, as previously described in section 3.4.

Table 22: Economic KPIs for Use Case B (adapted from Table 6 of deliverable D7.2 (Report on KPIs) [1]).

KPI Level	KPI Sublevel	KPI Name	KPI Measurement
Economic	Cost	CAPEX	€
Economic	Cost	OPEX	€/week
Economic	Cost	Maintenance costs	€/week
Economic	Cost	Port charges or THC	€
Economic	Cost	Fuel cost	€/week
Economic	Cost	Fuel cost	€/Km
Economic	Cost	Fuel cost	€/tKm
Economic	Cost	Wages	€/week
Economic	Cost	Transport Cost Per Unit	€/Km
Economic	Cost	Total Cost Per Unit	€
Economic	Time	Loading time	H
Economic	Time	Sailing time or Drive Time	H
Economic	Time	Unloading time	H
Economic	Time	Waiting time	H
Economic	Others	Energy consumption	Kwh/week
Economic	Others	Cargo carried	Number of Cargo/Ship
Economic	Others	Percentage of load	Cargo Car/Max Capacity
Economic	Others	Frequency of service	Shipments/week
Economic	Others	Energy efficiency	%
Economic	Others	Number of container moves	Number of Cargo /Routes

In the following, according to the use case explained in section 2.2 and can see more detail for both scenarios (basic and AEGIS) in Figure 23, the results obtained and are shown in Table 23.

	
a) Baseline (land-based system)	b) AEGIS (sea transport)

Figure 23: Route details of two scenarios at UCB.

Table 23: Result of UCB.

KPI	KPI Name	KPI Measurement	Result		Description
			AEGIS	Baseline-Truck	
Cost	***CAPEX***	€	48,000,000	5,328,000	3 ships vs. 36 trucks
Cost	***OPEX***	€/week	289,100	505,634	3 ships with (21*2) voyages vs. 36 trucks with (1160*2) travels. Round trip
Cost	***Maintenance Cost***	€/week	40,002	101,127	3 ships with (21*2) voyages vs. 36 trucks with (1160*2) travels. Round trip
Cost	***Port Charges or THC***	€/trailer	85	0	
Cost	***Port Charges or THC***	€/week	197,200	---	
Cost	***Fuel Cost***	€/week	40,002	151,690	3 ships with (21*2) voyages vs. 36 trucks with (1160*2) travels. Round trip
Cost	***Fuel Cost***	€/Km	(7.14;8.16)	0.4	For AEGIS, the first element is for Netherlands and the latter is for Belgium.

Cost	***Fuel Cost***	€/tKm	(0.0039 ;0.0045)	0.0127	For the AEGIS, the first element is for Netherlands and the latter is for Belgium. For the round trip we can assume the average of them and would be 0.0042.
Cost	***Wages***	€/week	11,900	252,817	3 ships with (21*2) voyages vs. 36 trucks with (1160*2) travels. Round trip
Cost	***Transport Cost Per Unit***	€/Km	0.5	1.4	
Cost	***Cost Per Unit Cargo in a week***	€	40	224	
Time	***Loading Time***	H	1	0.03	One AEGIS ship vs. One truck One way
Time	***Sailing or Drive Time***	H	10.7	2.5	One AEGIS ship vs. One truck One way We assumed the ship's average speed would be 8 Knot and for the truck would be 65 km/h.
Time	***Unloading Time***	H	1	0.03	One AEGIS ship vs. One truck One way
Time	***Waiting Time***	H	1	0	One AEGIS ship vs. One truvk One way
Others	***Energy consumption***	KWh/week	343,442.4	2,134,400	3 ships with (21*2) voyages vs. 36 trucks with (1160*2) travels. Round trip
Others	***Cargo carried***	Number of Cargo/Ship or truck	55	1	One AEGIS ship vs. One truvk Based on TEU measurement
Others	***Percentage of load***	Number of Cargo/Max Capacity	0.8	---	

Others	***Frequency of service***	Shipments or Truck/week	21	1,160	One way
Others	***Energy efficiency***	%	60	40	
Others	***Number of container moves***	Number of Cargo/Route per week	1,160	1,160	Based on TEU measurement (One way)

For the UCB, as one can see in Table 23, the calculation has been made for the round trip. According to the data we have received from DFDS, three AEGIS ships have been considered at the sea route between Ghent to Rotterdam and vice versa, which works daily and has 7 round trips during the week. To compare the land-based scenario with the AEGIS scenario, the number of trucks/trips required to equal the ship load is considered. However, for the KPI of CAPEX, due to the shorter travel time of the trucks, it is not necessary to purchase the same number of trucks, and a smaller number of trucks is needed, which was calculated in equation 18.

$$UCB := \frac{\frac{110}{2} * 7 * 3 \sim 1160}{\frac{24 * 7}{2.56 * 2}} = 35.35 \sim 36\ trucks \qquad (18)$$

Also, the trucks assumed price is 148,000 euros[7], like the previous use case. The data that we have from ISE, who are responsible for designing AEGIS ships, the CAPEX of new RoRo ships for the UCB would be 16,000,000 euros.

For the OPEX part of the baseline scenario, we have used the data from Podiotis and Daskalaki [8] and deliverable D10.3 (Potential for calling the two Danish ports by DFDS) [9], which can be seen in Table 24.

Table 24: Trucks cost breakdown for UCB.

Cost Type	Percentage (%)	Cost Value (€/km)	Cargo unit cost (€/t-km)
Labor	50	0.67	0.0257
Fuel	30	0.4	0.0154
Other expenses	20	0.27	0.0104
Total	100	1.34~1.4	0.0515

It should be noted that to estimate the OPEX of the AEGIS scenario, we have used data from DFDS. Indeed, DFDS stated that the current cost of each ship is usually 20,000 euros/week without considering THC (Table 25). However, since AEGIS ships comply with automation levels 3 and 4, there is no need for a crew on the ship's deck; therefore, a third of these costs are reduced. But, for the OPEX cost of the AEGIS scenario, we also need to calculate the control room and THC per week. At least six

[7] Source: https://autoline.info/-/sale/truck-tractors/VOLVO/FH-500--22120814404825303300

employees with a rotating schedule are necessary to operate that control centre[8] and DFDS estimated that salary costs are at around €50,000 per month, which means it should be around €11,900 per week. Also, THC for whole AEGIS ships during the week is around €197,200.

Table 25 – AEGIS ships cost breakdown for UCB.

Cost Type	Percentage (%)	Cost Value (€/week)
Labor	1/3~33.3	6667
Fuel	1/3~33.3	6667
Maintenance, depreciation, etc	1/3~33.3	6667
Total	100	20000

In addition, some other data, such as loading/unloading time, transport cost per unit, and frequency of services, were obtained directly from DFDS. Also, we got data from ISE related to this use case's port consumption. They stated that the port consumption would be 600 KWh in UCB.

As stated, the routes would be served by autonomous ships running on batteries. The existing battery technology allows for a range of up to 100 km without a requirement for recharging. For AEGIS route, the total distance is 160 km, and thus a recharge operation on battery swap would be necessary at some point midway. Based on the vessel specifications and under an assumption of a sailing speed of 8 knots, the required energy for a one-way trip without recharging is 6377.2 kWh. Accounting for potential losses and a safety factor, a capacity of 7000 kWh is selected. From existing technologies and in the context of the MSc thesis (under AEGIS) at DTU, the solution of Corvus Energy was selected as an illustrative scenario. This system can cover the propulsion requirements with two packs of six strings of batteries, each providing 3612 kWh, at a total weight of 61.1 tonnes. It is evident that this solution would slightly reduce the vessel's carrying capacity both in terms of weight and, perhaps more importantly, in terms of volume occupancy onboard the vessel. The carrying capacity of the autonomous ship will be therefore limited by two trailers to account for the battery pack placement, which would, in turn, affect the cargo unit transportation cost.

For the electric price, the assumption is that the vessel batteries would be charged at each port (so using the Belgian and Dutch grid and associated energy costs), and for the AEGIS route, that would require a recharge (or battery swap) midway. Table 26 presents the energy cost when charged at each port based on average grid prices per kWh, assuming that an industrial rate would be used and not the commercial ones. However, since we have a round trip in real and we should use the electricity of two countries, we assumed the average price of these two countries.

Table 26 – Energy cost of AEGIS solution for UCB when powered by batteries

If charged at	Ship energy consumption (kWh/km)	Payload (tonnes)	Cost (€/kWh)	Cost (€/tkm)
Netherlands	68	1821.6	0.105	0.0039
Belgium			0.12	0.0045

[8] http://www.unmanned-ship.org/munin/wp-content/uploads/2015/09/MUNIN-D8-8-Final-Report-Shore-Control-Centre-CTH-final.pdf

The energy efficiency of the AEGIS vessel is 60 %. This estimation is reasonable since sailing can commence when the vessel is fully loaded due to its autonomy levels. Also, we will use batteries that can be more effective propulsion systems that AEGIS could have an achievement in this KPI.

4.2.1 Analysis of UCB

In this section, we analyze the result obtained from UCB. First, a simple analysis has been conducted according to the results obtained for the use case in Table 27. As seen in these Tables, the green and red cells show the advantages of the AEGIS and baseline scenarios on that KPIs, respectively.

Table 27 – Comparing the superiority of the base scenario and AEGIS in UCB.

KPI Name	AEGIS	Baseline-Truck
CAPEX		
OPEX		
Maintenance Cost		
Port Charges or THC		
Fuel Cost		
Wages		
Transport Cost Per Unit		
Cost Per Unit Cargo		
Loading Time		
Sailing or Drive Time		
Unloading Time		
Energy consumption		
Cargo Carried		
Frequency of service		
Energy efficiency		

As can be seen in Table 27, the AEGIS solution, in terms of OPEX, fuel cost, and energy consumption, is obviously better than the road-based system. For example, we can observe that when comparing the electricity (or energy) cost with the fuel cost of road-based transportation, AEGIS results in a lower-cost solution per tonne-km.

But it is important to mention that in UCB, due to the fact that the AEGIS ships can visit both ports daily according to their travel time, there will be no delay or disruption in meeting even daily demands. Also, considering they will carry more cargo in one trip, the risk of the cargo not reaching the destination and its uncertainty are significantly reduced. Therefore, no visible advantage can be given to the road system in this KPI.

Furthermore, although the CAPEX cost of the baseline system is lower than the marine mode, considering the total (cumulative) CAPEX and OPEX costs at the same time, the results indicate that after about four years, AEGIS is better than road transportation in terms of total expense. The calculation of this time (BEP) can be seen in equation 19 and Figure 24. No discounting of future cash flows is assumed, which surely entails an approximation, which we think is reasonable, given the time frames used and the low levels of interest rates. It is important to mention that after holding a meeting with our colleagues at DFDS, we have found information that, in practice, this company has yet to purchase trucks for the route between Rotterdam and Ghent and is using a third-party logistics company. However, in this report, it is assumed that these trucks will be purchased, so as to make the CAPEX costs comparable.

$$48.000.000 + 289.100 * x = 5.328.000 + 505.634 * x \\ \Longrightarrow \ x = 197.1 \text{ weeks} \sim 47 \; months \tag{19}$$

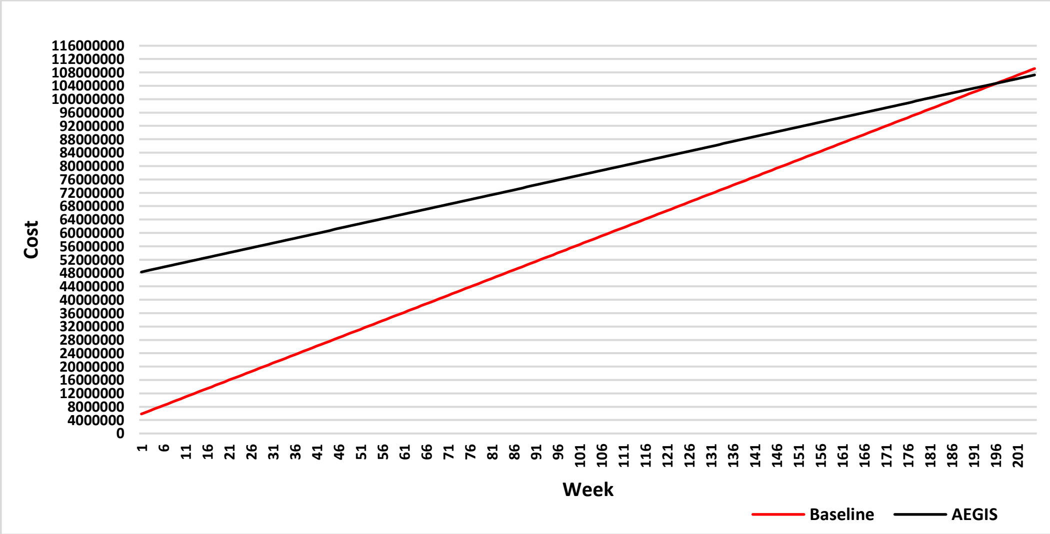


Figure 24: The BFP for UCB.

Again, and as in use case A, we believe that these results are conservative, for the same reasons as outlined in use case A (OPEX figures being overestimated for the AEGIS solution).

4.3 Use Case C

The final list of relevant and obtainable KPIs for the specific UCC for the Aalborg and Vordingborg cases are presented in Tables 28 and 29, respectively. This is the result of the Mapping of the KPIs in terms of use case relevance and context, as previsouly described in section 3.4.

Table 28: Economic KPIs for Use Case C- Aalborg Case (adapted from Table 6 of deliverable D7.2 (Report on KPIs) [1]).

KPI Level	KPI Sublevel	KPI Name	KPI Measurement
Economic	Cost	CAPEX	€
Economic	Cost	OPEX	€/day
Economic	Cost	Maintenance costs	€/day
Economic	Cost	Port charges	€
Economic	Cost	Fuel cost	€/day
Economic	Cost	Fuel cost	€/Km

Economic	Cost	Fuel cost	€/tKm
Economic	Cost	Wages	€/day
Economic	Cost	Total Cost Per Unit Cargo	€
Economic	Time	Loading time	H
Economic	Time	Sailing time	H
Economic	Time	Unloading time	H
Economic	Time	Last mile	H
Economic	Time	Waiting time	H
Economic	Time	Cargo handling time	Number of Cargo/H
Economic	Others	Energy consumption	Kwh/Day
Economic	Others	Cargo carried	Number of Cargo/Ship
Economic	Others	Percentage of load	Cargo Car/Max Capacity
Economic	Others	Frequency of service	Shipments/week
Economic	Others	Energy efficiency	%
Economic	Others	Number of container moves	Number of Cargo /Routes

Table 29: Economic KPIs for Use Case C- Vordingborg Case (adapted from Table 6 of deliverable D7.2 (Report on KPIs) [1]).

KPI Level	KPI Sublevel	KPI Name	KPI Measurement
Economic	Cost	CAPEX	€
Economic	Cost	OPEX	€/week
Economic	Cost	Maintenance costs	€/week
Economic	Cost	Port charges	€
Economic	Cost	Fuel cost	€/week
Economic	Cost	Wages	€/week
Economic	Cost	Total Cost Per Unit	€
Economic	Time	Loading time	H
Economic	Time	Sailing time	H
Economic	Time	Unloading time	H
Economic	Time	Waiting time	H
Economic	Time	Cargo handling time	Number of Cargo/H
Economic	Others	Energy consumption	Kwh/week
Economic	Others	Cargo carried	Number of Cargo/Ship
Economic	Others	Percentage of load	Cargo Car/Max Capacity

Economic	Others	Frequency of service	Shipments/week
Economic	Others	Energy efficiency	%
Economic	Others	Number of container moves	Number of Cargo /Routes

Based on the questionnaires shown in Annex A, we have made efforts to collect data from our partners and stakeholders. However, some data in the Aalborg case and the Vordingborg case, were still unavailable. For these data we made some assumptions and approximations. These are explained in Tables 30 and 31 for the Port of Aalborg and Vordingborg, respectively.

Table 30: Assumptions and approximations in UCC- port of Aalborg.

KPIS	Explanation
Waiting time	We do not have any specific data for this KPI. Since we have a calculation for Loading/Unloading and Sailing time and because of the time difference between the AEGIS and the non-AEGIS, calculating the waiting time does not affect the result and determining the superiority of one of the scenarios.

Table 31: Assumptions and approximations in UCC- port of Vordingborg.

KPIS	Explanation
OPEX	We got the data from ISE for the AEGIS ship that the OPEX cost for the fully automated vessel (level 4) without considering THC is around €22,000 per week, which includes fuel cost and maintenance costs. But since the level of autonomy, in this case, is 2, the port of Vordingborg has informed us that in addition to the control room, two crew members are needed on the ship's deck, whose cost is equivalent to €945 (approximately €1000) per day. That is €7000 per week. On the other hand, at least six employees with a rotating schedule are necessary to operate that control room[9], and DFDS estimated that salary costs are estimated at around €50,000 per month, which means it should be around €11900 per week. THC is also added to the above to calculate the final OPEX. We could not succeed to get data for the OPEX of non-AEGIS. To solve this issue and have a rigorous comparison, we have assumed that the conventional ship in its best condition will have the same OPEX cost rate as the AEGIS ship. we calculated the cost difference based on the distance covered by both ships. Also, for this purpose, since THC costs do not include the distance, this cost is first reduced from OPEX of the AEGIS scenario and finally added to the final cost in OPEX for the conventional ships. Therefore, this KPI is calculated as follows for the baseline scenario. OPEX of conventional ship = ((OPEX of AEGIS- THC of AEGIS scenario) * (The route traveled by the non-AEGIS ship/The route traveled by the AEGIS ship))+ THC of baseline scenario

[9] http://www.unmanned-ship.org/munin/wp-content/uploads/2015/09/MUNIN-D8-8-Final-Report-Shore-Control-Centre-CTH-final.pdf

Maintenance Cost	We could not succeed to get data for the maintenance cost of non-AEGIS. We have used the data from ISE, which stated that usually around 10% of OPEX costs for the bulk carrier are related to maintenance and insurance costs of ships.
Wages	We could not succeed to get an estimation for wages of non-AEGIS. We have used the data from ISE, which stated that usually, 13% of OPEX costs for the bulk carrier are related to wages costs of ships.
Fuel Cost	We could not succeed to get an estimation for fuel cost of non-AEGIS. We have used the data from ISE, which stated that usually, 69% of OPEX costs for the bulk carrier are related to fuel costs of ships.
Waiting time	We do not have any specific data for this KPI. This issue might be not important because both the base scenario and AEGIS have ships and we can consider the waiting time of both to be similar.
Laoding/Unloading time	We could not succeed in getting data for these KPIs for non-AEGIS. To deal with this issue, we assumed the loading/unloading time of the non-AEGIS ship is like the AEGIS ship. These assumptions can be good estimations since both ships convey the same amount of cargo.
Sailing or Drive Time	We could not succeed in getting data for this KPI for non-AEGIS. To deal with this issue, we assumed the speed of the conventional ship is like AEGIS ships and is equal to 10 knots.
Cargo Handling Time	We could not succeed in getting data for this KPI for non-AEGIS. To deal with this issue, we assumed the cargo handling time of both scenarios is the same.
Energy consumption	We could not succeed in getting data for this KPI for the non-AEGIS ship. To solve this issue and have a rigorous comparison, we have assumed that this KPI is calculated as follows for the non AEGIS ship: Energy consumption of non-AEGIS ship = Energy consumption of AEGIS ship*(route distance sailed by the non-AEGIS ship/route distance sailed by the AEGIS ship)

In the following, according to the use case explained in section 2.3, the results obtained in both scenarios (basic and AEGIS) for the Aalborg and Vordingborg are, respectively, in Tables 32 to 33.

Table 32: Result of the Aalborg case in UCC.

<table>
<tr><th rowspan="3">KPI</th><th rowspan="3">KPI Name</th><th rowspan="3">KPI Measurement</th><th colspan="3">Result</th><th>Description</th></tr>
<tr><th colspan="2">AEGIS</th><th rowspan="2">Baseline (Truck)</th><th rowspan="2"></th></tr>
<tr><th>New Vessel</th><th>Truck</th></tr>
<tr><td rowspan="2">Cost</td><td rowspan="2">CAPEX</td><td rowspan="2">€</td><td>Battery: 24,000,000</td><td rowspan="2">3,848,000</td><td rowspan="2">5,328,000</td><td rowspan="2">(One ship and 26 trucks) vs. 36 trucks</td></tr>
<tr><td>Methanol: 21,000,000</td></tr>
</table>

Cost	***OPEX***	€/week	217,000	666,850	937,660	Round trip
Cost	***Maintenance Cost***	€/week	108,500	133,370	187,530	Round trip
Cost	***Port Charges or THC***	€/trailer	60	---	---	
Cost	***Port Charges or THC***	€/week	67,200			
Cost	***Fuel Cost***	€/week	54,250	200,050	281,300	Round trip
Cost	***Fuel Cost***	€/Km	Battery: (2.8,2.6) Methanol: 4.9	0.78	0.78	For the new vessel in Battery section, the first element is for Denmark and the second terms is related to Sweden.
Cost	***Fuel Cost***	€/tKm	Battery: 0.003 Methanol: 0.006	0.04	0.04	
Cost	***Wages***	€/week	4,830	333,420	468,830	Round trip
Cost	***Total Cost Per Unit***	€	388	1,191	1,647	
Time	***Loading time***	H	2	0.03	0.03	
Time	***Sailing or Drive Time***	H	10.8	7.6	10.7	We assumed the average speed of ship is 8 knots and truck is 60 km/h.
Time	***Unloading time***	H	2	0.03	0.03	
Time	***Last mile***	H	0.8	---	---	
Time	***Waiting time***	H		0	0	
Time	***Cargo Handling Time***	Number of Cargo/H	12	---	---	For cargo handling time, there are three scenarios (3, 4, and 5) that I assumed were 5 minutes per trailer per tug master.

Others	***Energy consumption***	KWh/week	Battery: 99,533 Methanol: 97,900	1,566,208	2,205,056	Round trip This calculation is based on automation level 3. If we use automation level 2. we also should consider auxilary engine. We also calculated the lastmile consumption.
Others	***Cargo carried***	Number of Cargo/Ship	40	1	1	
Others	***Percentage of load***	Number of Cargo/Max Capacity	0.8	---	---	
Others	***Frequency of service***	Shipments/week	14	560	560	Round trip But depends on available cargo
Others	***Energy efficiency***	%	(60,50)	40	40	The first element is related to the battery and second term is for methanol
Others	***Number of container moves***	Number of Cargo /Routes per week	280		280	Round trip At this step, we have assumed the whole cargo is shifted from land to sea route

Table 33: Result of the Vordingborg case in UCC.

KPI	KPI Name	KPI Measurement	Result			Description
			AEGIS	Baseline		
			New Vessel	Vessel	Truck	
Cost	***CAPEX***	€	11,500,000	9,000,000	3,552,000	24 trucks
Cost	***OPEX***	€/week	51,100	13,700	131,300	One way The number of truck movement would be equal 3500/33 For the conventional ship, we acted like the AEGIS ship (the difference is just in distance).
Cost	***Maintenance Cost***	€/week	25,500	1,370	26,260	One way
Cost	***Port Charges or THC***	€/cargo	60	60	---	
Cost	***Port Charges or THC***	€/week	10,200		---	
Cost	***Fuel Cost***	€/week	12,775	9,450	39,390	One way
Cost	***Wages***	€/week	18,900	1,780	65,650	The data for the AEGIS part comes from the Vordingborg port that we need two people onboard of AEGIS ship plus workers in the control centre room.
Cost	***Total Cost Per Unit***	€	300	80	772	
Time	***Laoding time***	H	10	10	0.03	
Time	***Sailing or Drive Time***	H	36	2.64	11.69	We assumed the speed of vessels 10 knots
Time	***Unloading time***	H	10	10	0.03	
Time	***Waiting time***	H			---	
Time	***Cargo Handling Time***	H	17	17	---	

Others	***Energy consumption***	KWh/week	33,248	4,292	460,305	One way
Others	***Cargo carried***	Number of Cargo/Ship	170	170	1	
Others	***Percentage of load***	Number of Cargo/Max Capacity	1,000	100	---	
Others	***Frequency of service***	Shipments/week	1	1	107	One way
Others	***Energy efficiency***	%	60	40	40	
Others	***Number of container moves***	Number of Cargo/Routes	170	170		One way

For the Aalborg case, as one can see in Table 32, the calculation has been done for round trip. Also, according to the data we have received from deliverable D10.1 (Potential transfer from road transport to short-sea-shipping in Denmark) [6], one AEGIS ship has been considered at the sea route between Gothenburg to Aalborg and vice versa, which works daily and has 7 round trips during the week.

To compare the land-based scenario with the AEGIS solution, the number of trucks/trips have considered equal to the ship's capacity. However, for the KPI of CAPEX, due to the shorter travel time of the trucks, it is not necessary to purchase the same number of trucks, and a smaller number of trucks is needed, which was calculated in equation 20. Also, the number of trucks that are needed for the AEGIS scenario (land section- Aalborg to Hamburg) according to the travel time of this scenario was estimated in equation 21. It should be noted that the truck assumed price is (again) 148,000 euros[10]..

$$UCC - Aalborg\ case\ for\ baseline\ scenario := \frac{\frac{80}{2}}{\frac{24}{10.76 * 2}} = 35.71 \sim 36\ trucks \tag{20}$$

$$UCC - Aalborg\ case\ for\ AEGIS\ scenario := \frac{\frac{80}{2}}{\frac{24}{7.66 * 2}} = 25.52 \sim 26\ trucks \tag{21}$$

To calculate the OPEX related to the truck side and AEGIS's ship, we used Tables 34 and 35 extracted from deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0.

Table 34: The OPEX cost for truck side of the UCC-Aalborg case.

Range	Price (Euro/Km)
0-250 km	2.6
251-500 km	2.25
501-750 km	1.75

[10] Source: https://autoline.info/-/sale/truck-tractors/VOLVO/FH-500--22120814404825303300

751-1000 km	1.25
1000+ km	1

Table 35: The OPEX cost for the sea side of the UCC-Aalborg case (source: Deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0).

In Euro	Price (Euro for 24h cost cycle)
Price/day	1100
Price (THC) per move * 2	120
Number of moves in a full cycle (40*2)	80
Price total (SSS+THC)	20,600
Price for last mile Price for last mile (25 km*2 per truck at 2.6 Euro per move)	10,400
Total price for moving 80 trucks in 24 hours	31,000
Minimum price per truck for SSS solution (/80)	387.5

It is worth mentioning that based on deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0, we assumed the THC is 60 Euros per move. However, different conditions could apply (for example, autonomous or non-autonomous tug master). The reader can find more detailed information in deliverables D10.3 (Potential for calling the two Danish ports by DFDS) 0 and Table 36.

Table 36: The THC based on the number of tug masters and their type for the UCC-Aalborg case.

THC (+10% margin)	Terminal Type	2 operation	3 operation	4 operation
4 tug masters, 5 min per trailer	At non- autonomous terminal	62.71	47.02	39.17
	At autonomous terminal	65.7	47.65	38.62
2 tug masters, 5 min per trailer	At non- autonomous terminal	44.95	33.03	27.08
	At autonomous terminal	51.53	38.2	31.54
3 tug masters, 4 min per trailer	At non- autonomous terminal	53.74	39.94	33.03
	At autonomous terminal	58.53	42.83	34.99
2 tug masters, 4 min per trailer	At non- autonomous terminal	44.86	32.94	26.98
	At autonomous terminal	51.44	38.11	31.45
3 tug masters, 3 min per trailer	At non- autonomous terminal	53.65	39.84	32.94
	At autonomous terminal	58.43	42.74	34.9
2 tug masters, 3 min per trailer	At non- autonomous terminal	44.76	32.85	26.89
	At autonomous terminal	51.35	38.02	31.36
4 tug masters, removing the backup terminal workers from the autonomous setup	At non- autonomous terminal	62.71	47.02	39.17
	At autonomous terminal	62.48	44.43	35.41
2 tug masters, removing the backup terminal eorkers from the autonomous setup	At non- autonomous terminal	44.95	33.03	27.08
	At autonomous terminal	48.32	34.99	28.32
4 tug masters, removing the both backup terminal eorkers, as well as the control centre worker from the autonomous setup	At non- autonomous terminal	62.71	47.02	39.17
	At autonomous terminal	56.93	38.88	29.85
2 tug masters, removing the both backup terminal eorkers, as well as the control	At non- autonomous terminal	44.95	33.03	27.08
	At autonomous terminal	42.77	29.43	22.77

centre worker from the autonomous setup				
4 tug masters, removing all the above, as well as removing the backup tug masters from both the autonomous and non-autonomous setup	At non- autonomous terminal	57.05	43.24	36.34
	At autonomous terminal	49.85	34.16	26.31
2 tug masters, removing all the above, as well as removing the backup tug masters from both the autonomous and non-autonomous setup	At non- autonomous terminal	39.28	29.26	24.24
	At autonomous terminal	35.68	24.71	19.23

For cargo handling time, there are three modes (3, 4, and 5 minutes per trailer) that we assumed were 5 minutes per trailer per tug master which could be 12 cargo (60/5) per hour. Indeed, we have assumed this mode to consider the worst possible scenario for AEGIS and compare it with the base scenario. In addition, based on the data that we got from ISE, the port consumption for this type of AEGIS ship is 100 kWh for the methanol system and 700 KWh for the battery system.

In the Aalborg case, as one can see in Table 37 (deliverable 10.3 (Potential for calling the two Danish ports by DFDS) 0), we have different salaries for autonomous terminal worker and non- autonomous terminal worker (12 scenarios). Finally based on deliverable D10.3 (Potential for calling the two Danish ports by DFDS) 0, we have assumed 2 tug masters, 2 weekly calls, and 5 min per trailer with a terminal worker and control centre worker. Also, based on the data, we need six people for the control centre[11]. It is important to mention that in Table 32, we have not considered the costs of terminal workers in the wages section because these costs are included in THC.

Table 37: The worker yearly salary for the UCC-Aalborg case (€).

	Worker Type	2 weekly calls	3 weekly calls	4 weekly calls
4 tug masters, 5 min per trailer	At non- autonomous terminal	97297	145945	194594
	At autonomous terminal	24324	36486	48648
	Control Centre Worker	42000	63000	84000
2 tug masters, 5 min per trailer	At non- autonomous terminal	48648	72972	97297
	At autonomous terminal	24324	36486	48648
	Control Centre Worker	42000	63000	84000
3 tug masters, 4 min per trailer	At non- autonomous terminal	72972	109459	145945
	At autonomous terminal	24324	36486	48648
	Control Centre Worker	42000	63000	84000
2 tug masters, 4 min per trailer	At non- autonomous terminal	48648	72972	97297
	At autonomous terminal	24324	36486	48648
	Control Centre Worker	42000	63000	84000
3 tug masters, 3 min per trailer	At non- autonomous terminal	72972	109459	145945
	At autonomous terminal	24324	36486	48648
	Control Centre Worker	42000	63000	84000
2 tug masters, 3 min per trailer	At non- autonomous terminal	48648	72972	97297
	At autonomous terminal	24324	36486	48648
	Control Centre Worker	42000	63000	84000
	At non- autonomous terminal	97297	145945	194594
	At autonomous terminal	42000	63000	84000

[11] http://www.unmanned-ship.org/munin/wp-content/uploads/2015/09/MUNIN-D8-8-Final-Report-Shore-Control-Centre-CTH-final.pdf

4 tug masters, removing the backup terminal workers from the autonomous setup	Control Centre Worker	48648	72972	97297
2 tug masters, removing the backup terminal workers from the autonomous setup	At non- autonomous terminal	42000	63000	84000
	At autonomous terminal	97297	145945	194594
	Control Centre Worker	48648	72972	97297
4 tug masters, removing both backup terminal workers, as well as the control centre worker from the autonomous setup	At non- autonomous terminal	97297	145945	194594
	At autonomous terminal	48648	72972	97297
	Control Centre Worker	97297	145945	194594
2 tug masters, removing both backup terminal workers, as well as the control centre worker from the autonomous setup	At non- autonomous terminal	24324	36486	48648
	At autonomous terminal	42000	63000	84000
	Control Centre Worker	48648	72972	97297
4 tug masters, removing all the above, as well as removing the backup tug masters from both the autonomous and non-autonomous setup	At non- autonomous terminal	24324	36486	48648
	At autonomous terminal	42000	63000	84000
	Control Centre Worker	72972	109459	145945
2 tug masters, removing all the above, as well as removing the backup tug masters from both the autonomous and non-autonomous setup	At non- autonomous terminal	24324	36486	48648
	At autonomous terminal	42000	63000	84000
	Control Centre Worker	48648	72972	97297

For the fuel price (Euro/kWh), the actual energy cost will depend on where the vessels would be using energy because the price is different in the country of Sweden and Denmark. The estimation of this cost for fuel of battery and methanol are shown in Tables 38 and 39, respectively. It should be noted that since we have a round trip in real and we should use from both countries, we assumed the average price of these two countries.

Table 38: Energy cost of AEGIS solution for UCC-port of Aalborg when powered by battery.

If charged at	Cost (€/kWh) Household	Cost (€/kWh) Business
Denmark[12]	0.38	0.065
Sweden[13]	0.22	0.062

Table 39: Energy cost of AEGIS solution for UCC-port of Aalborg when powered by methanol.

If charged at	Cost (€/kWh) Household	Cost (€/kWh) Business
Denmark[14]	0.19	0.116
Sweden[15]	0.24	0.116

For the Vordingborg case, as onee can see in Table 33, the calculation has been done one way (for example, port of Vordingborg to port of Elblag). In this case, we got most of the data from Vordingborg port Chiefs, such as the speed of the ship, number of cargo carried, wages of crews, sailing time, and

[12] Source: https://www.globalpetrolprices.com/Denmark/electricity_prices/
[13] Source: https://www.globalpetrolprices.com/Sweden/electricity_prices/
[14] Source: https://www.globalpetrolprices.com/Denmark/natural_gas_prices/
[15] Source:
https://www.globalpetrolprices.com/Sweden/natural_gas_prices/#:~:text=Sweden%2C%20December%202021%3A%20The%20price,Dollar%20per%20kWh%20for%20businesses

loading and unloading time. Also, based on the data that we got from ISE, the port consumption for this type of AEGIS ship would be 100 kWh.

Like the previous use cases that included the truck system, to calculate the number of trucks that we need, we used equation 22. Also, for estimation of OPEX cost of trucks side, we have acted like Table 34. And for the side of the ship, we used the data that comes from deliverable D10.3 (Potential for calling the two Danish ports by DFDS) [9], ISE, and port of Vordingborg.

$$UCC - Vordingborg\ case := \frac{\frac{340}{2}}{\frac{24 * 7}{11.75 * 2}} = 23.77 \sim 24\ trucks \quad (22)$$

4.3.1 Analysis of UCC

In this section, we analyze the results obtained from UCC. First, a simple analysis has been made according to the results obtained for the cases of Aalborg and Vordingborg in Tables 40 and 41, respectively. As seen in these tables, the green and red cells show the advantages of the AEGIS and baseline scenarios on that KPIs, respectively. Also, orange cells represent there is no significant difference between the two scenarios.

Table 40 – Comparing the superiority of the base scenario and AEGIS in UCC- port of Aalborg.

KPI Name	AEGIS	Baseline-Truck
CAPEX		
OPEX		
Maintenance Cost		
Port Charges or THC		
Fuel Cost		
Wages		
Transport Cost Per Unit		
Cost Per Unit Cargo		
Loading Time		
Sailing or Drive Time		
Unloading Time		
Energy consumption		
Cargo Carried		
Frequency of service		
Energy efficiency		

As can be seen in Table 40, the AEGIS solution in most KPIs is better, except CAPEX, sailing, and loading/unloading time. Energy consumption, time, OPEX cost, and fuel cost, which are essential KPIs in the economic analysis, are better for AEGIS.

It is important to mention that in UCC- Port of Aalborg, since the AEGIS vessel can visit both ports daily according to their travel time, there will be no delay or disruption in meeting even daily demands. Considering they will carry more cargo in one trip, the risk of the cargo not reaching the destination and its uncertainty is significantly reduced. Therefore, no visible advantage can be ascribed to the baseline scenario in this KPI.

Table 41 – Comparing the superiority of the base scenario and AEGIS in UCC- Port of Vordingborg.

KPI Name	AEGIS	Baseline-Truck
CAPEX		
OPEX		
Maintenance Cost		
Port Charges or THC		
Fuel Cost		
Wages		
Transport Cost Per Unit		
Cost Per Unit Cargo		
Loading Time		
Sailing or Drive Time		
Unloading Time		
Energy consumption		
Cargo Carried		
Frequency of service		
Energy efficiency		

As can be seen in Table 41, in terms of CAPEX, OPEX, fuel cost and energy consumption, the AEGIS solution performs better than the baseline (non-AEGIS) system. However, from the point of view of the time KPIs, the baseline scenario has a noticeable superiority. But the interesting thing to note in this case is that since the AEGIS scenario only includes ships, it will have lower CAPEX than the base scenario which includes both ships and trucks.

In the rest of this section, we shall determine the Breakeven Point (BEP) for each of the cases. To be more precise, we seek to determine when the sum of CAPEX and OPEX costs of the AEGIS scenario will be superior to the base scenario. Again, no discounting of future cash flows is assumed.

Equations 23, 24, and Figure 25 show the BFP of the Aalborg case and declare that if we use battery propulsion after around eight years and six months, the AEGIS can be cheaper than the baseline scenario. Also, if we develop the AEGIS ship using methanol, after around seven years, the AEGIS scenario will be better in terms of cost.

It is also important to mention that the methanol system has a faster return on investment than the battery (about one year).

As one can see from Figure 26, in the Vordingborg port, unlike all other use cases, the AEGIS scenario will be superior to the base scenario from the beginning in terms of cumulative expenses. Therefore, in this scenario, the only negative factor for the AEGIS solution will be the time KPI.

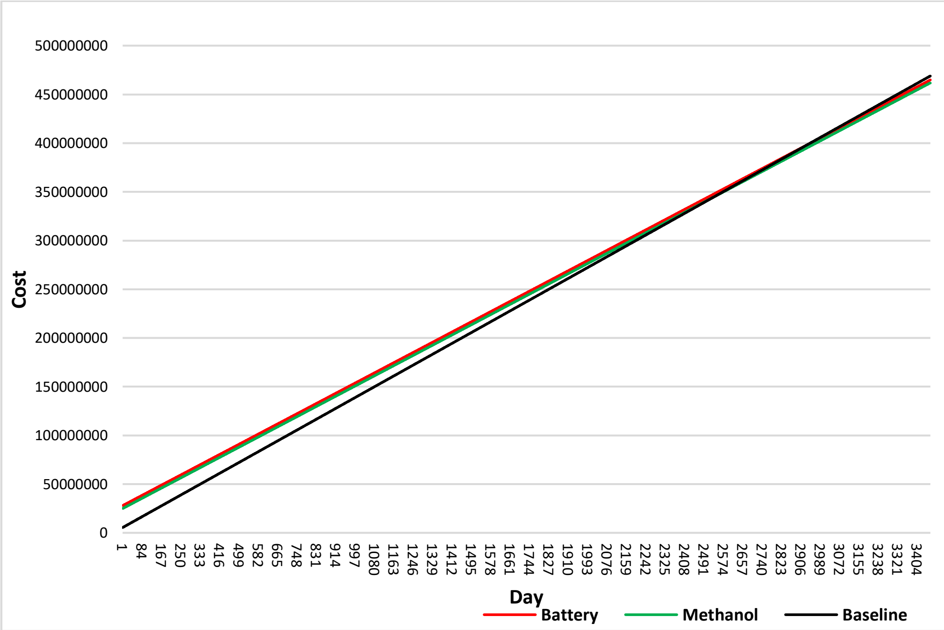


Figure 25: The BFP for UCC-port of Aalborg.

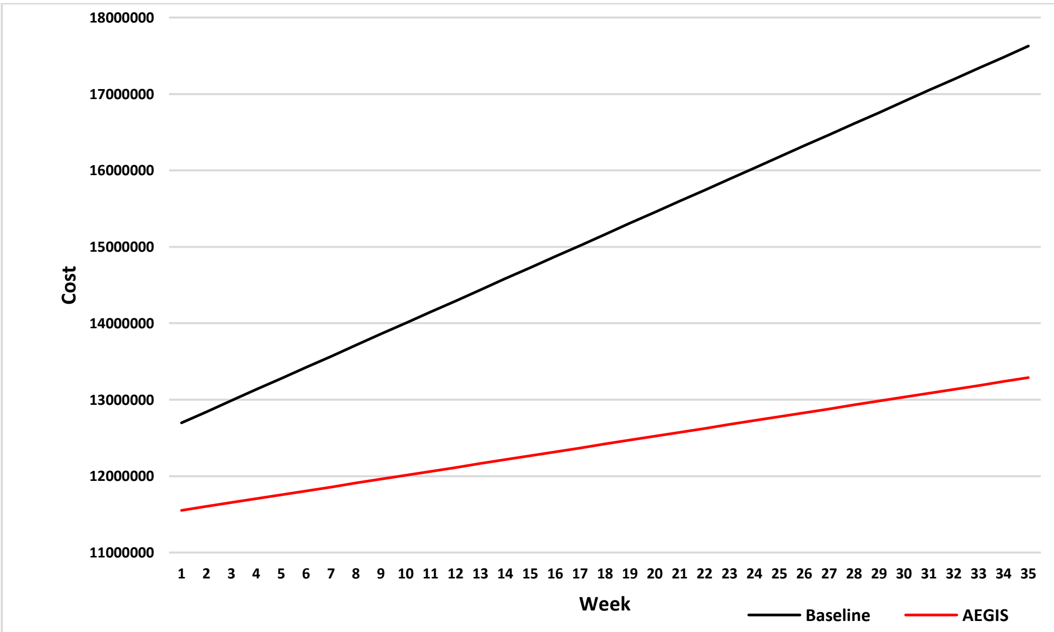


Figure 26: The BFP for UCC-port of Vordingborg.

Last but not least, and as in use cases A and B, we believe that the above results are conservative, for the same reasons as outlined earlier (OPEX figures being overestimated for the AEGIS solution).

5 Conclusions

This report had the following main objectives:

- Perform analyses of the economic performance of AEGIS solutions.
- Examining the general and specific parts of each use case in terms of economic KPIs

Generally, from the analysis conducted, the following would seem to summarize where we stand as regards the main economic KPIs (cost and time KPIs) for each use case, particularly how the AEGIS solution compares to the non-AEGIS baseline solution (see Table 41 below):

Table 41: Economic KPIs for the three use cases.

		Cost KPIs	*Time KPIs*
Use case A		After around seven years and a half of operating the AEGIS solution, it will be less expensive than the baseline scenario, in terms of cumulative cost.	AEGIS solution is generally slower than the baseline solution. However, this result is for mother and daughter vessels analysed separately and is expected to be better if they are analysed together.
Use case B		After around four years of operating the AEGIS solution, it will be less expensive than the baseline scenario, again in terms of cumulative cost.	AEGIS solution is generally slower than the baseline solution. But since the AEGIS ships can work daily, there will be no delay or disruption in meeting even daily demands. Therefore, in this case, time would not be a serious challenge.
Use case C	*Aalborg*	After around 8.5 years for the battery system and about seven years for the methanol propulsion system, the AEGIS scenario will have a better cost situation than the baseline scenario.	AEGIS solution is generally slower than the baseline solution. But, since the AEGIS ships can work daily, there will be no delay or disruption in meeting even daily demands. Therefore, in this case, time would not be a serious challenge.
	Vordingborg	AEGIS solution is cheaper.	AEGIS solution is generally slower than the baseline solution.

Among the cost and time KPIs, CAPEX and time KPIs seem to be the only KPIs in which the AEGIS solution is inferior to the non-AEGIS, baseline solution. However, the fact that CAPEX is higher in the AEGIS solution is to be expected due to the advanced nature of the AEGIS solution. It is also expected that the level of CAPEX will get gradually lower in the future, as is common with all advanced technologies. But even with the figures assumed in this analysis, the cumulative (CAPEX+OPEX) cost of operation of the AEGIS system is seen to be lower than the equivalent cost of the non-AEGIS solution after some years of operation.

Regarding time KPIs, whereas the AEGIS solution was generally found to be slower than the non-AEGIS solution, this result is also to be expected given that in many cases AEGIS competes (even partially) with the road mode, which is faster. However, this result is subject to improvement once a better interoperability among the various components of the AEGIS system is achieved, and/or once some key parameters of logistical system design, such as vessel speed, sailing frequency, number of ships, or just-in-time arrival are better adjusted. Such an analysis would be, among other things, the subject of AEGIS Task 7.5, which will deal with the identification of win-win solutions.

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[1] Deliverable D7.2: Report on KPIs (2021). AEGIS. Advanced, Efficient and Green Intermodal Systems, 2021.

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[8] Podiotis, A., Daskalaki, F. (2021). Cross Disciplinary Assessment of Autonomous Shipping, Ports and Intermodal Innovations. DTU MSc. Thesis, July 2021.

[9] Deliverable D10.3: Potential for calling the two Danish ports by DFDS (2022). AEGIS. Advanced, Efficient and Green Intermodal Systems, 2022.

Annex A. Data Template

This annex contains the data template circulated to the AEGIS partners.

Data	Units	ENTER INPUT HERE	COMMENT		Comparis on with data
Vessel Name	Name				
Vessel Type	Name				
Route deployed in	Name				
Geometric Characteristics (LPP, LOA, B, T)	meters				
Main Engine Power (MCR)	kW				
Main Engine Type/Model					
Main Engine Fuel Type					
Main Engine Fuel Consumption at 75% MCR	tonnes/day				
Auxiliary Engine & Boiler Power (MCR)	kW				
Auxiliary Engine & Boiler Type/Model					
Auxiliary Engine & Boiler Fuel Type					
Auxiliary Engine & Boiler Fuel Consumption at 75% MCR	tonnes/day				
Design speed	knots				
Vessel capacity	TEU/lane meters				
Vessel cargo handling equipment (if any): name	Name				
Vessel cargo handling equipment; number	#				
Cargo handling rate (per cargo handling unit)	TEUs/hour, LM/hour				
CAPEX-Price New Vessel	€				
OPEX- crew	€/year				
OPEX-maintenance	€/year				
OPEX-other (no fuel)	€/year				
Crew size (non-hotel)	#				
Autonomy Level	Fully manual/Operator Controlled/Automatic/Partial Autonomy/ Constrained Autonomous/ Fully Autonomous				
Load factor	%				
Any other relevant info.					

Figure 27: The "Ship" worksheet

Data	Units	ENTER INPUT HERE	COMMENT
Route Length	NM		
Route description including transshipment nodes (ports, other)	Names		
Number of transshipment nodes	#		
Route Cargo Volume A to B	Lane meters/year or TEUs/year		
Route Cargo Volume B to A	Lane meters/year or TEUs/year		
Ship Speed (average)	Kn		
Total Sailing Time	hours		
Total Loading Time	hours		
Total Unloading Time	hours		
Total Terminal Cargo Residence Time	hours		
Other waiting time	hours		
Number of ships on route	#		
Punctuality	%		
Frequency of Service	shipments/week		
Bunkering Possibilities and Availabilities (LNG, Hydrogen, Battery…)	-		
Competing services on route and their shares			
Non-maritime leg of route- type of vehicle	name		
Non-maritime leg of route- total distance	km		
Non-maritime leg of route- total transit time	hours		
Non-maritime leg of route- total cost (last mile)	€		
Any other relevant info.			

Figure 28: The "route" worksheet

Data	Units	ENTER INPUT HERE	COMMENT		CHECK WITH DATA
Volume of Cargo Moved (both loaded and unloaded) per Port Call and type of cargo	#TEUs/port call or #Lane meters/port call				
Type of cargo	name				
Average value of cargo	€/tonne				
Origin of cargo (if known)	name				
Destination of cargo (if known)	name				
Door to door transit time of cargo (if known)	name				
Door to door freight rate	€/tonne				
Any other relevant info.					

Figure 29: The "cargo" worksheet

Data	Units	ENTER INPUT HERE	COMMENT
Name of port/terminal	Name		
Number of berths	#		
Storage capacity	TEUs, LMs		
Shore cargo handling equipment (if any): name	Name		
Shore cargo handling equipment; number	#		
Cargo handling rate (per cargo handling unit)	TEUs/hour, LM/hour		
People on shore needed to operate cargo handling equipment	#		
Other people on shore needed for operation	#		
Any other relevant info.			

Figure 30: The "port" worksheet

Data	Data Measurement	ENTER INPUT HERE	COMMENT
Number of successful Cyber-Attacks per Year	#/year		
Number of intended Cyber-Attacks per Year	#/year		
Recovery Time due to Crime (cyber-attack…) from detection to recovery	hours		
Restored Level of Performance after a Cyber-Attack	% of Original Level of Performance		
Education Level Employees Needed	No Degree/BSc/MSc/PhD		
Maximum Noise Emitted Vessel + Port	dB		
Use of Renewable Energy Sources of the total Energy Required	%		
Accident Rate	#/year		
Fatality Rate	#/year		
Fire Incidents	#/year		
Crime (thefts, piracy…)	#/year		
Training time per worker	hours/worker		

Figure 31: The "other" worksheet