Win-win solutions

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Advanced, Efficient and Green Intermodal Systems

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Executive Summary

AEGIS is a concept for improving short-sea transportation logistics. It focuses on finding automated solutions to tackle the challenges faced by the industry. By using technology and innovation, AEGIS aims to make operations more efficient and effective. This document, D7.9 Win-win solutions, is the last deliverable of Work Package 7 (WP7). The objectives of WP7 are to conduct a thorough Cost Benefit Analysis (CBA) and environmental assessment while also taking into consideration social aspects. By considering all these factors, WP7 aims to provide a comprehensive analysis of the proposed initiatives.

This report's objective is to identify “win-win” solutions by considering the whole sustainability aspects that provide the most significant overall benefits while minimizing costs. A “win-win” solution is one that is acceptable in terms of most of the KPIs (Key Performance Indicators) that have been used in the CBA.

Looking at the previous deliverables of WP7, the results of the economic, environmental and social analyses [[1],[2],[3]], it should be clear that most of the AEGIS solutions are already win-win, in the sense that significant benefits of the AEGIS solution vs the non-AEGIS (baseline) solution have been identified in all three analyses and in all three use cases. Some exceptions however exist, mainly in terms of the CAPEX and time KPIs, in which the AEGIS solution performs worse than the non-AEGIS solution. This result is to be expected, and as far as CAPEX goes the fact that CAPEX is higher for AEGIS is perhaps of lesser importance as it was shown that the overall cumulative (CAPEX+OPEX) cost of the AEGIS solution is less than the equivalent total cost of the non-AEGIS solution after some years of operation. The result of the time KPIs (i.e., that the AEGIS solution is generally slower than the non-AEGIS solution) is also to be expected. We clarify here that by “slower” we mean that transit time KPIs are generally expected to be higher in the AEGIS solution, vs the baseline solution, without implying any sort of lower efficiency in the AEGIS supply chain. It remains to be seen what can be done to improve this KPI, and how significant that result really is, in a holistic way. This report attempts to address this issue.

Another issue that is open is how the economic KPIs are expected to change due to significant developments in EU legislation in the context of the “fit-for-55” package, and specifically as regards the impending inclusion of shipping and road transport into the EU Emissions Trading System (ETS). This will impact some of the economic KPIs for both the AEGIS and non-AEGIS solutions and was not examined in the economic CBA [[2]]. Analyzing such impact was actually not stipulated in the AEGIS Grant Agreement. However, in this report we take this opportunity to investigate how this development will impact our results.

With this in mind, the main objectives of this report are to:

- See if time KPIs can be improved by examining the impact of measures such as speed changes and other operational adjustments
- Examine the impact of the new EU ETS legislation on the AEGIS economic KPIs

With respect to time KPIs, our analysis has shown that some improvements can be realized by a vessel speed increase (in all use cases) and by other adjustments (in the case of Use Case A). Obviously however, with the increase in the ship's speed, OPEX are expected to increase as well due to increased energy consumption.

Furthermore, it has been observed that with the application of the EU ETS, the competitive advantage of the AEGIS solution is expected to increase in most use cases, versus the case of no application of EU ETS.

Finally, a questionnaire was also prepared to get the opinions of AEGIS partners and AG members on the relative importance of KPIs. The general result is that three KPIs, time, CO_2 emissions, and OPEX, seem to exhibit the highest importance.

Definitions and abbreviations

AG: Advisory Group

CAPEX: Capital Expenditure

EC: European Commission

EEA: European Economic Area

EEX: European Energy Exchange

ETS: Emissions Trading System

EUAs: European Union Allowances

GHG: Greenhouse Gases

KPI: Key Performance Indicators

LNG: Liquefied Natural Gas

MRV: Monitoring, Reporting, and Verification

OPEX: Operational Expenditure

TTW: Tank to Wake or Tank to Wheel

UC: Use Case

WP: Work Package

WTT: Well to Tank

WTW: Well to Wake or Well to Wheel

1 Purpose and structure of this report

This report, deliverable D7.9 is the outcome of AEGIS Task 7.5, whose description is as follows: *For each of the case studies studied under WP8, WP9 and WP10, and the analyses performed in Tasks 7.2, 7.3 and 7.4, this task will identify "win-win" solutions, as well as the conditions for these solutions to be realized. A "win-win" solution is defined in terms of being acceptable in terms of most of the KPIs that have been identified as important in the context of Task 7.1. These solutions will also be compared to the solutions in common use today.*

It builds upon progress made in previous WP7 tasks, and specifically Task 7.2 (Economic Analysis)- deliverable D7.6 [[1]], Task 7.3 (Environmental Analysis)- deliverable D7.7 [[2]], and Task 7.4 (Social Analysis)- deliverable D7.8 [[3]]. As before, this report encompasses all three use cases, A, B, and C, providing a comprehensive analysis of the identified win-win solutions within their respective contexts. In fact, this deliverable used the output from other related tasks and work packages. In summary, Figure 1 below depicts the conceptual approach of this work and shows how this report ties in with other WPs.

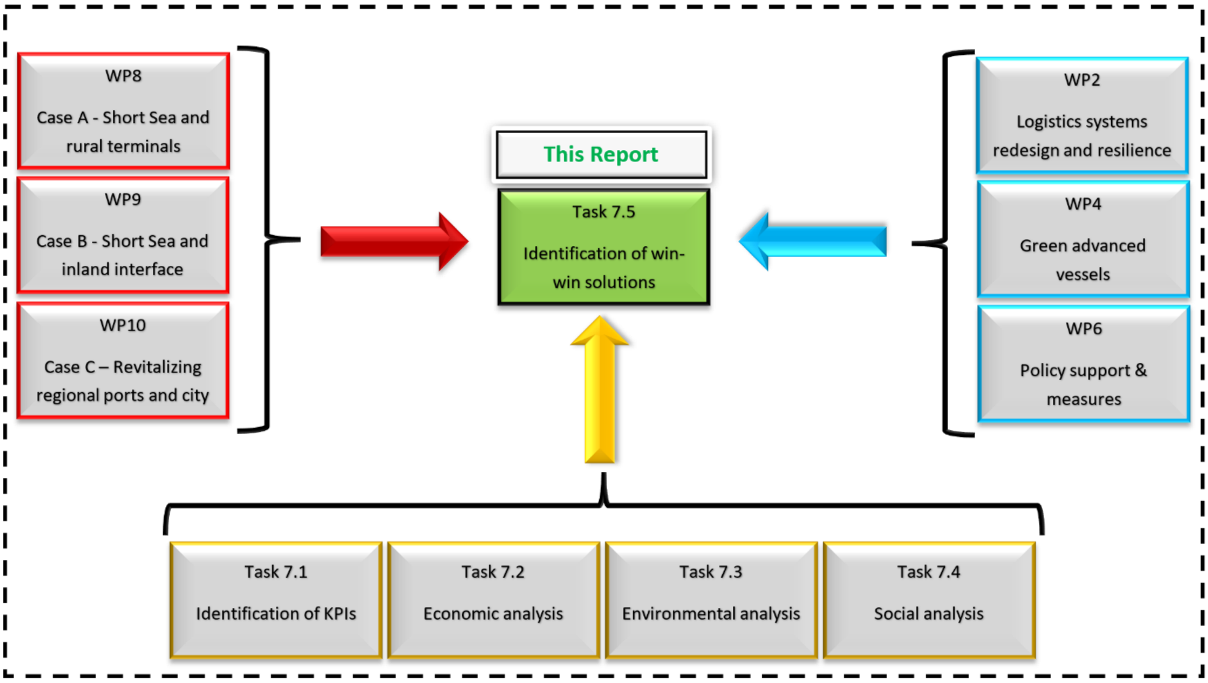

Figure 1: Task 7.5 conceptual approach

Looking at the previous deliverables of WP7 [[1],[2],[3]], it should be clear that most of the AEGIS solutions are already win-win, in the sense that significant benefits of the AEGIS solution vs the non-AEGIS baseline solution have been identified in all three dimensions and in all three use cases. Some exceptions however exist, mainly in terms of the CAPEX and time KPIs, in which the AEGIS solution performs worse than the non-AEGIS solution. This result is obviously to be expected, and as far as CAPEX goes the fact that CAPEX is higher for AEGIS is perhaps of lesser importance as it was shown that the overall cumulative (CAPEX+OPEX) cost of the AEGIS solution is less than the equivalent total cost of the non-AEGIS solution after some years of operation. The result of the time KPIs (ie that the AEGIS solution is generally slower than the non-AEGIS solution) is also to be expected. We clarify here that by "slower" we mean that transit time KPIs are generally expected to be higher in the AEGIS solution, vs the baseline solution, without implying any sort of lower efficiency in the AEGIS supply chain. It remains to be seen what (if anything) can be done to improve this KPI, and how significant that result really is, in a holistic way. This report attempts to address this issue.

Another issue that is open is how the economic KPIs are expected to change due to significant developments in EU legislation in the context of the “fit-for-55” package, and specifically as regards the impending inclusion of shipping and road transport into the EU Emissions Trading System (ETS). Analyzing the implications of such an inclusion was obviously not foreseen in the AEGIS grant agreement, however we felt that this is an issue that should not be left open: the inclusion surely will impact some of the economic KPIs for both the AEGIS and non-AEGIS solutions and was not examined in the economic CBA [2]. Thus, in this report we take this opportunity to investigate how this development will impact our results.

With this in mind, the main objectives of this report are to:

- See if time KPIs can be improved by examining the impact of measures such as speed changes and other operational adjustments
- Examine the impact of the new EU ETS legislation on the AEGIS economic KPIs

In addition, a questionnaire was also prepared to get the opinions of AEGIS partners and AG members on the relative importance of KPIs. Even though the number of responses to this questionnaire was not very high, we show them as we think they are worthy of note.

The rest of this report is organized as follows.

Section 2 explores the identification of the impact of operational measures.

Section 3 examines the impact of market-based measures for both scenarios.

Section 4 investigates the survey results and ranks the KPIs based on their importance.

Section 5 presents the conclusions of this report.

2 Impact of operational measures

In this section, we first explore the advantages of integrating the entire AEGIS transport systems in use case A (mother and daughter vessels) by comparing it to the baseline scenario. By integration we mean evaluating the KPIs of the mother and daughter vessels in combination instead of separately (as it was done in previous tasks), plus seeing what other operational measures can be taken to improve these KPIs. To do this, we examined two ship capacity scenarios: 1) utilizing the maximum TEU capacity available and 2) considering a reasonable TEU capacity based on the current situation. For the details of the three use cases, the reader is directed to previous deliverables in WP8, WP9 and WP10. In the context of WP7, descriptions of the use cases can be found in references [[1],[2],[3]] and need not be repeated here

Next, we analyse the effects of different ship speeds on various key performance indicators (KPIs), particularly time, energy consumption, and OPEX, across all use cases.

It is important to note that for enhanced accuracy and up-to-date calculations, in this report we have used updated energy prices [[4],[5]]. In the rest of this section, because the price of fuel/energy is different in each case, these prices are included. in the section of each use case.

2.1 Use Case A Integration

In previous deliverables [[1],[2],[3]], daughter and mother ships, and the corresponding KPIs, were investigated separately. In this report they are investigated as an integrated system, and the corresponding KPIs are considered in combination. This approach provides an estimation of the costs in the transport system, including CAPEX and OPEX, energy consumption, and travel time when these KPIs are considered in combination. By comparing the AEGIS system to the current transport system, this report attempts to provide a more comprehensive understanding of the advantages and disadvantages of the AEGIS system in this particular use case.

It should be mentioned here that we calculated only the KPIs that are impacted by the integration. For example, in this section, we did not consider the social KPIs that are already described in deliverable D7.8 [[3]]. Also, the prices of energy consumption for electricity, methanol, and diesel are considered equal to 0.14 €/kWh, 0.17 €/kWh and 0.119 €/kWh, respectively [[4],[5]].

2.1.1 Maximum TEU capacity

Table 1 below presents the results obtained in two scenarios: the baseline (non-AEGIS) scenario and the AEGIS scenario, with the AEGIS' ships utilizing their maximum capacity. The maximum capacity for the mother ship and daughter ship 1 is approximately 100%.

Table 1: Result of UCA based on maximum TEU capacity

KPI	KPI Name	Unit	Result		Better KPI
			AEGIS	Baseline	
Cost	*CAPEX*	€	130,000,000	98,812,000	*Baseline*
Cost	*OPEX*	€/week	1,064,720	1,205,370	*AEGIS*
Cost	*Maintenance Cost*	€/week	127,392	151,044	*AEGIS*
Cost	*Port Charges or THC*	€/week	488,880	470,880	*Baseline*
Cost	*Fuel Cost*	€/week	411,670	446,065	*AEGIS*
Cost	*Wages*	€/week	36,790	137,380	*AEGIS*
Time	*Loading Time*	H	238	237	*Almost Equal*
Time	*Sailing or Drive Time*	H	149.86	122.16	*Baseline*

Time	***Unloading Time***	H	238	237	*Almost Equal*
Others	***Energy consumption***	KWh/week	2,917,470	3,640,505	*AEGIS*
Others	***Percentage of load***	%	(1,1)		---
Emissions	***CO_2-WTT***	Tonnes of CO_2/week	215.7	362.2	*AEGIS*
Emissions	***CO_2-TTW***	Tonnes of CO_2/week	1,520	1,934	*AEGIS*
Emissions	***NO_x-TTW***	Tonnes of NOx/week	23.4	45.5	*AEGIS*
Emissions	***SO_x-TTW***	Tonnes of SOx/week	0.92	1.95	*AEGIS*
Emissions	***Particulate Matter (PM_{10})-TTW***	Tonnes of PM_{10}/week	0.25	0.52	*AEGIS*

As can be seen in Table 1, the AEGIS scenario in most KPIs is better than the baseline scenario, except for CAPEX and sailing time. However, energy consumption, OPEX cost, and energy cost, which are essential economic KPIs, are better for AEGIS.

Equation 1 shows the Breakeven Point (BEP) of the UCA, which shows that after around four years and a half in terms of cost KPI, the AEGIS scenario will cost less than the base scenario.

$$130{,}000{,}000 + 1{,}064{,}720 * x = 98{,}812{,}000 + 1{,}205{,}370 * x \implies x = 221 \text{ weeks} \sim 52\ months \quad (1)$$

These results are more promising than the previous results in deliverable D7.6, which stated that the mother ship is economically good after about seven and a half years. This is because when we view the whole system in an integrated way, the AEGIS scenario in terms of OPEX KPI is better than if we examine each ship separately. Indeed, the reason for this improvement in terms of cost and even the reduction of emissions in the AEGIS system compared to the baseline scenario is that we use daughter ships with electricity as a fuel, and it is the point where the transportation of goods is shifting from land to sea. As a result, with an integration perspective at the UCA system, the weight of the advantages of using daughter ships in the calculations becomes more apparent, and as a result, the competitive advantage of the AEGIS system become more pronounced.

In addition, from an environmental point of view, a significant amount of emissions will be reduced. For example, as shown in Figure 2, we calculated the total CO_2 production cycle over ten years (WTW= WTT+TTW). As one can see, the superiority is with the AEGIS scenario, and the amount of total CO_2 reduction increases significantly with time.

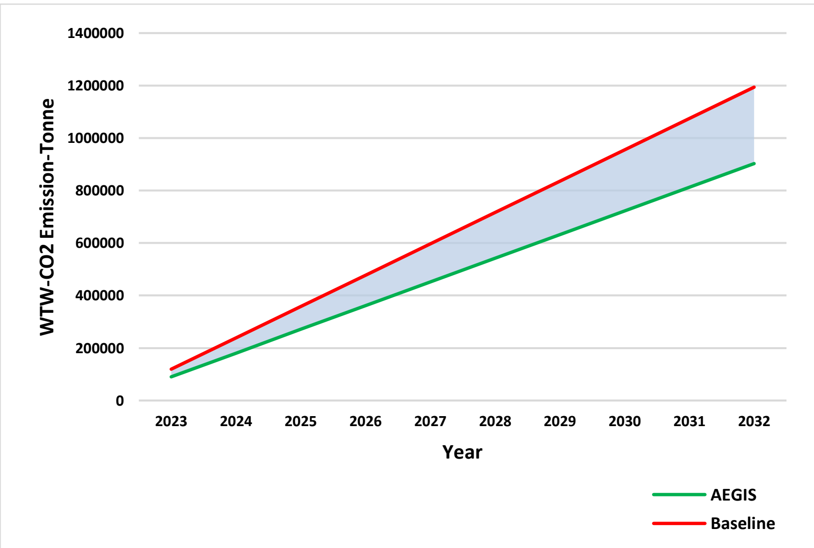

Figure 2: WTW CO_2 emissions for UCA-max TEU

2.1.2 Moderate TEU capacity

In the following, Table 2 represents the results obtained in two scenarios: the baseline and the AEGIS, with the AEGIS' ships utilizing the current capacity of AEGIS ships. The current usage capacity for the mother ship is around 0.66, and daughter ships are approximately 80%. We have received this percentage usage from SINTEF Ocean.

Table 2: Result of UCA based on current TEU capacity

KPI	KPI Name	Unit	Result		Better KPI
			AEGIS	Baseline	
Cost	*CAPEX*	€	130,000,000	98,812,000	*Baseline*
Cost	*OPEX*	€/week	900,165	1,045,270	*AEGIS*
Cost	*Maintenance Cost*	€/week	127,392	151,044	*AEGIS*
Cost	*Port Charges or THC*	€/week	324,315	310,780	*Baseline*
Cost	*Fuel Cost*	€/week	411,670	446,065	*AEGIS*
Cost	*Wages*	€/week	36,790	137,380	*AEGIS*
Time	*Loading Time*	H	157	157	*Equal*
Time	*Sailing or Drive Time*	H	149.86	122.16	*Baseline*
Time	*Unloading Time*	H	157	157	*Equal*
Others	*Energy consumption*	KWh/week	2,917,470.3	3,640,506	*AEGIS*
Others	*Percentage of load*	%	(0.66,0.8,0.8)		---
Emissions	*CO_2-WTT*	Tonnes of CO_2/week	204.9	357.3	*AEGIS*
Emissions	*CO_2-TTW*	Tonnes of CO_2/week	1,519.6	1,915.4	*AEGIS*
Emissions	*NO_x-TTW*	Tonnes of NOx/week	24.3	47.2	*AEGIS*
Emissions	*SO_x-TTW*	Tonnes of SOx/week	0.89	1.89	*AEGIS*
Emissions	*Particulate Matter (PM_{10})-TTW*	Tonnes of PM_{10}/week	0.25	0.54	*AEGIS*

As can be seen in Table 2, like previously, the AEGIS scenario in most KPIs has competitive advantages except for CAPEX and sailing time. However, in terms of energy consumption, OPEX cost, and fuel cost, which are essential economic KPIs, the AEGIS solution is better.

Equation 2 shows the BEP of the UCA and declare that after around four years and a half in terms of cost KPI, the AEGIS scenario will be cheaper than the baseline scenario.

$$130{,}000{,}000 + 900{,}165 * x = 98{,}812{,}000 + 1{,}045{,}270 * x \implies x = 215 \text{ weeks} \sim 51\, months \qquad (2)$$

Like previous, these results are much more promising than the previous results in deliverable D7.6.

In addition, from an environmental point of view, AEGIS will reduce a significant amount of emissions. For example, as shown in Figure 3, we calculated the total CO_2 production cycle over ten years (WTW= WTT+TTW). As one can see, the absolute superiority is with the AEGIS scenario, and the amount of CO_2 reduction decreases significantly every year that passes.

It is also important to mention that by comparing this section with the previous section, we find that the amount of gas reduction is higher when we use the maximum capacity. The reason for this is that, in that case, we have shifted more goods toward the AEGIS solution, which is a greener transportation mode.

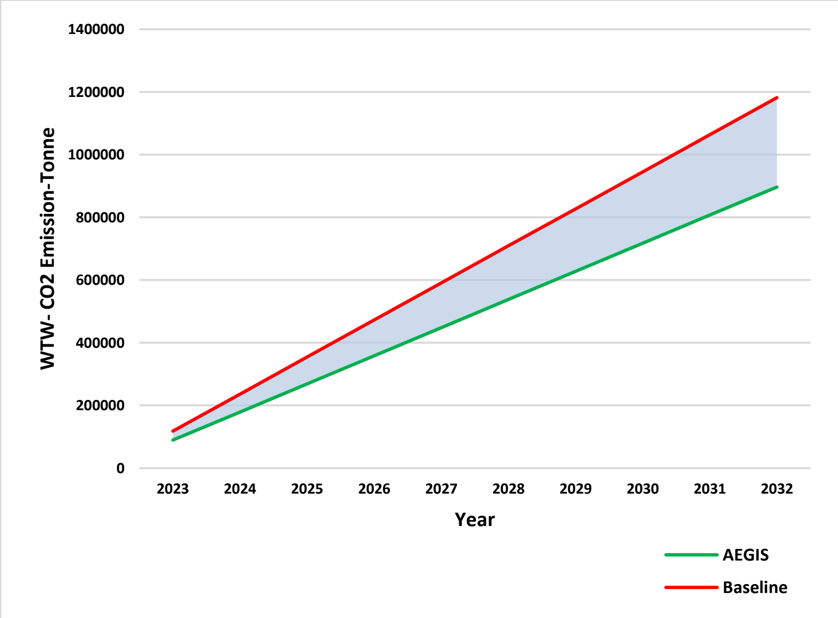

Figure 3: WTW CO_2 emissions for UCA – current TEU

2.2 Impact of speed changes on the KPIs

In this section, we have calculated the KPIs relevant to each Use Case based on different conditions in speed in the AEGIS scenario. Also, we have compared these conditions to investigate the advantages of each of them.

2.2.1 Use case A

According to the routes explained in Deliverable D7.6 [1], the results obtained in both scenarios (basic and AEGIS) are in Table 3. Also, we consider the AEGIS scenario as an integrated way (mother and daughters).

It is important to note that we have only considered speed changes for the daughter ships. One can find the speed values considered in the table below. This is because in the mother scenario, we encounter the ship in both scenarios and in practice, they should have the same conditions.

Table 3: Result of UCA based on different speed

KPI	KPI Name	KPI Measurement	Result			
			AEGIS			Baseline
			Daughter 1: 8 kn Daughter 2: 5 kn	Daughter 1: 9 kn Daughter 2: 9 kn	Daughter 1: 10 kn Daughter 2: 10 kn	
Cost	***CAPEX***	€	130,000,000			98,812,000
Cost	***OPEX***	€/week	1,064,720	1,066,860	1,068,600	1,205,370
Cost	***Maintenance Cost***	€/week	127,390			151,044
Cost	***Port Charges or THC***	€/week	488,880			470,880
Cost	***Fuel Cost***	€/week	411,670	413,805	415,540	446,065
Cost	***Wages***	€/week	36,790			137,380
Time	***Loading Time***	H	238			237
Time	***Sailing or Drive Time***	H	149.86	144.96	141.16	122.16
Time	***Unloading Time***	H	238			237
Others	***Energy consumption***	KWh/week	2,917,470.3	2,932,721.2	2,945,111.2	3,640,505.6
Others	***Percentage of load***	%	(1,1)			

Emissions	***CO_2-WTT***	Tonnes of CO_2/week	215.7	215.9	216.1	362.2
Emissions	***CO_2-TTW***	Tonnes of CO_2/week	1,520			1,934
Emissions	***NO_x-TTW***	Tonnes of NOx/week	23.4			45.5
Emissions	***SO_x-TTW***	Tonnes of SOx/week	0.92			1.95
Emissions	***Particulate Matter (PM_{10})-TTW***	Tonnes of PM_{10}/week	0.25			0.52

In Table 3, it is evident that increasing the speed of the daughter ships leads to a slight rise in the OPEX of the AEGIS scenario (approximately € 4,000 per week). However, since the daughters' ships run on battery, there are no changes in the TTW emission for all gases by speed increase. But the CO_2 WTT emissions experience only a marginal increase of around 1 tonne.

However, on the other hand, the impact of speed increase on the KPI of travel time is noticeable and leads to significant improvement. There is an approximate reduction of 8 hours in travel time, which not only enhances the competitive advantages of the AEGIS scenario but also prepares us to meet potential future increases in demand from the daughters' perspective. Indeed, by increasing the speed, the number of trips of daughter vessels can be increased within a certain timeframe, enabling us to respond to higher customer demand.

2.2.2 Use case B

For this section, most of the results are based on findings summarized in an MSc thesis that was conducted at DTU [6]. The thesis was successfully defended in July 2023, and the results presented were based on data provided by AEGIS partners.

According to the routes explained in Deliverable D7.6 [1], the results obtained in both scenarios (basic and AEGIS) are in Table 4. As can be seen in Table 4, we analysed the AEGIS vessel at 8, 9, and 10 knots speed. In addition, it is important to mention that in this case, our ship uses electric energy, and its price is 0.18 €/kWh.

Table 4: Result of UCB based on different speed

KPI	KPI Name	KPI Measurement	Result			
			AEGIS			Baseline
			8 kn	9 kn	10 kn	
Cost	***CAPEX***	€	48,000,000			5,328,000
Cost	***OPEX***	€/week	291,260	308,810	329,890	541,901
Cost	***Maintenance Cost***	€/week	20,000			108,380
Cost	***Port Charges or THC***	€/week	196,350			0
Cost	***Fuel Cost***	€/week	63,010	80,560	101,640	270,951
Cost	***Wages***	€/week	11,900			252,817
Time	***Loading Time***	H	1			0.03
Time	***Sailing or Drive Time***	H	10.8	9.6	8.6	2.5
Time	***Unloading Time***	H	1			0.03
Time	***Waiting Time***	H	1			0
Others	***Energy consumption***	KWh/week	350,043	447,552	564,660	2,125,200
Emissions	***CO_2-WTT***	g of CO_2/tkm	9.3	11.8	14.95	3.97
Emissions	***CO_2-TTW***	g of CO_2/tkm	0			20.5
Emissions	***NO_x-TTW***	g of SO_x/tkm	0			$7.09X10^{-3}$
Emissions	***SO_x-TTW***	g of NO_x/tkm	0			$7.88X10^{-5}$
Emissions	***Particulate Matter (PM_{10})-TTW***	g of PM_{10}/tkm	0			$7.88X10^{-5}$

In Table 4, it is evident that increasing the speed of the ships leads to a rise in the OPEX of the AEGIS scenario (approximately € 30,000 per week). However, since the UCB runs on battery energy, there are no changes in the TTW emission for all gases by speed increase. But the CO_2 WTT emissions experience an increase of around 5 tonnes. But the AEGIS scenario is still more environmentally friendly than the baseline scenario in terms of WTW emissions.

On the contrary, increasing the speed will allow us to decrease the travel time by 2 hours per round trip, thereby placing the AEGIS scenario in a more advantageous position than before in this KPI. Although this achievement is accompanied by a significant increase in fuel consumption.

Therefore, in general, we can conclude that in UCB, if we anticipate an increase in demand in the future, then we can consider increasing the speed of ships. Because at the moment, and without such a demand increase, it seems that an increase in speeds is not justified.

2.2.3 Use case C

According to the routes explained in Deliverable D7.6 [1], the results obtained in both scenarios (basic and AEGIS) for Aalborg and Vordingborg cases are in Tables 5-7. Indeed, Table 5 and

Table 6 are related to the Aalborg case and show the result for the methanol and battery propulsion systems, respectively. Also, Table 7 is related to the Vordingborg case. Also, the price of electricity and methanol in this use case are considered equal to 0.19 €/kWh and 0.17 €/kWh, respectively.

For the Aalborg case, we considered 8, 9, and 10 knots speeds for the AEGIS vessel, and for the Vordingborg, we examined the effect of speed changes in 10, 11, and 12 knots speeds.

Table 5: Result of UCC-Aalborg case based on different speed for methanol propulsion system

KPI	KPI Name	KPI Measurement	Result				
			AEGIS				Baseline
			Vessel			Truck	
			8 kn	9 kn	10 kn		
Cost	***CAPEX***	€	21,000,000			3,848,000	5,328,000
Cost	***OPEX***	€/week	197,177	201,167	205,795	666,848	937,664
Cost	***Maintenance Cost***	€/week	108,500			133,371	187,530
Cost	***Port Charges or THC***	€/week	67,200			0	0
Cost	***Fuel Cost***	€/week	16,644	20,634	25,262	200,053	281,302
Cost	***Wages***	€/week	4,830			333,420	468,830
Time	***Loading Time***	H	2			0.03	0.03
Time	***Sailing or Drive Time***	H	10.8	9.6	8.6	7.6	10.7
Time	***Unloading Time***	H	2			0.03	0.03
Time	***Last Mile***	H	0.8			0	0
Others	***Energy consumption***	KWh/week	97,903	121,373	148,601	1,566,208	2,205,056
Emissions	***CO_2-WTT***	g of CO_2/tkm	0.9	1.2	1.4	5.95	5.95
Emissions	***CO_2-TTW***	g of CO_2/tkm	26.9	33.3	40.8	30.7	30.7
Emissions	***NO_x-TTW***	g of SO_x/tkm	0.08	1.10	0.13	0.0106	0.0106
Emissions	***SO_x-TTW***	g of NO_x/tkm	0			$1.18X10^{-4}$	$1.18X10^{-4}$
Emissions	***Particulate Matter (PM_{10})-TTW***	g of PM_{10}/tkm	$1.44X10^{-7}$	$1.78X10^{-7}$	$2.19X10^{-7}$	$1.18X10^{-4}$	$1.18X10^{-4}$

Table 6: Result of UCC-Aalborg case based on different speed for battery propulsion system

KPI	KPI Name	KPI Measurement	Result				
			AEGIS				Baseline
			Vessel			Truck	
			8 kn	9 kn	10 kn		
Cost	***CAPEX***	€	24,000,000			3,848,000	5,328,000
Cost	***OPEX***	€/week	199,444	203,163	207,472	666,848	937,664
Cost	***Maintenance Cost***	€/week	108,500			133,371	187,530
Cost	***Port Charges or THC***	€/week	67,200			0	0
Cost	***Fuel Cost***	€/week	18,911	22,630	26,939	200,053	281,302
Cost	***Wages***	€/week	4,830			333,420	468,830
Time	***Loading Time***	H	2			0.03	0.03
Time	***Sailing or Drive Time***	H	10.8	9.6	8.6	7.6	10.7
Time	***Unloading Time***	H	2			0.03	0.03
Time	***Last Mile***	H	0.8			0	0
Others	***Energy consumption***	KWh/week	99,533	119,105	141,785	1,566,208	2,205,056
Emissions	***CO_2-WTT***	g of CO_2/tkm	5.1	6.1	7.3	5.95	5.95
Emissions	***CO_2-TTW***	g of CO_2/tkm	0			30.7	30.7
Emissions	***NO_x-TTW***	g of SO_x/tkm	0			0.0106	0.0106
Emissions	***SO_x-TTW***	g of NO_x/tkm	0			$1.18X10^{-4}$	$1.18X10^{-4}$
Emissions	***Particulate Matter (PM_{10})-TTW***	g of PM_{10}/tkm	0			$1.18X10^{-4}$	$1.18X10^{-4}$

Table 7: Result of UCC-Vordingborg case based on different speed

KPI	KPI Name	KPI Measurement	Result				
			AEGIS			Baseline	
			10 kn	11 kn	12 kn	Vessel	Truck
Cost	***CAPEX***	€	11,500,000			9,000,000	3,552,000
Cost	***OPEX***	€/week	60,252	60,685	62,308	13,700	131,300
Cost	***Maintenance Cost***	€/week	25,500			1,370	26,260
Cost	***Port Charges or THC***	€/week	10,200			10,200	0
Cost	***Fuel Cost***	€/week	5,652	6,085	7,708	9,451	39,390
Cost	***Wages***	€/week	18,900			1,780	65,650
Time	***Loading Time***	H	10			10	0.03
Time	***Sailing or Drive Time***	H	36	28	26	2.64	11.69
Time	***Unloading Time***	H	10			10	0.03
Others	***Energy consumption***	KWh/week	33,248	35,796	45,342	4,292	460,305
Emissions	***CO_2-WTT***	g of CO_2/tkm	0.31	0.34	0.43	2.61	3.97
Emissions	***CO_2-TTW***	g of CO_2/tkm	8.98	9.66	12.24	13.95	20.5
Emissions	***NO_x-TTW***	g of SO_x/tkm	0.028	0.03	0.04	0.35	$7.09X10^{-3}$
Emissions	***SO_x-TTW***	g of NO_x/tkm	0			0.014	$7.88X10^{-5}$
Emissions	***Particulate Matter (PM_{10})-TTW***	g of PM_{10}/tkm	$4.81X10^{-9}$	$5.18X10^{-9}$	$6.56X10^{-9}$	0.004	$7.88X10^{-5}$

For the Aalborg case, as can be seen in Table 5 and

Table 6 it is evident that increasing the speed of the AEGIS ships leads to a slight rise in the OPEX of the AEGIS scenario for both propulsion systems. The main reason for this change is due to the fuel cost, which originates from the fuel consumption KPI.

Furthermore, as the speed increases, it becomes apparent that there is a larger increase in gas emissions when the ship operates on methanol fuel compared to battery fuel. This disparity arises from the fact that electric fuel exhibits a zero-emission rate in the TTW index. Consequently, the advantage of electric fuel over methanol fuel becomes more pronounced with the acceleration in speed.

On the other hand, increasing the speed will allow us to decrease the travel time by 2 hours per round trip, thereby placing the AEGIS scenario in a more advantageous position than before in this KPI.

Therefore, in conclusion, for the UCC-Aalborg case, if we anticipate a future increase in demand that necessitates the acceleration of our vessels, it is advisable to prioritize battery propulsion systems. By doing so, we can ensure that our scenario maintains a superior position in terms of emissions compared to the baseline scenario.

For the Vordingborg case, as can be seen in Table 7 it is evident that increasing the speed of the AEGIS ships leads to a slight rise in the OPEX of the AEGIS scenario (approximately € 2,000 per week). We can see also, there are noticeable changes in terms of fuel consumption when we use higher speeds (approximately % 30 increases).

In addition, as the speed increases, it becomes apparent that there is a larger increase in gas emissions. But the AEGIS scenario will still keep its competitive advantages over the baseline scenario.

However, on the other hand, the impact of speed increase on the KPI of travel time is noticeable and leads to significant improvement. There is an approximate reduction of 10 hours in travel time per week, which not only enhances the competitive advantages of the AEGIS scenario but also prepares us to meet potential future increases in demand. Indeed, by increasing the speed, the number of trips can be increased within a certain timeframe, enabling us to respond to higher customer demand.

3 Impact of market based measures

3.1 Introduction

Market-based measures refer to environmental policies such as carbon taxes and emissions trading systems, which uphold the principle of "polluters pay" and provide financial incentives for stakeholders to reduce their emissions. The primary objective of these measures is to internalize the external costs associated with emissions, while also generating revenues that can bridge the competitiveness gap between low/zero carbon fuels and conventional systems. Examples of market-based measures include environmental taxes and cap and trade systems [7].

One prominent example of a market-based measure is the European Union Emissions Trading System (EU ETS), established by the European Union in 2005 to combat climate change. The EU ETS is the largest carbon trading system globally, covering over 11,000 power stations and manufacturing plants in 31 countries, including all European Economic Area (EEA) countries (i.e., EU member states, Norway, Iceland, and Liechtenstein) [8].

The EU ETS operates by setting a cap on the total amount of greenhouse gas (GHG) emissions allowed in covered sectors, such as power generation, aviation, and shipping. This cap is then divided among regulated entities in the form of EU Allowances (EUAs). EEA member states distribute EUAs to their respective companies, enabling them to emit a specific amount of GHGs. The total number of allowances decreases each year in line with the overall cap [9].

Each emissions allowance permit represents the permission for a company to emit one tonne of carbon. Currently, the EU carbon market price ranges between 90-95 EUR/tonne of CO2. The inclusion of the ETS increases the overall operational expenses for companies, thereby incentivizing them to adopt energy efficiency measures, introduce less energy-intensive technologies, and reduce their carbon footprint [10].

The purpose of this analysis is to investigate the potential impacts of the impending inclusion of the shipping sector in the EU ETS, as well as the announcement of a new EU ETS 2 specifically designed for road transport and residential buildings. The objective is to assess how these developments can influence the economic and environmental KPIs of the AEGIS project, aiming to identify a future "win-win" solution for the project.

3.2 Literature Review

This chapter collects and analysis prior research on the implications of EU ETS on European and international routes and examined relevant research on EU ETS 2 for road transport and residential buildings.

3.2.1 EU ETS 1 for the international maritime sector

On 14 July 2021, the European Commission (EC) proposed an extension of the EU ETS to encompass GHG emissions from the maritime sector [11]. This revision is part of the 'Fit for 55' package, aligning with the EU's objective of achieving net-zero GHG emissions by 2050. Alongside the inclusion of shipping in the EU ETS, the legislative proposal incorporates the FuelEU Maritime Initiative, which establishes GHG intensity targets and fuel standards for ships. Additionally, the Energy Taxation Directive eliminates fuel tax exemptions within the sector, while the Alternative Fuels Infrastructure

Regulation seeks to enhance the availability of shore side electricity and Liquefied Natural Gas (LNG) in ports [11].

As per the Directive, the obligation to surrender emissions allowances will be phased, starting with 20% of verified emissions reported for 2024, followed by 70% of reported emissions for 2025, and ultimately reaching 100% of emissions in 2026. The inclusion of shipping will cover 100% of CO2 emissions occurring during voyages between ports within the European Economic Area (EEA), 100% of CO2 emissions while ships are at berth in an EEA port, and 50% of CO2 emissions from international voyages between an EEA and a non-EEA port. At the end of each year, shipping companies must demonstrate a balance between allowances and verified emissions. If they exceed their purchased allowances, they will be required to purchase the excess amount from the carbon market. European Union Allowances (EUAs) can be acquired through either the primary market, i.e., auctions conducted by Member States through the European Energy Exchange (EEX), or the secondary market through the trading of EUAs on the EEX. Currently, the system applies to ships above 5000 gross tonnage (GT), but there are plans to extend the coverage to all ships above 400 GT in the future [11].

Hermeling et al., analyze the legal feasibility of implementing the EU ETS in the shipping sector and argue that the scheme places a burden on routes with a high proportion of regulated emissions, particularly short routes predominantly sailing within EU territorial waters. This, in turn, hinders cost-efficient emission reduction among regulated ships [12]. Franc and Sutto study the impacts of a cap-and-trade scheme on the organization of container shipping lines and EU ports, highlighting the risk of modal shifts from maritime to land transport, particularly road transport [13].

The potential administrative, technical, and operational challenges arising from the inclusion of shipping in the EU ETS have been examined by Enderle (2013) [14]. The study emphasizes that the volatility of carbon prices, influenced by market demand, does not contribute to stability within the sector. In a similar vein, Lagouvardou and Psaraftis investigate the significance of a fuel levy in providing stable carbon signals, enabling energy producers and shipowners to make investment decisions without concerns about fluctuating carbon costs [15]. Finally, Lagouvardou et al. investigate the level of carbon pricing needed to investigate the uptake of alternative marine fuels [16].

3.2.2 EU ETS 2 for road transport

As part of the "Fit for 55%" package, aimed at aligning EU policy with the objectives of the European Green Deal, the European Parliament and Council of the EU reached an agreement in December 2022 to establish a new ETS 2 for the building, road transport, and certain industrial sectors not covered by the existing EU ETS. This agreement is currently awaiting formal approval from the relevant institutions [17].

The ETS 2 is intended to complement Member States' efforts to reduce emissions in line with national targets under the "Effort Sharing Regulation" and will operate separately from the existing EU ETS, which covers emissions from electricity and heat generation, industrial production, maritime transport, and commercial aviation within the EU.

Scheduled to be launched in either 2027 or 2028, the ETS 2 will regulate fuel suppliers rather than end-consumers and will set an absolute cap on emissions, progressively reducing in accordance with a linear reduction factor. Allowances will be exclusively distributed through auctions, with higher auction volumes in the initial year to facilitate a smooth start for the system. To maintain market balance, a market stability reserve will be implemented to adjust the supply of allowances, and in the event of exceptionally high energy prices, the start of the system may be postponed by one year.

The new system is accompanied by complementary policies aimed at shaping market participants' expectations and providing measures to mitigate undue price impacts. Establishing an efficient monitoring, reporting, and verification system is crucial, given the extensive number of small emitters in the new sectors.

Given the large number of small emitters in the buildings and road transport sectors, and for reasons of technical feasibility and administrative efficiency, the point of regulation is established further upstream in the supply chain rather than directly with the emitters. Thus, the release for consumption of fuels used for combustion in buildings and road transport will be the regulated activity under the new system. The scope of these sectors is defined based on relevant sources of emissions outlined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Annex III) [17].

The emissions cap for the new emissions trading system will be set from 2026 using data collected under the Effort Sharing Regulation and ambitious targets, aiming for a 43% reduction in emissions by 2030 compared to 2005 levels for the buildings and road transport sectors. The agreed start date for the system is 2027. The linear reduction factor has been set at 5.15 starting from 2024, increasing to 5.43 from 2028. In the first year of the system's launch, an additional 30% of auction volume will be frontloaded to ensure a smooth start. Once the monitoring and reporting system for the new emissions trading is established, the total quantity of allowances for 2028 will be adjusted based on the available MRV (Monitoring, Reporting, and Verification) data from the period 2024 to 2026. The linear reduction factor will only be revised if the MRV data significantly exceeds the initial cap, not due to minor discrepancies with EU UNFCCC inventory data[1].

No free allocation of allowances will be provided under the new ETS; instead, allowances will be auctioned. To address the potential risk of excessive price volatility, particularly in the initial years of emissions trading in the new sectors, mitigation measures have been established. Furthermore, emissions trading for road transport and buildings will contribute to existing low-carbon funds to address transitional and social challenges associated with carbon pricing in these sectors and support innovation. Approximately 150 million allowances issued under the new emissions trading system for road transport and buildings will be made available to the Innovation Fund, encouraging the transition to greener practices. The Commission will closely monitor the application of the rules for the new emissions trading system and, if necessary, propose a review by 1 January 2028 to enhance its effectiveness, administration, and practical application.

To provide certainty to citizens, an additional price stability mechanism will be implemented, ensuring that the carbon price in the initial years of the new emissions trading system does not exceed EUR 45. This mechanism will release allowances from the Market Stability Reserve in case the carbon price surpasses this level. Initially, the mechanism will be applicable once within a 12-month period, but it may be activated again if the Commission, assisted by the Climate Change Committee, deems it necessary based on the price evolution. The Commission will assess the functioning of this mechanism and determine whether it should continue beyond 2029.

[1] https://di.unfccc.int/time_series

As an additional precautionary measure prior to the start of emissions trading in buildings, road transport, and additional sectors, there should be a possibility to delay the application of the emissions cap and surrendering obligations in the event of exceptionally high gas or oil wholesale prices compared to historical trends. This automatic mechanism would postpone the cap and surrendering obligations by one year if specific energy price triggers are met. The reference prices would be based on benchmark contracts in the gas and oil wholesale markets that are readily available and most relevant for end consumers. The Commission will provide clarity on the application of this delay well in advance through a notice in the Official Journal to ensure market certainty.

3.3 Analysis and Calculation

In this section we have calculated the KPIs relevant to each Use Case in baseline and AEGIS scenarios. The analysis examined the implementation of the EU ETS 1 on maritime transport and EU ETS 2 on road transport and their implications on the AEGIS project. We examined several EU carbon prices to identify their effects on the economic KPIs of Aegis. For EU ETS1 we examined the carbon prices of 80, 100 and 120 Euros/tonne of CO_2 and for EU ETS2 carbon prices of 10, 30 and 45 Euros/tonne of CO_2 respectively. We focused on the operational (TTW) CO_2 emissions for all our cases.

3.3.1 Use Case A

The implementation of EU ETS 1 and 2 applies to UCA for the AEGIS mother vessel and for the baseline vessel in the non-AEGIS scenario (Table 8). Also, For the daughter cases the implementation of EU ETS 1 and 2 applies only for the trucks in the non-AEGIS scenario (Table 9 and Table 10).

Table 8: Results of mother vessel in UCA

KPI	Carbon price	KPI Measurement	Result		
			AEGIS		Baseline
			New Vessel	NCL	
Cost	***EU ETS 1: 80 €/tonne CO_2***	€/week	60,808.19		73,711.92
Cost	***EU ETS 1: 100 €/tonne CO_2***	€/week	76,010.24		92,139.90
Cost	***EU ETS 1: 120 €/tonne CO_2***	€/week	91,212.29		110,567.88

Below equations show the Breakeven Point (BEP) of the mother case at each level of EU ETS. To be more precise, we seek to determine at each level of EU ETS when the CAPEX and OPEX costs of the AEGIS scenario would be cost-efficient compared to the baseline scenario.

$$\boldsymbol{EU\ ETS_{80}}: 114{,}000{,}000 + 611{,}860 * x = 96{,}000{,}000 + 671{,}669 * x \implies x = 301 \text{ weeks} \sim 72\ \ months \quad (3)$$

$$\boldsymbol{EU\ ETS_{100}}: 114{,}000{,}000 + 627{,}062 * x = 96{,}000{,}000 + 690{,}097 * x \implies x = 286 \text{ weeks} \sim 68\ \ months \quad (4)$$

$$\boldsymbol{EU\ ETS_{120}}\ 114{,}000{,}000 + 642{,}265 * x = 96{,}000{,}000 + 708{,}525 * x \implies x = 272 \text{ weeks} \sim 65\ \ months \quad (5)$$

Table 9: Results of daughter vessel 1 in UCA

KPI	Carbon Price	KPI Measurement	Result	
			AEGIS	Baseline
Cost	***EU ETS 2: 10 €/tonne CO_2***	€/week	N/A	705.18
Cost	***EU ETS 2: 30 €/tonne CO_2***	€/week	N/A	2,115.53
Cost	***EU ETS 2: 45 €/tonne CO_2***	€/week	N/A	3,173.30

The below equations show the BEP of the daughter vessel 1 at each level of EU ETS.

$$\boldsymbol{EU\ ETS_{10}}: 8{,}000{,}000 + 16.800 * x = 1{,}628{,}000 + 114{,}429 * x \implies x = 66 \text{ weeks} \sim 16 months \quad (6)$$

$$\boldsymbol{EU\ ETS_{30}}: 8{,}000{,}000 + 16.800 * x = 1{,}628{,}000 + 115{,}840 * x \implies x = 64 \text{ weeks} \sim 15.5\ months \quad (7)$$

$$\boldsymbol{EU\ ETS_{45}}: 8{,}000{,}000 + 16.800 * x = 1{,}628{,}000 + 116{,}897 * x \implies x = 63 \text{ weeks} \sim 15\ months \quad (8)$$

Table 10: Results of daughter vessel 2 in UCA

KPI	Carbon Price	KPI Measurement	Result	
			AEGIS	Baseline
Cost	***EU ETS 2: 10 €/tonne CO_2***	€/week	N/A	381.32
Cost	***EU ETS 2: 30 €/tonne CO_2***	€/week	N/A	1,143.95
Cost	***EU ETS 2: 45 €/tonne CO_2***	€/week	N/A	1,715.93

The below equations show the BEP of the daughter vessel 2 at each level of EU ETS.

$$\boldsymbol{EU\ ETS_{10}}: 8{,}000{,}000 + 19{,}320 * x = 1{,}184{,}000 + 61{,}878 * x \implies x = 160 \text{ weeks} \sim 38\ months \quad (9)$$

$$\boldsymbol{EU\ ETS_{30}}: 8{,}000{,}000 + 19{,}320 * x = 1{,}1848{,}000 + 62{,}641 * x \implies x = 157 \text{ weeks} \sim 37.5\ months \quad (10)$$

$$\boldsymbol{EU\ ETS_{45}}: 8{,}000{,}000 + 19{,}320 * x = 1{,}184{,}000 + 63{,}213 * x \implies x = 155 \text{ weeks} \sim 37\ months \quad (11)$$

According to the deliverable D7.6, the AEGIS scenario for mother vessel would become cost-effective after 90 months in operation without EU ETS enforcement. The daughter vessel 1 would require 16 months, and daughter vessel 2 would need 38 months, respectively [1].
The results with ETS can be summarized as follows:

Table 11: Summary for mother vessel in UCA

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
80	N/A	72	Better after EU ETS
100	N/A	68	Better after EU ETS
120	N/A	65	Better after EU ETS

Table 12: Results of daughter vessel 1 in UCA

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
N/A	10	16	No effect
N/A	30	15.5	No effect
N/A	45	15	No effect

Table 13: Summary for daughter vessel 2 in UCA

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
N/A	10	38	No effect
N/A	30	37.5	No effect
N/A	45	37	No effect

3.3.2 Use Case B

The implementation of EU ETS 1 and 2 applies to UCB only for the trucks in the non-AEGIS scenario (Table 14).

Table 14: Results of UCB

KPI	Carbon Price	KPI Measurement	Result		
			AEGIS	Baseline	
Cost	***EU ETS 2: 10 €/tonne CO_2***	€/week	N/A	N/A	2,511.17
Cost	***EU ETS 2: 30 €/tonne CO_2***	€/week	N/A	N/A	7,533.50
Cost	***EU ETS 2: 45 €/tonne CO_2***	€/week	N/A	N/A	11,300.26

The below equations show the BEP for UCB at each level of EU ETS.

$$\boldsymbol{EU\ ETS_{10}}: 48.000.000 + 289.100 * x = 5.328.000 + \ 508{,}145 * x \Longrightarrow \ x = 195 \text{ weeks} \sim 46\ months \tag{12}$$

$$\boldsymbol{EU\ ETS_{30}}: 48.000.000 + 289.100 * x = 5.328.000 + \ 513{,}168 * x \Longrightarrow \ x = 191 \text{ weeks} \sim 45\ months \tag{13}$$

$$\boldsymbol{EU\ ETS_{45}}: 48.000.000 + 289.100 * x = 5.328.000 + \ 516{,}934\ * x \ \Longrightarrow \ x = 187 \text{ weeks} \sim 44\ months \tag{14}$$

According to the deliverable D7.6 the AEGIS scenario would become cost effective after 47 months in operation without an EU ETS enforcement [1].
The results with ETS can be summarized as follows:

Table 15: Summary for UCB

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
N/A	10	46	Better after EU ETS
N/A	30	45	Better after EU ETS
N/A	45	44	Better after EU ETS

3.3.3 Use Case C

The implementation of EU ETS 1 and 2 applies to UCC for the Alborg scenario in the AEGIS vessels and AEGIS trucks and the trucks in the non-AEGIS scenario (Table 16). For the Vordingborg case the EU ETS applies only to the non AEGIS scenario (Table 17). Note that the carbon prices of EU ETS 1 and EU ETS 2 are not connected to one another.

Table 16: Results of the Aalborg case in UCC

KPI	Carbon Price	Unit	AEGIS		Baseline
			Battery	Methanol	
Cost	***EU ETS 1: 80 €/tonne CO_2*** ***EU ETS 2: 10 €/tonne CO_2***	€/week	1,737.02	5,990.70	2,442.45
Cost	***EU ETS 1: 80 €/tonne CO_2*** ***EU ETS 2: 30 €/tonne CO_2***	€/week	5,211.07	9,464.75	7,327.36
Cost	***EU ETS 1: 80 €/tonne CO_2*** ***EU ETS 2: 45 €/tonne CO_2***	€/week	7,816.61	12,070.29	10,991.04

Cost	***EU ETS 1: 100 €/tonne CO_2 EU ETS 2: 10 €/tonne CO_2***	€/week	1,737.02	7,054.12	2,442.45
Cost	***EU ETS 1: 100 €/tonne CO_2 EU ETS 2: 30 €/tonne CO_2***	€/week	5,211.07	10,528.17	7,327.36
Cost	***EU ETS 1: 100 €/tonne CO_2 EU ETS 2: 45 €/tonne CO_2***	€/week	7,816.61	13,133.71	10,991.04
Cost	***EU ETS 1: 120 €/tonne CO_2 EU ETS 2: 10 €/tonne CO_2***	€/week	1,737.02	8,117.54	2,442.45
Cost	***EU ETS 1: 120 €/tonne CO_2 EU ETS 2: 30 €/tonne CO_2***	€/week	5,211.07	11,591.59	7,327.36
Cost	***EU ETS 1: 120 €/tonne CO_2 EU ETS 2: 45 €/tonne CO_2***	€/week	7,816.61	14,197.13	10,991.04

Table 17: Results of Vordingborg case in UCC

KPI	Carbon Price	KPI Measurement	Result		
			AEGIS	Baseline	
				Vessel	Truck
Cost	***EU ETS 2: 10 €/tonne CO_2***	€/week	N/A	N/A	503.11
Cost	***EU ETS 2: 30 €/tonne CO_2***	€/week	N/A	N/A	1,509.33
Cost	***EU ETS 2: 45 €/tonne CO_2***	€/week	N/A	N/A	2,264.00

The below equations show the BEP for UCC for both sub cases at each level of EU ETS that we considered in Table 16 and Table 17.

Aalborg Case-battery:

$$\boldsymbol{EU\ ETS_{10}}: 27{,}848{,}000 + 885{,}585 * x = 5{,}328{,}000 + 940{,}102 * x \Longrightarrow x = 413.1 \text{ weeks} \sim 98\ months \quad (15)$$

$$\boldsymbol{EU\ ETS_{30}}: 27{,}848{,}000 + 889{,}059 * x = 5{,}328{,}000 + 944{,}987 * x \Longrightarrow x = 402.66 \text{ weeks} \sim 96\ months \quad (16)$$

$$\boldsymbol{EU\ ETS_{45}}: 27{,}848{,}000 + 891{,}665 * x = 5{,}328{,}000 + 948{,}651 * x \Longrightarrow x = 395.18 \text{ weeks} \sim 94\ months \quad (17)$$

Aalborg Case-methanol:

$$\boldsymbol{EU\ ETS_{80\&10}}: 24{,}848{,}000 + 889{,}838 * x = 5{,}328{,}000 + 940{,}102 * x \Longrightarrow x = 389.12 \text{ weeks} \sim 92.5\ months \quad (18)$$

$$\boldsymbol{EU\ ETS_{80\&30}}: 24{,}848{,}000 + 893{,}313 * x = 5{,}328{,}000 + 944{,}987 * x \Longrightarrow x = 377.75 \text{ weeks} \sim 90\ months \quad (19)$$

$$\boldsymbol{EU\ ETS_{80\&45}}: 24{,}848{,}000 + 895{,}918 * x = 5{,}328{,}000 + 948{,}651 * x \Longrightarrow x = 370.16 \text{ weeks} \sim 88\ months \quad (20)$$

$$\boldsymbol{EU\ ETS_{100\&10}}: 24{,}848{,}000 + 890{,}902 * x = 5{,}328{,}000 + 940{,}102 * x \Longrightarrow x = 396.74 \text{ weeks} \sim 94.5\ months \quad (21)$$

$$\boldsymbol{EU\ ETS_{100\&30}}: 24{,}848{,}000 + 894{,}376 * x = 5{,}328{,}000 + 944{,}987 * x \Longrightarrow x = 385.68 \text{ weeks} \sim 92\ months \quad (22)$$

$$\boldsymbol{EU\ ETS_{100\&45}}: 24{,}848{,}000 + 896{,}982 * x = 5{,}328{,}000 + 948{,}651 * x \Longrightarrow x = 377.79 \text{ weeks} \sim 90\ months \quad (23)$$

$$\boldsymbol{EU\ ETS_{120\&10}}: 24{,}848{,}000 + 891{,}966 * x = 5{,}328{,}000 + 940{,}102 * x \Longrightarrow x = 405.52 \text{ weeks} \sim 96.5\ months \quad (24)$$

$$\boldsymbol{EU\ ETS_{120\&30}}: 24{,}848{,}000 + 895{,}440 * x = 5{,}328{,}000 + 944{,}987 * x \Longrightarrow x = 393.96 \text{ weeks} \sim 94\ months \quad (25)$$

$$\boldsymbol{EU\ ETS}_{120\&45}: 24{,}848{,}000 + 898{,}045 * x = 5{,}328{,}000 + 948{,}651 * x \Longrightarrow x = 385.72 \text{ weeks} \sim 92\ months \quad (26)$$

Vordingborg Case:

$$\boldsymbol{EU\ ETS}_{10}: 11{,}500{,}000 + 51{,}100 * x = 12{,}552{,}000 + 145{,}503 * x \Longrightarrow x = -11.4 \text{ weeks} \sim -2.6\ months \quad (27)$$

$$\boldsymbol{EU\ ETS}_{30}: 11{,}500{,}000 + 51{,}100 * x = 12{,}552{,}000 + 146{,}509 * x \Longrightarrow x = -11.03 \text{ weeks} \sim -2.6\ months \quad (28)$$

$$\boldsymbol{EU\ ETS}_{45}: 11{,}500{,}000 + 51{,}100 * x = 12{,}552{,}000 + 147{,}264 * x \Longrightarrow x = -10.94 \text{ weeks} \sim -2.6\ months \quad (29)$$

According to deliverable D7.6, the AEGIS scenario for Alborg would become cost effective after 99.5 and 86.5 months in operation without an EU ETS enforcement for the Battery and Methanol cases, respectively [1]. As the EU ETS will be enforced differently for the two vessels this analysis distinguishes the Battery and Methanol cases as different EU ETS prices will yield different OPEX.

The results with ETS can be summarized as follows:

Table 18: Summary for UCC Aalborg Battery vessel

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
N/A	10	98	Better after EU ETS
N/A	30	96	Better after EU ETS
N/A	45	94	Better after EU ETS

Table 19: Summary for UCC Aalborg Methanol vessel

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
80	10	92.5	Worse after EU ETS
80	30	90	Worse after EU ETS
80	45	88	Worse after EU ETS
100	10	94.5	Worse after EU ETS
100	30	92	Worse after EU ETS
100	45	90	Worse after EU ETS
120	10	96.5	Worse after EU ETS
120	30	94	Worse after EU ETS
120	45	92	Worse after EU ETS

Table 20: Summary for UCC Vordingborg vessel

Combination of Prices		New Break Even Point	Comment
EU ETS1	EU ETS 2		
N/A	10	-2.6	Already cost effective
N/A	30	-2.6	Already cost effective
N/A	45	-2.6	Already cost effective

A general observation from the above results is that with the application of the EU ETS, the competitive advantage of the AEGIS solution is expected to increase in most use cases, versus the case of no application of EU ETS. An exception is for use case C (Aalborg)/methanol scenario, for which results are worse with ETS than without ETS, but this can perhaps be attributed to the fact that there is a cap of the ETS carbon price for road transport (€45/tonne maximum) whereas there is no such cap for the ETS carbon price applicable to maritime transport.

4 AEGIS stakeholders survey results

For this section, the results are based on findings summarized in an MSc thesis that was conducted at DTU [6].

To that effect, and among other things, a survey was conducted via a questionnaire distributed among the AEGIS Consortium and the Advisory Group. The primary objective of this survey was to determine the relative weights assigned to the selected set KPIs to assess the trade-offs between them. The stakeholders were requested to assign a rating on a scale of one to ten to evaluate the chosen set of KPIs, wherein a rating of ten indicated the highest level of significance for the respective KPIs. It is worth mentioning that while the survey did not yield a substantial level of participation, the collected responses (Figure 4) provide a directional indication despite not being statistically robust enough for formal analysis.

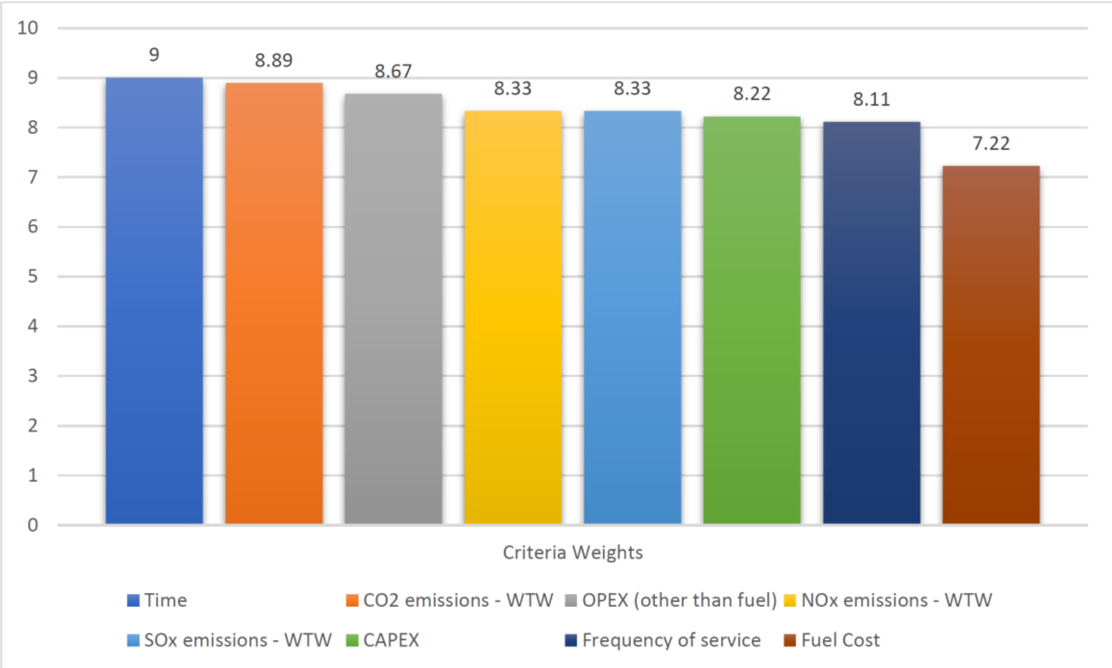

Figure 4: KPI weights from stakeholders' perspective

As illustrated in Figure 4, the AEGIS community assigns higher importance to Time KPIs, followed by CO_2 emissions and operational costs, which are regarded as the most significant factors. The subsequent level of significance is attributed to local emissions (NO_x and SO_x), then CAPEX and frequency of service, whereas fuel cost is considered the least influential.

One can argue that although the baseline scenario outperforms the AEGIS proposal in terms of time related KPIs and entails lower initial investment costs, these advantages could be offset by considering all other KPIs based on the perspective of the AEGIS community, as determined through the conducted survey. Furthermore, as previously mentioned, when considering the overall cargo transit time of the AEGIS proposal, time related KPIs may not play such a significant role, given that the cargo might require several days to reach a European port from its origin port. In this context, adding half a day to the overall transit time for the final delivery to the consignee by utilizing inland waterways instead of trucks does not present a significant drawback. Furthermore, with regards to capital expenditure, as stated in the conclusion, the application of the BEP equation has demonstrated that the AEGIS proposal will reach the break-even point with the baseline scenario of trucks after a period of three years. Given a range of factors elucidated earlier, it can be deduced that the collective assessment of these KPIs indicates a favorable inclination towards the AEGIS proposal when compared to road haulage.

5 Conclusions

This is the last deliverable of WP7. It aimed at identifying what we call "win win" solutions, that is, solutions that are acceptable with respect to most of the KPIs previously identified.

Looking at the previous deliverables of WP7, the results of the economic, environmental and social analyses [1],[2],[3], it should be clear that most of the AEGIS solutions are already win-win, in the sense that significant benefits of the AEGIS solution vs the non-AEGIS (baseline) solution have been identified in all three analyses and in all three use cases. Some exceptions however exist, mainly in terms of the CAPEX and time KPIs, in which the AEGIS solution performs worse than the non-AEGIS solution. This result is obviously to be expected, and as far as CAPEX goes the fact that CAPEX is higher for AEGIS is perhaps of lesser importance as it was shown that the overall cumulative (CAPEX+OPEX) cost of the AEGIS solution is less than the equivalent total cost of the non-AEGIS solution after some years of operation. The result of the time KPIs (i.e., that the AEGIS solution is generally slower than the non-AEGIS solution) is also to be expected. Again, we clarify that by "slower" we mean that transit time KPIs are generally expected to be higher in the AEGIS solution, vs the baseline solution, without implying any sort of lower efficiency in the AEGIS supply chain.

This report set out to seek the two main objectives below:

- See if time KPIs can be improved by examining the impact of measures such as speed changes and other operational adjustments
- Examine the impact of the new EU ETS legislation on the AEGIS economic KPIs

The latter analysis was not foreseen in the AEGIS Grant Agreement, however we felt necessary to perform it due to the significant EU legislation that is incoming and is in the context of the European Green Deal and the "Fit for 55" package.

After performing these analyses, it is confirmed that in most cases and for most of the KPIs the AEGIS solution outperforms the baseline non-AEGIS solution. In that sense, and as also mentioned in previous deliverables [1],[2],[3], the AEGIS solution is expected to contribute positively to the goals of EU transport policy and to those of the EU environmental policy.

As far as the time KPIs that were seen to be generally inferior to the corresponding KPIs of the baseline non-AEGIS solution, this is ascribed to transit times only, and it is our opinion that this is alleviated by the fact that the KPIs under study typically concern only one part of a very long supply chain. If for instance a cargo takes about a month (or more) to come from the Far East to Antwerp and then has to go to Ghent, a few hours difference in the transit time for the leg Antwerp-Ghent will not be that important. In that sense, and at a high-level context, the inferiority of the time KPIs (whenever it exists) is not considered as very significant.

Additional specific conclusions from the analyses of this report are the following:

- By integrating UCA, the competitive advantage of the AEGIS scenario will be increased and it would be cost-efficient in a shorter period of time compared to the baseline scenario.
- By increasing in the ship's speed, the OPEX has generally increased due to fuel consumption, but on the other hand, the travel time has decreased. This time reduction has been much more tangible in some scenarios, for example, UCA and UCC- Vordingborg case.

- By implementing the EU ETS, the competitive advantage of the AEGIS scenario has increased in most use cases. An exception is for use case C (Aalborg)/methanol scenario, for which results are worse with ETS than without ETS, but this can perhaps be attributed to the fact that there is a cap of the ETS carbon price for road transport (€45/tonne maximum) whereas there is no such cap for the ETS carbon price applicable to maritime transport.

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