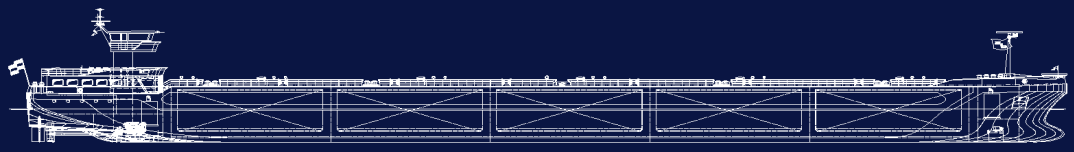


Decarbonizer Premium Report

A guide on upcoming rules and regulations on maritime sustainability

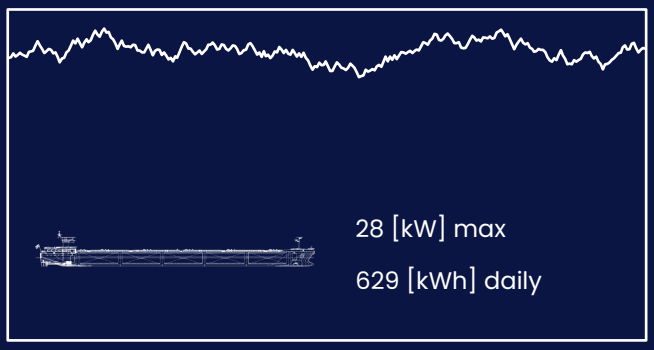
+ measures to reduce carbon emissions for Sunny Sailer

Client Name	**Rhineland Express**
Date	**2023-05-11**
Source	**Sustainable Ships**

EXECUTIVE SUMMARY

The purpose of this document is to provide Rhineland Express with guidance and insights on maritime sustainability of Sunny Sailer. This report elaborates on your operational profile, applicable rules and regulations and finally on carbon reduction measures and costs.

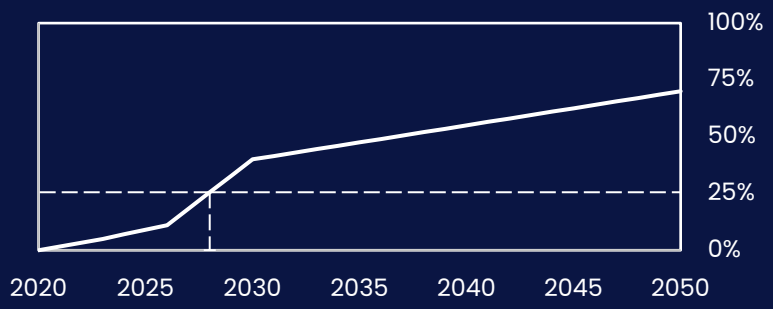
Operational Profile

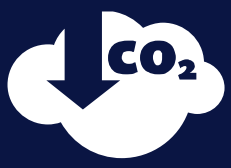


day/year

Fuel	167	[l/day]
CO2	476	[kg/day]
ETS	€ 40	[€/day]
OPEX	€ 703	[€/day]
CII	Not Applicable	
EEXI	Not Applicable	

Rules and Regulations





2028
Target Date

26%
Reduction

Decarbonization Measures	CO_2	CAPEX	Δ-OPEX [daily]	Payback [days]
-				
Solar_PV	45%	€ 177,165	-€ 67	**2637**
-				

	CO_2	CAPEX	OPEX [daily]	Payback [days]
Current situation	0%	€ 0	€ 703	-
Future Sunny Sailer	**-45%**	**€ 177,165**	**€ 636**	**2,637**

A negative Δ-OPEX means you will pay less than your current OPEX

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About Report

Legislation is uncertain

Legislation, rules and regulations or politics in general are vague by nature. In contrast to the engineer's worldview, there is and will always remain uncertainty over upcoming rules and regulations due to 'the political process'. Additionally, the engineering performed for retrofitting is uncertain as well, as it is subject to significantly varying parameters and assumptions.

Our solution to this conundrum is twofold. First, we provide you with a free to use helpdesk, that can help you clarify and answer questions even after this report has been delivered. You can ask any question related to maritime sustainability by clicking on the 'contact helpdesk' button on the top of the page.

Secondly, we provide you with a model, not a solution. Our tools are fully customizable to your vessel and provide you with the option to easily change input parameters when new information is provided. In other words, you can use the Decarbonizer tool as a sensitivity analysis for your vessel, in which you can easily determine what works for you and what does not.

Class is exempt

Class rules and regulations from either DNV, Lloyds or other classification bureaus are excluded in the upcoming rules and regulations section because these are technical of nature. They are included in the cost breakdowns as lump-sum estimates that you can easily customize.

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1.0 OPERATIONAL PROFILE SUNNY SAILER

1.1 Vessel and operational properties

Parameter	Value	Unit
Ship name	Sunny Sailer	
Ship type	Inland Waterways	
Fuel type	MDO	
Main Engines	Cummins Main	
Installed Power	1760	[kW]
Engine Type	4-Stroke	184 [g/kWh]
Engine Speed	Medium	
Aux Engines	Cummins Aux	
Aux Power	102.4	[kW]
Aux. Engine Type	4-Stroke	
Aux. Engine Speed	High	[kW]
Year built	1988	[years]
Ship age	35	[years]
Lifetime from today	40	[years]
Target Date	2028	
Gross Tonnage	2,000	[-]
Deadweight	3,013	[mT]
Cargo capacity	3,013	[m3]
Area	Europe	
Propulsion Type	Diesel-electric	
Cruising speed	9	[knts]
Fuel Tank Capacity	38	[m3]
Length overall	110	[m]
Extreme Beam	11.4	[m]
Hull Roughness	Smooth	

Parameter		
Idle / Moored	100%	365 days per year
Sailing	0%	0 days per year
Working	0%	0 days per year

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1.2 Current OPEX Sunny Sailer

		Idle / Moored 365 [days/year]	Sailing 0 [days/year]	Working 0 [days/year]	Average per [day]
Max Power	[kW]	28	-	-	28
Average Power	[kW]	26	-	-	26
Energy Required	[kWh]	629	-	-	629
Fuel Consumption	[liter]	167	-	-	167
Engine Hours	[hrs]	24	-	-	24

CO2 Emissions	[kg]	476	-	-	476
NOx Emissions	[kg]	8	-	-	8
SOx Emissions	[kg]	0	-	-	0
PM Emissions	[kg]	0	-	-	0
CH4 Emissions	[kg]	0	-	-	0

Fuel	[€]	€ 130	-	-	€ 130
Lease / Rental	[€]	€ -	-	-	€ -
Engine Maintenance	[€]	€ 480	-	-	€ 480
Spares / Consumables	[€]	€ 48	-	-	€ 48
ETS Costs	[€]	€ 40	-	-	€ 40
Coating	[€]	€ 5	-	-	€ 5

OPEX	**daily**	**€ 703**	**-**	**-**	**€ 703**
	yearly	**€ 256,723**	**-**	**-**	**€ 256,723**

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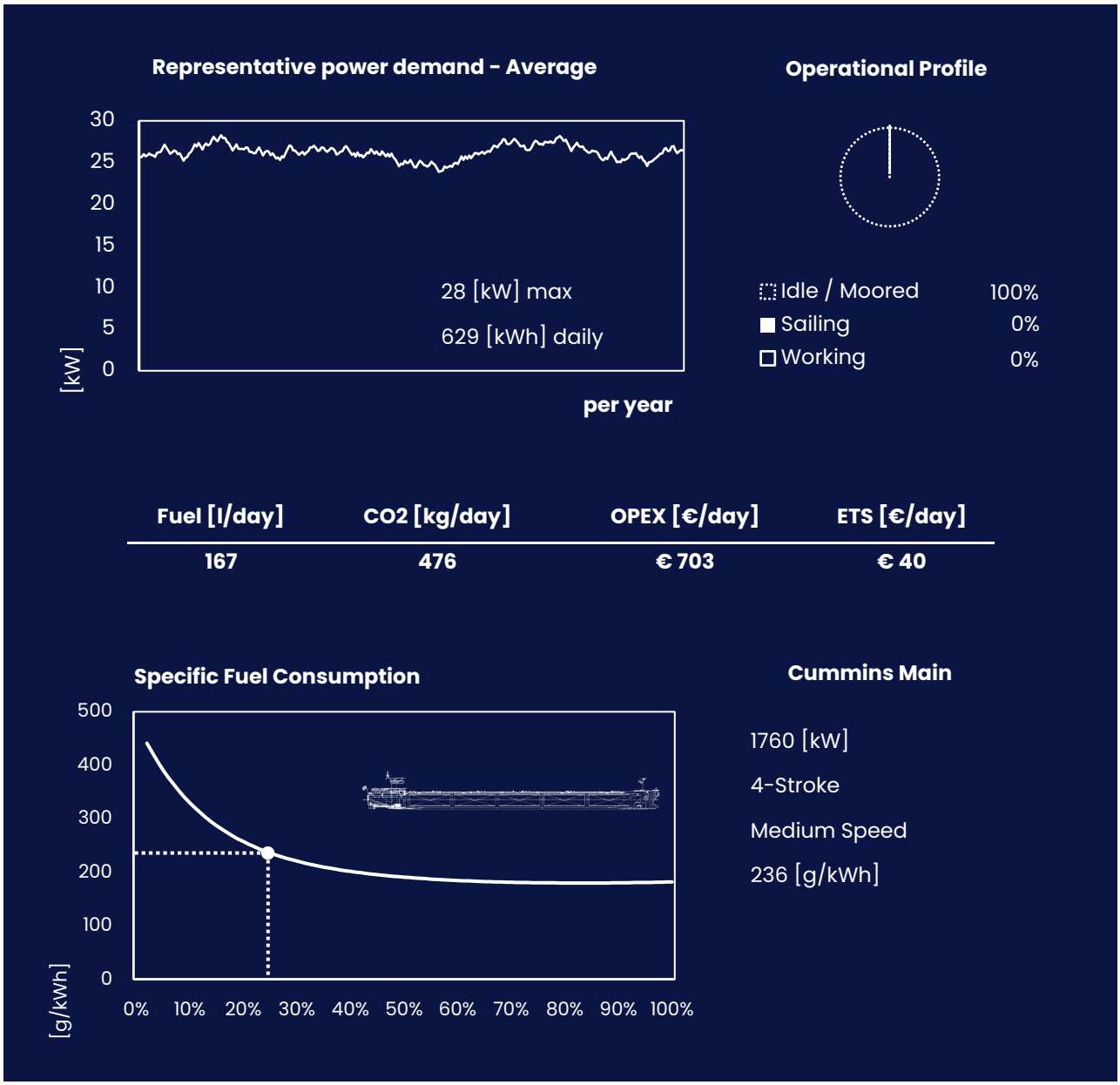
1.3 Combination – Yearly



The estimated operational profile of Sunny Sailerwhen operational modes are combined (i.e. idle/moored, sailing and working). For example, a vessel can be moored for 25% of the year and sailing for 75% of the year, which results in a combined power demand representing vessel operations. This can be viewed as 'yearly combined profile".

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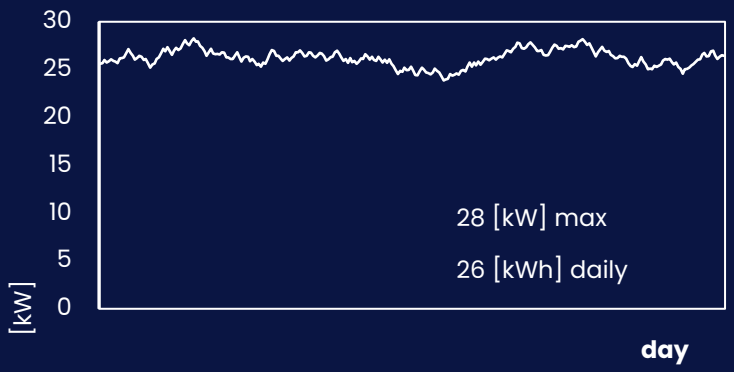
1.4 Idle/Moored – Daily

Power demand - Idle / Moored

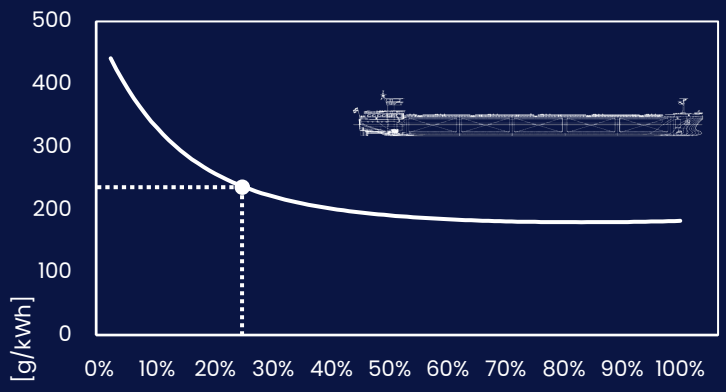


Operational Profile

Idle / Moored	100%
Sailing	0%
Working	0%

Fuel [l/day]	CO2 [kg/day]	OPEX [€/day]	ETS [€/day]
167	476	€ 703	€ 40

Specific Fuel Consumption



Cummins Aux

102.4 [kW]

4-Stroke

Medium Speed

236 [g/kWh]

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1.5 Sailing – Daily

Not applicable

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1.6 Working – Daily

Not applicable

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2.0 KEY UPCOMING RULES AND REGULATIONS FOR SUNNY SAILER

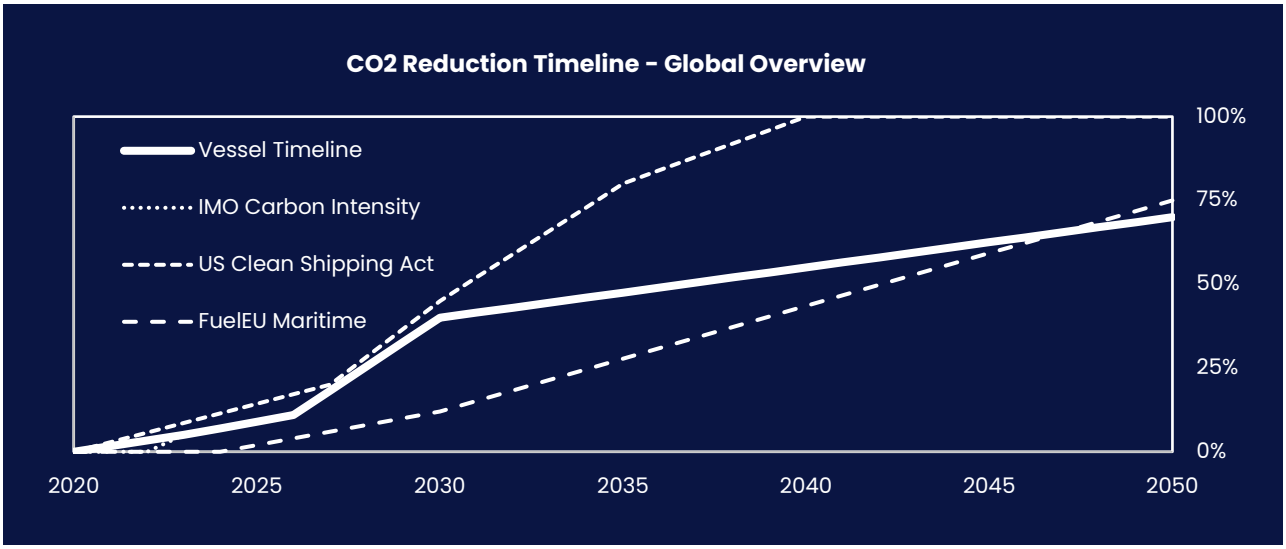

Figure 5. CO2 reduction timelines for key organizations around the world.

Key takeaways	
For 2028 a CO2 reduction of 26% is required	Key regulatory frameworks for maritime sustainability include IMO and EU, of which IMO is more stringent at the moment and EU probably after 2030. In addition, the US Clean Shipping Act requires all vessels to be fully zero emission by 2040. Client requirements have not yet been incorporated.
Electrification is excluded	Electric vessels 'pass' all rules and regulations that have been identified. It is therefore highly recommended to pursue a course of electrification of your vessel where possible to ensure smooth sailing in the future.
Shore power is mandatory	Shore power will become fully mandatory in EU and US by 2030, as per FuelEU and US clean shipping act and this trend in expected to be tightened while at berth. Shore power in the Netherlands is more attractive for operators due to HBE.
Carbon tax & fossil is expensive	Shipping industry will be incorporated into EU ETS from 2025 onwards. With the current price of €85 per mT CO2, that would equate to a surtax of roughly €255 per mT of fuel.

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Key rules and regulations for Sunny Sailer				
Rule/Reg	**Organization**	**In Effect**	**Area**	**Impact / Restraint**
PAS	Netherlands	2021	Europe	-80% NOx
HBE	Netherlands	2022	Europe	Get € 0.04-0.20 kWh
EU ETS	EU	2024	Europe	€ 14753 per year
ECA Norway	IMO	2019	Europe	0.1% SOx max
Global Sulphur Limit	IMO	2020	Global	0.5% SOx max
ECA North Sea	IMO	2021	Europe	0.1% SOx max
ECA Mediterranean	IMO	2025	Europe	0.1% SOx max
IMO Carbon Price	IMO	2026	Global	Unknown

CII / EEXI / EU ETS		
CII	**EEXI**	**EU ETS [year]**
Not Applicable	Not Applicable	€ 14,753

Purchase the **premium Rules and Regulations report** for only €399 for an overview on all rules and regulations on sustainability. This includes regulations imposed by energy majors, shipping companies and ports around the world that might affect your operations. Click below fore more information.

Learn more

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3.0 CARBON REDUCTION MEASURES & COSTS

3.1 All carbon reduction measures

Below is an overview of several key carbon reduction measures. Δ-OPEX represent the difference between current OPEX and OPEX when measures is implement. OPEX of carbon reduction measures include fuel, ETS and maintenance costs. All costs are indicative. No rights or claims can be made based on this analysis.

Measure	CO_2	CAPEX	Δ-OPEX [daily]	Payback [days]
Shore_Power	-100%	€ 201,000	-€ 509	395
Shore_Battery	-100%	€ 423,959	-€ 509	832
Solar_PV	**-45%**	**€ 177,165**	**-€ 67**	**2,637**
Wind_Power	0%	€ 54,800	€ 2	-
Hull_Coating	0%	€ 107,720	€ 90	-
Battery_Hybrid	n.a.	-	-	-
Biofuels	12%	€ 40,000	-€ 83	484
Ammonia	-55%	€ 1,453,899	-€ 63	22,912
Methanol	-52%	€ 1,037,281	-€ 69	15,017
Hydrogen	-55%	€ 4,584,586	-€ 477	9,602
Full_Electric	-55%	€ 1,060,079	-€ 653	1,624
Carbon_Capture	n.a.	-	-	-

Current situation	**0%**	**€ 0**	**€ 703**	**-**
After measures	**-45%**	**€ 177,165**	**€ 636**	**2,637**

Target reduction **-26%** Estimate based on vessel end-of-life

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3.2 Selected measures for Sunny Sailer

The below carbon reduction measures have been applied to Sunny Sailer Click on the buttons below the figures to learn more, or contact the helpdesk to clarify any questions.

Selected carbon reduction measures		
Shore Power	Prevent Measure	Change Measure
None Chosen		None Chosen
-	Solar_PV	-

3.3 CII / EEXI / EU ETS

Below is an overview of CII, EEXI and EU ETS before and after implementation of carbon reduction measures. Elaboration on the calculation of CII, EEXI and EU ETS are provided in Appendix I.

CII / EEXI / EU ETS			
	CII	**EEXI**	**EU ETS**
Current	Not Applicable	Not Applicable	€ 14,753
After	Not Applicable	Not Applicable	€ 8,096

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3.4 Technical Details -

None chosen

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3.5 Technical Details Prevent Measure Solar_PV

Solar PV is the use of solar PV panels, either on-board and fixed to your vessel, or floating solar next to your vessel. LCOE for offshore solar has been cited to be in the range of €0.02 - €0.05 by suppliers. These values have not been verified by long-term usage. Current LCOE for your vessel is in the order of € 0.23 per kWh. Solar PV electricity production is strongly dependent on time of year and location of the vessel. For its calculations, Sustainable Ships assumes a standard solar insolation which represent a low, medium and high production (December, March and June) Electricity production due to solar PV directly reduces electricity consumption. Direct-drive vessels might require power intake devices or changes to switchboard.

Other	Value	Unit
Length	110	[m]
Beam	11	[m]
Percentage covered	20%	-
Surface area available	251	[m2]
Solar panel Wpeak	375	[Wp/m2]
System / Solar efficiency	75%	-
Peak power	94	[kWP]
Day / time of year	21 March 2023	-
Peak Sun hours	6	[hrs/day]
Estimated total energy available	523	[kWh/day]
Solar Irradiance	1,000	[kWh/kWP]
Yearly energy output	94,050	[kWh/year]
Solar panel costs	€ 500	[€/kW]
Inverter costs	€ 1,000	[€/kW]
Cabling	€ 200	[€/kW]
OPEX	€ 3,543	[€/year]
Lifetime	10	[years]
Lifecycle CAPEX + OPEX	€ 212,598	[€]
Estimated lifecycle kWh production	940,500	[kWh]
Costs per kWh	€ 0.23	[€/kWh]

Learn more about Solar_PV

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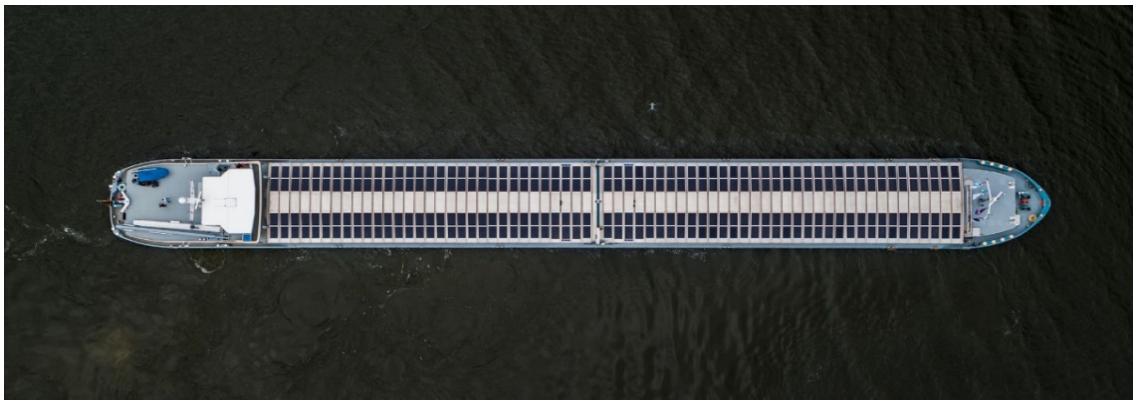
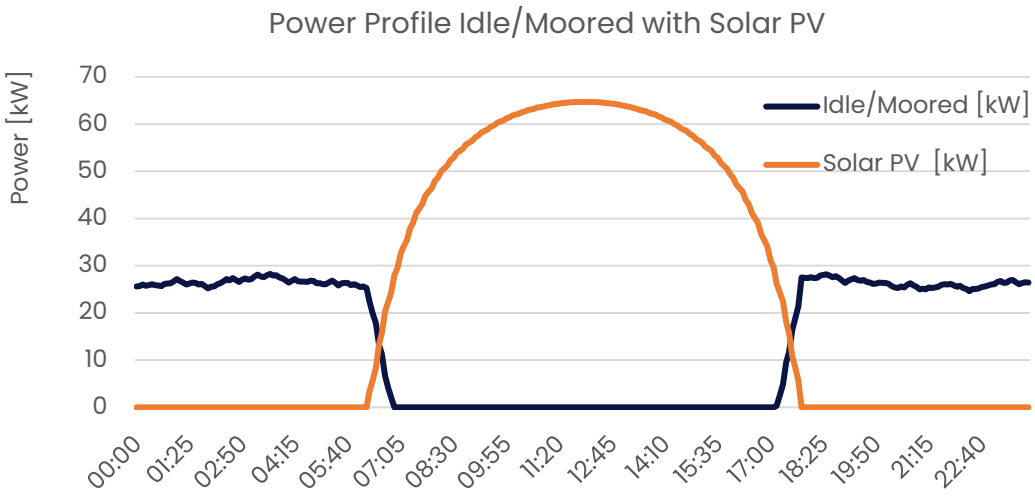
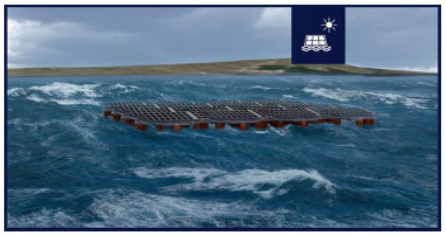




Making the Impossible Possible

This blog sketches a vision on how to convert the largest crane vessel in the world - Sleipnir - owned by Heerema Marine Contractors, to a zero-emission vessel. Several promising carbon reduction measures are combined which are technically viable and based on matured technology, although scaling of existing

Learn more



Equinor Flirts with Floating Solar

Equinor will explore opportunities within the realm of floating solar power. Together with Moss Maritime the company wants to start testing near the island of Frøya in the late summer of 2021. The plant will measure 6400 m2 and rise 3 meters above sea level and appears to be made of interlinked rigid structures.

Learn more

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3.6 Technical Details Change Measure n.a.

None chosen

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3.7 CAPEX Breakdown -

None chosen

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None chosen

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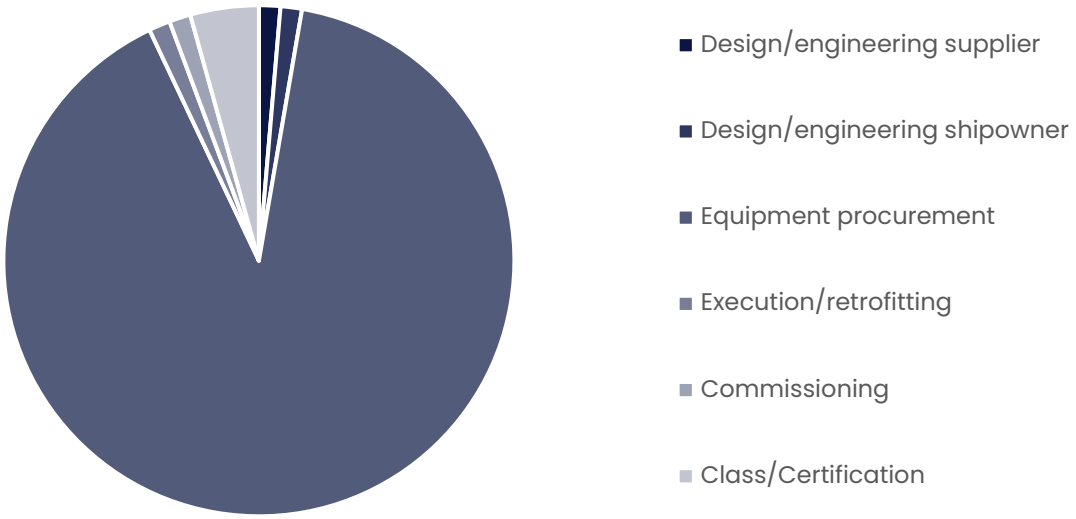
3.8 CAPEX Breakdown Prevent Measure Solar_PV

	Time [hours]	Costs
Design/engineering supplier	20	€ 2,400
Design/engineering shipowner	20	€ 2,400
Equipment procurement	-	€ 159,885
Execution/retrofitting	20	€ 2,400
Commissioning	20	€ 2,400
Class/Certification	64	€ 7,680
Total	**4 fte weeks**	**€ 177,165**



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	Time [hrs]	Units	Parameter	Price per hour/unit	Total Cost
Design/engineering supplier	**20**				**€ 2,400**
General design and engineering supplier	20		EUR/hr	€ 120	€ 2,400
Design/engineering shipowner	**20**				**€ 2,400**
General design and engineering shipowner	20		EUR/hr	€ 120	€ 2,400
Equipment procurement	**0**				**€ 159,885**
Solar panels		1	[lot]	€ 47,025	€ 47,025
Inverter(s)		1	[lot]	€ 94,050	€ 94,050
Cabling		1	[lot]	€ 18,810	€ 18,810
Execution/retrofitting	**20**				**€ 2,400**
General execution and retrofitting	20		EUR/hr	€ 120	€ 2,400
Commissioning	**20**				**€ 2,400**
General commissioning	20		EUR/hr	€ 120	€ 2,400
Class/Certification	**64**				**€ 7,680**
Approval costs of drawings/calculations	24		EUR/hr	€ 120	€ 2,880
Surveyor attendence for fabrication/installation incl. travel expense	20		EUR/hr	€ 120	€ 2,400
(Writing) Operational manuals and procedures	20		EUR/hr	€ 120	€ 2,400

All numbers are indicative. Ask your supplier for fixed numbers.

It is assumed transportation costs for all equipment is included in the pricing.

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3.9 CAPEX Breakdown Change Fuel n.a.

None chosen

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None chosen

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3.10 Future OPEX Breakdown Sunny Sailer

The below table shows the current and future OPEX breakdown for Sunny Sailer, based on the representative daily operational profile. Depreciation of equipment has not been taken into account (neither for existing or newly purchased equipment). Rental of equipment will be made available soon.

		Current	Future
Max Power	[kW]	28	28
Average Power	[kW]	26	14
Energy Required	[kWh]	629	343
Fuel Consumption	[liter]	167	91
Engine Hours	[hrs]	24	14

Fuel	[€]	€ 130	€ 71
Lease / Rental	[€]	€ 0	€ 0
Engine Maintenance	[€]	€ 480	€ 485
Spares / Consumables	[€]	€ 48	€ 53
ETS Costs	[€]	€ 40	€ 22
Coating	[€]	€ 5	€ 10

OPEX	**daily**	**€ 703**	**€ 641**
	yearly	**€ 256,723**	**€ 234,008**

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3.11 Potential suppliers

The below partners can assist in implementing the proposed measures on-board your vessel. You can contact them directly, or contact the helpdesk for further guidance. In case you prefer to work with (local) partners on your own, feel free to use this report as a guideline for their input.

Preferred Suppliers		
Technology	**Supplier**	**Contact**
-	-	
Solar_PV	Wattlab	**sarah@wattlab.com**
-	-	

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4.0 APPENDIX I – ASSUMPTIONS AND CALCULATIONS

4.1 Input values and assumptions

Parameter	Value	Unit
Fuel Price	€ 0.78	[€/l]
ETS	€ 85	[€/mT]
Engine Maintenance Costs	€ 20	[€/hr]
Spares / Consumables Costs	€ 2	[€/hr]
Parasitic Load Engine	15%	[-]
(Engineering) Hour External	€ 120	[€]
(Engineering) Hour Internal	€ 100	[€]
Depreciation Time	10	[years]
Annual (Fuel) Price Increase	1.03	[-]

MDO density	0.89	[kg/l]
CO2 Emission Factor MDO	3.206	[kg/kg]
NOx Emission Factor MDO	0.05488	[kg/kg]
SOx Emission Factor MDO	0.00215	[kg/kg]
PM Emission Factor MDO	0.00095	[kg/kg]
CH4 Emission Factor MDO	0.00005	[kg/kg]

Fuel after change	-	[-]
Fuel density after change measures	0.89	[kg/liter]
Fuel price after change measure	€ 0.78	[€/liter]
Shore-side kWh price	€ 0.35	[€/kWh]
CO2 Emission Factor	3.206	[kg/kg]
Nox Emission Factor	0.05488	[kg/kg]
Sox Emission Factor	0.00215	[kg/kg]
PM Emission Factor	0.00095	[kg/kg]
CH4 Emission Factor	0.00005	[kg/kg]

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4.2 CII Calculation

Sunny Sailer CII Scores	2023	2024	2025	2026
Baseline	n.a.	n.a.	n.a.	n.a.
After reduction measures	n.a.	n.a.	n.a.	n.a.

CII Input Values		
Operational Mode	Combined	
CO2 Emissions	173,559,380	[g/year]
Capacity	n.a.	[mT]
Distance Sailed	0	[nm/year]
a		for Reference line
c		for Reference line
CII ref	n.a.	Reference line
Required CII 2023	n.a.	5% reduction
Required CII 2024	n.a.	7% reduction
Required CII 2025	n.a.	9% reduction
Required CII 2026	n.a.	11% reduction
Attained Current CII	n.a.	Baseline
Attained CII	n.a.	After modifications

Learn more about CII

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CII Scores per Technology	2023	2024	2025	2026
Shore_Power	n.a.	n.a.	n.a.	n.a.
Shore_Battery	n.a.	n.a.	n.a.	n.a.
Solar_PV	n.a.	n.a.	n.a.	n.a.
Wind_Power	n.a.	n.a.	n.a.	n.a.
Hull_Coating	n.a.	n.a.	n.a.	n.a.
Battery_Hybrid	n.a.	n.a.	n.a.	n.a.
Biofuels	n.a.	n.a.	n.a.	n.a.
Ammonia	n.a.	n.a.	n.a.	n.a.
Methanol	n.a.	n.a.	n.a.	n.a.
Hydrogen	n.a.	n.a.	n.a.	n.a.
Full_Electric	n.a.	n.a.	n.a.	n.a.
Carbon_Capture	n.a.	n.a.	n.a.	n.a.

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4.3 EEXI Calculation

$$EEXI = \frac{CO2\ emissions}{Transportation\ work}$$

$$EEXI = \frac{Main\ engine\ emissions + Auxiliary\ engine\ emissions + (PTI - Innovative\ electrical\ energy\ technologies) - Innovative\ propulsion\ energy\ technologies}{Capacity * Reference\ speed * Reduction\ factors}$$

$$EEXI = \frac{\left(\prod_{j=1}^{n} f_j\right)\left(\sum_{i=1}^{nME} P_{ME(i)} C_{ME(i)} SFC_{ME(i)}\right) + \left(P_{AE} C_{AE} SFC_{AE}\right) + \left(\left(\prod_{j=1}^{n} f_j \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} P_{AEeff(i)}\right) C_{FAE} SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} P_{eff(i)} C_{FME} SFC_{ME}\right)}{Capacity\ V_{ref} f_i f_c f_l f_w f_m}$$

EEXI Input values		
Ship Type	Inland Waterways	
Operational Mode	Sailing	
CO2 Emissions	19,813	[gram/hour]
Capacity	3,013	[mT]
Reference Speed	9	[knts]
fi	n.a.	
fc	n.a.	
fl	n.a.	
fw	n.a.	
fm	n.a.	
Reduction factor	n.a.	

EEXI	**Not Applicable**	**[gram/mT mile]**
EEXI After	**Not Applicable**	**[gram/mT mile]**
EEXI Required	**Not Applicable**	**[gram/mT mile]**

Learn more about EEXI

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4.4 EU ETS Calculation

Yearly ETS Costs	2024	2025	2026	2027
Current	€ 0	€ 5,901	€ 10,327	€ 14,753
Shore_Power	€ 0	€ 0	€ 0	€ 0
Shore_Battery	€ 0	€ 0	€ 0	€ 0
Solar_PV	**€ 0**	**€ 3,238**	**€ 5,667**	**€ 8,096**
Wind_Power	€ 0	€ 5,901	€ 10,327	€ 14,753
Hull_Coating	€ 0	€ 5,901	€ 10,327	€ 14,753
Battery_Hybrid	n.a.	n.a.	n.a.	n.a.
Biofuels	€ 0	€ 3,930	€ 6,878	€ 9,826
Ammonia	€ 0	€ 0	€ 0	€ 0
Methanol	€ 0	€ 190	€ 332	€ 474
Hydrogen	€ 0	€ 0	€ 0	€ 0
Full_Electric	€ 0	€ 0	€ 0	€ 0
Yearly Gains	**€ 0**	**-€ 2,663**	**-€ 4,660**	**-€ 6,657**

Year	% Phase-in
2024	0%
2025	40%
2026	70%
2027	100%

Learn more about EU ETS

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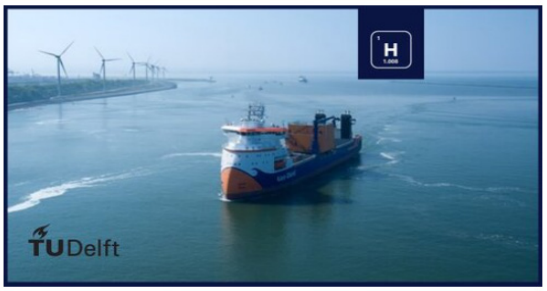
5.0 APPENDIX II - CASE STUDIES SIMILAR TO SUNNY SAILER

This section is under development. In the future, case studies similar to your vessel type will be taken from sustainable-ships.org/stories as reference. Feel free to browse or contact the helpdesk for more stories!

4/30/21

Hydrogen Powered Propulsion for an Offshore Crane Vessel

This thesis performs a technical, economical and environmental feasibility study of three dense hydrogen carriers as a fuel to power the largest semi-submersible offshore crane vessel in the world – Heerema's Sleipnir.



3/12/21

Methanol Hybrid Offshore Working Vessels

This thesis by J.M. Rozendaal at van Oord focuses on the technical, environmental and economic impact of a methanol hybrid power plant design for new-build offshore working vessels. Its conclusion is that a methanol solution has a CO2 reduction potential up to 99% and a CO2 price of 78 euro per ton CO2 reduction.

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