Zero waste Heat vessel towards relevant Energy savings also thanks to IT technologies

D 1.2 | Hybrid propulsion on-board integration and guidelines for coupling it with WHR solutions

WP1 – Vessel audit and requirement definition towards zero waste heat

Version 1.0 | July 2023

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Clean and competitive solutions for all transport modes - Innovative on-board energy saving solutions

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List of Organizations

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1	RINA Consulting Spa	RINA-C	Italy	
1.1	RINA Services Spa	RINA-S	Italy	
2	Ethnicon metsovion polytechnion	NTUA	Greece	
3	Kyma as	KYMA	Norway	
4	Fundacion tecnalia research & innovation	TECNALIA	Spain	
4.1	Universidad del pais vasco/ euskal herriko unibertsitatea	UPV/EHU	Spain	
5	Anonimi naftiliaki eteria kritis (anek) s.a.	ANEK	Greece	
6	Consiglio nazionale delle ricerche	CNR	Italy	
6.1	Consorzio di ricerca per l'innovazione tecnologica, sicilia trasporti navali, commerciali e da diporto scarl	NAVTEC	Italy	
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7.1	Sorption technologies srl	SORTIT	Italy	
8	Bound 4 blue sl	B4B	Spain	
9	Encontech bv	ECT	Netherlands	
10	Gruppo sigla srl	SIGLA	Italy	
11	The university of Birmingham	UoB	United kingdom	

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Abbreviation and Acronyms

Acronym	Description
B4B	Bound 4 Blue, S.L.
WH	Waste Heat
WAPS	Wind Assisted Propulsion System
eSAIL	Commercial name of the WAPS developed by B4B
DWT	Dead Weight Tonnage
LOA	Length Overall
Kn.	Knot; unit of speed equal to one nautical mile per hour
AoA	Angle Of Attack
CFD	Computational Fluid Dynamics
AWS	Apparent Wind Speed
TWS	True Wind Speed
AWA	Apparent Wind Angle
TWA	True Wind Angle
DF	Driving Force
HF	Heeling Force

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Executive Summary

The ZHENIT project aims to exploit waste heat recovery potential on-board vessels using energy management methods, clean energy solutions and low-emissions ship services. The targets of the project are new technologies development, on-board validation, a regulatory framework analysis and a replication roadmap at regulatory and economic level.

In the context of the WP2 of ZHENIT, Task 1.3 - *Hybrid propulsion assessment on the overall vessel energy/thermal balance*- leads by Bound 4 Blue (B4B), has the aim to evaluate the impact of hybrid propulsion (combination of conventional engines and wind-assisted propulsion systems, WAPS) in terms of waste heat temperature available for its valorisation.

The wind-assisted technology developed by B4B, eSAIL, is, in short, a fully automated rigid sail based on active boundary layer control using the suction of a small amount of air that addere the airflow to the sail body.

To perform the WH availability assessment, a general cargo vessel has been selected as a reference. Nevertheless, as a result of several issues related to the availability of real and valuable performance data of LA NAUMON - one of the demo vessels involved in the project - B4B has finally worked with a similar vessel, EEMS TRAVELLER, whose owner has collaborative relationship with B4B. This allowed for a more realistic assessment of WH availability in the context of a theoretical hybrid vessel.

During the execution of Task 1.3, performance polar plots of the power and driving forces produced by the eSAIL has been defined for different wind speeds and angles.

On the other hand, a vessel characterisation has been developed, focused on the main engine parameters and on the trading routes followed for a certain period of time, evaluating the potential winds observed by the WAPS.

Merging both results, potential savings generated by the eSAIL in terms of engine-equivalent power demanded has been obtained and its impact in the exhaust gas temperature analysed for a 5-year period of a typical comercial trade route followed by a conventional general cargo vessel (EEMS TRAVELLER).

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1 Introduction

The aim of this deliverable is to assess how advanced hybrid propulsion based on WAPS will impact in waste heat availability and, as a result of that, the potential replication and feasibility of the technologies that will be developed and tested in the framework of the ZHENIT project. To solve this uncertainty, an approach based on the collection and use of realistic data has been conducted.

This report is the project deliverable D1.2 – *Hybrid propulsion on-board integration and guidelines for coupling it with WHR solution* and covers the whole performance modelling analysis of one type of wind propulsion technology, the eSAIL, showing the expected engine exhaust temperature variations on a wind-assisted vessel (hybrid vessel).

It is necessary to point out the difficulty to find a correlation between the engine power and the exhaust temperature reached during sailing. It was hard to find actual data for both variables and for the same vessel because; only large vessels usually monitor the true shaft power during sailing. In the segment of vessels evaluated, the exhaust temperature is usually checked on board by crew members, but sensors are not used, it is not collected in a database and it is not linked to the engine power.

To overcome this lack of real-time information, technical documentation, load balances and data sheets of the vessels LA NAUMON and EEMS TRAVELLER have been checked to obtain relevant data about the correlation between engine power and exhaust temperature.

This deliverable is based on the results and conclusions obtained along Task 1.3, which includes a wingsail assisted vessel performance modelisation, a main engine heat modelization, an evaluation of engine-equivalent power savings for a specific sailing period and the analysis of the effects on the available waste heat.

The outcomes of this report will also be used as standarized measurement procedure for future hybrid systems integrations (WAPS and WHR systems), seeking a more accurate evaluation of the combined savings of energy.

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2 Selected eSAIL assisted vessel configuration.

2.1 Description of the vessel

General Cargo and Multipurpose vessels are extensively used in short-sea shipping to transport a large variety of cargo and goods. They can be considered as the "trucks of the sea". This type of vessels is widely used in European trading. These vessels range from small vessels (50-60m LOA) with cargo capacities below 2.000 DWT up to vessels of about 120-130m LOA and cargo capacities below 10.000 DWT. The two most common segments are <2.000 DWT (50-60m LOA) and 2.000-5.000DWT (80-100m LOA). However, the smaller ones are widely focussed on inland and river shipping, where wind propulsion is not feasible. For this reason, the selected vessel for this study belongs to the 2.000-5.000DWT segment, so that it is representative of the most common general cargo vessels where eSAILs can be applicable.

Despite the fact that the LA NAUMON is one of the vessels included in the project proposal as part of the assesment of waste heat availability and demo site for the validation on board of different ZHENIT technologies, the lack of relevant performance data on the vessel´s previous salings and other critical parameters of the main engine temperature ranges, determined the convenience of performing the waste heat availability assesment on a similar general cargo vessel: EEMS TRAVELLER.

In order to obtain the most reliable and relevant data for a vessel with similar characteristics to LA NAUMON, b4b checked all the vessels for which the company has an open lead to install our eSAIL suction sail technology and the shipowner is willing to provide and use relevant data and operational parameters of his vessel.

EEMS TRAVELLER is a general cargo / multipurpose vessel owned and operated by Amasus Shipping. It was built in the Netherlands in 2000, with Dutch Flag and classified by Bureau Veritas. She is 2850 DWT, 90m LOA and 13.75m breadth.

Compared to LA NAUMON, the EEMS TRAVELLER offers us more realistic data because the vessel operates under real commercial conditions (LA NAUMON is a theatre vessel) and it is equiped with various data collection equipment on board (torque meters, flow meters to measure the fuel consumption, etc.). Additionally, the length of the vessel and it´s operation in open waters (not only in inland waters) make it a better example of the typical general cargo vessel used in the EU waters and a relevant market segment for the ZHENIT´s technologies.

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Figure 1: EEMS TRAVELLER vessel

The following table summarizes the main vessel characteristics.

Table 1 Summary table of EEMS Traveller main characteristics

Name of ship	EEMS TRAVELLER
Vessel type	Multipurpose
Delivery date	May 2000
Builder	Tille Schpsb. (Netherlands)
IMO number	9218234
International call sign	PECH
MMSI number	246498000
Registered tonnage	Gross: 2,137 / Net: 1,164
Class Society	Bureau Veritas
Flag	Netherlands
Length Overall	90.00 m
Breadth, moulded	13.75 m
Depth	5.55 m
Draft	4.35 m
Service speed	12.5 kn
Main Engine	Wärtsila 8L20 – 1440kW

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2.2 General overview of the eSAIL

Figure 2 shows the conceptual geometry and operation of the eSAIL. The airfoil is thicker compared to an ordinary airfoil, and it is equipped with two suction areas (only one is represented) at each size of the airfoil (upper and lower) at the position where the flow would detach. There is a flap (roughly triangular) with a double function: 1) creating the asymmetry of the airfoil and 2) covering the second suction area which is not in use (the one at the intrados).

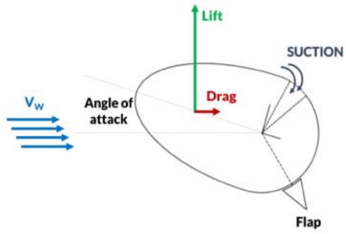

Figure 2: eSAIL conceptual airfoil

Such an airfoil shape (if no suction of the boundary layer exists) behaves as a cylinder exposed to an aiflow: the air detaches from the surface, generating a low-pressure turbulent zone downwind. No lift is created (aerodynamic force perpendicular to the airflow) and only drag exists (aerodynamic force parallel to the airflow). This is the out-of-operation mode of an eSAIL. This is represented in Figure 3

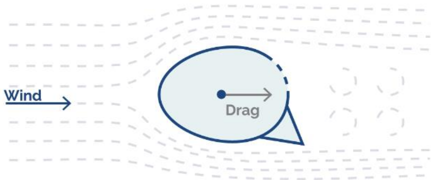

Figure 3: eSAIL aerodynamic behavior with suction OFF

However, if suction is done strategically, the boundary layer remains attached to the airfoil. The current lines of the extrados are curved, and lift force is created. This is the operational mode of an eSAIL. This is represented in Figure 4.

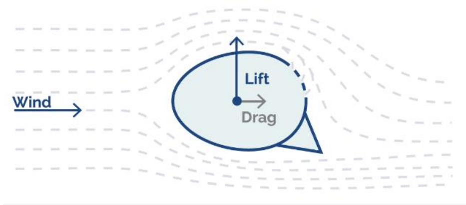

Figure 4: eSAIL aerodynamic behavior with suction ON

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The eSAIL is conceptually made up by the following parts:

Figure 5 3D of the eSAIL.

- **Orientable pedestal.** It is the structure connecting the vessel foundations and the eSAIL itself. The pedestal contains a slew-bearing and a motor for the rotation of the eSAIL body. This rotation is required to orient the eSAIL to the wind direction as desired. This part is similar to those used in standard marine deck cranes.
- **eSAIL body.** It is a tubular metallic structure which offers the main structural resistance of the system and, at the same time, defines the aerodynamic shape of the airfoil. The eSAIL body also contains the suction areas, the suction system and the mechanism to position the flap.
- **Movable flap.** It is a structure that positions on one side or the other of the eSAIL body, generating the desired airfoil asymmetry.
- **Autonomous control system.** As any other Wind Assisted Propulsion System, the eSAIL operation shall be fully autonomous with minimal crew intervention. This becomes even more important on the eSAIL to ensure a correct performance of the active boundary layer control system (suction). The autonomous control system shall trim, for each sailing condition, the suction power, eSAIL body rotation and flap positioning in an autonomous way. Additionally, it shall ensure safety in case of any malfunction or risk. An interesting advantage of the eSAIL is that it is inherently safe, as failure modes cause the stop of the suction fan, removing all aerodynamic forces and taking the eSAIL to a safe rest position. It is, thus, *fail-safe*. Note that the autonomous control system controls 3 actuators: eSAIL body rotation motor, flap positioning motor and suction fan.
- **Actuators.** eSAIL body rotation is done by an electric motor that actuates on the slew bearing. Flap movement is also done by means of electric motors. Suction is created by

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means of an electric fan located on top of the eSAIL body, discharging air away from vessel's deck and moving away the fan from the crew to reduce noise. All these actuators can be controlled either manually or autonomously through the control system.

2.3 eSAIL-assisted vessel configuration selected.

General Cargo and Multipurpose vessels have a large hatch covering the cargo area that extends from the bridge to the forecastle. This area shall be free of any element, as hatches shall be opened and closed and because cargo is usually located on the hatches. This leaves only two possible locations for the eSAILs: 1) the forecastle, or 2) behind the bridge. In these two positions, two different configurations can be imagined: 1) 2 eSAILs Model 1, or 2) 1 eSAIL Model 2.

For the present analysis it has been selected a configuration of two (2) eSAIL Model 1 of 17x2.85m located at the aft, behind the bridge, as sketched in the following image.

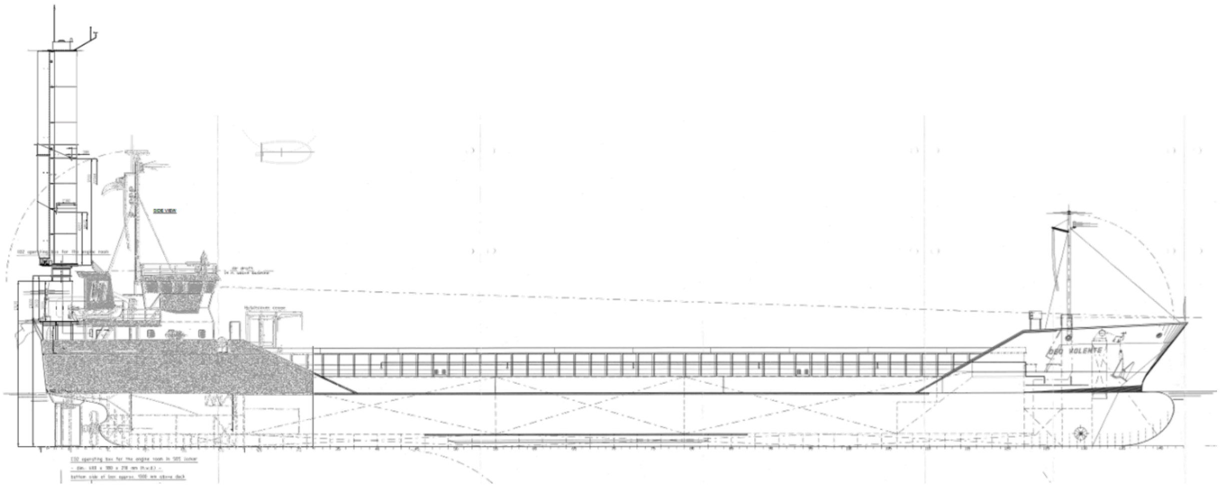

Figure 6: eSAIL-assisted EEMS Traveller configuration selected.

2.4 eSAIL operational envelope and limitations

The following table offers a summary of the main operational envelope and limitations for the eSAILs in the specific case of EEMS Traveller vessel.

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Table 2: Operational envelope and limitations for eSAIL operation.

OPERATIONAL ENVELOPE AND LIMITATIONS		
Maximum operational (apparent) wind speed	50 kn	Above this value, eSAIL is taken to safe status (switch-off fan to minimize aerodynamic loads.
Maximum survival wind speed	100 kn	With the eSAIL in safe status (switch-off fan).

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3 Physics applied for performance analysis

3.1 Aerodynamics of an eSAIL

An eSAIL, as any other aerodynamic body, when exposed to a certain airflow, generates two aerodynamic forces while in operation:

- LIFT, a force perpendicular to the airflow direction, and
- DRAG, a force in the same direction to the airflow.

Those two loads are modified and adjusted by changing the angle of attack (AoA) of the eSAIL with respect to the airflow. Increasing AoA increases Lift and Drag.

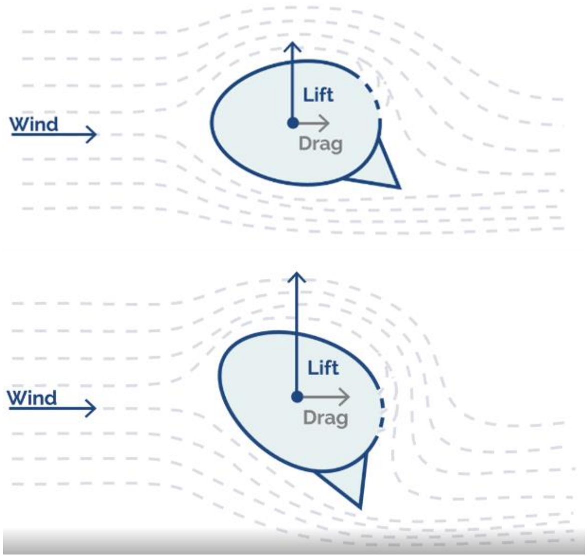

Figure 7: eSAIL in operation (suction on), at two different angles of attack

The main particularity of the eSAIL is that thanks to the boundary layer suction, detachment of the airflow is prevented, and larger lift coefficients can be achieved.

At the same time, if suction is switched off, the airflow detaches, and lift disappear, only remaining drag. This is a fail-safe mechanism.

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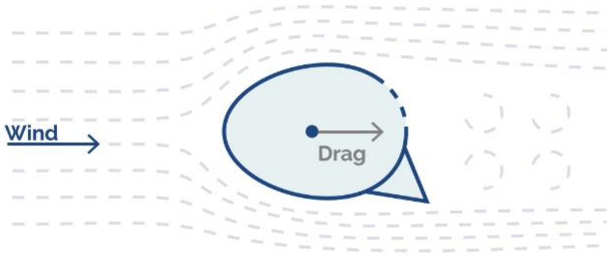

Figure 8: eSAIL out-of-operation (suction off)

Lift and Drag can be calculated with the following equations:

$$L = \frac{1}{2}\rho V_{ap}^2 S C_L$$
$$D = \frac{1}{2}\rho V_{ap}^2 S C_D$$

Where:

ρ = air density
V_{ap} = apparent wind speed
S = eSAIL area
C_L, C_D = Lift and Drag Coefficients,

Lift and Drag Coefficients (C_L & C_D) are aerodynamic characteristics of each particular lifting body (sails, eSAIL, rotor flettner…) which depends on its trim (positioning and actuation with respect to the airflow).

In the case of the eSAIL, trim is controlled by:

- Suction power – the amount of boundary layer air that is aspirated.
- Angle of Attack (AoA) – angle of the eSAIL with respect to the airflow.

The aerodynamic data used for the calculations of this report is based on the on CFD results obtained from b4b internal development for the eSAIL, which has been validated by means of wind tunnel test.

The following plots show the eSAIL Lift Coefficient (C_L), Drag Coefficient (C_D) and Power Coefficient (C_P) used for the performance calculations. Power Coefficient is a non-dimensional coefficient of the suction power required for each Lift Coefficient. Note that the results are compared with previous Turbovoile data (Malavard) showing the improvement achieved by bound4blue in its eSAIL design.

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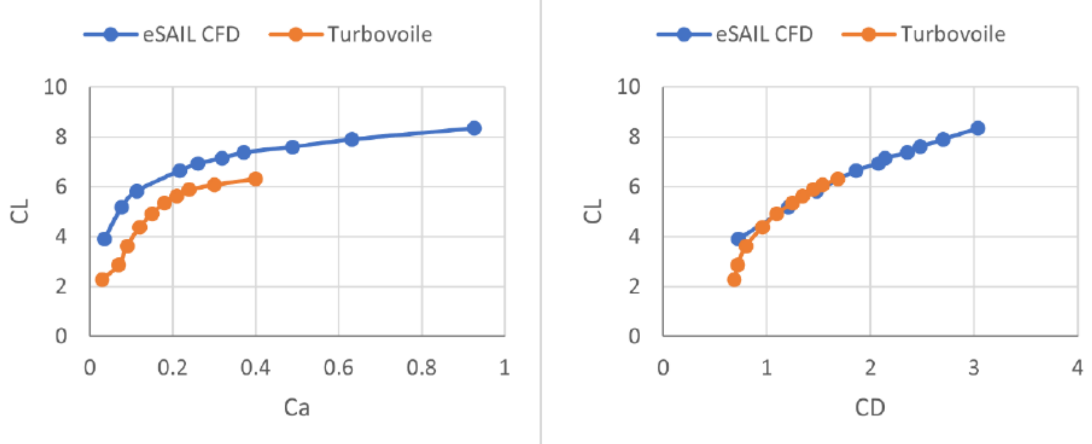

Figure 9: Polar and power plots used in the analysis.

3.2 Formulae for eSAIL-assisted vessel performance calculation

A vessel is exposed to a wind speed, known as **Apparent Wind Speed (AWS or V_{ap})**. It results from the composition of the existing wind, *True* **Wind Speed (TWS or V_T)** and the wind speed induced by the **vessel sailing speed (V_S)**.

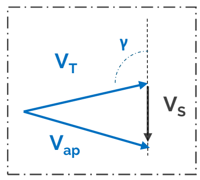

Figure 10: Speed triangle

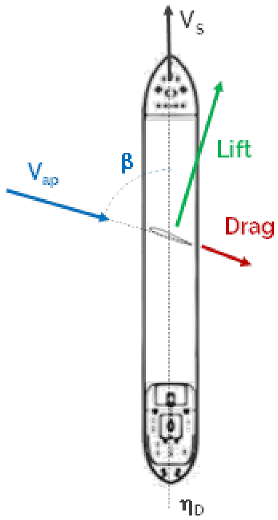

Figure 11: eSAIL loads on a vessel

AWS may blow from any direction, known as **Apparent Wind Angle (AWA or β)**, measured from bow. The resulting Apparent Wind Speed is dependent on **True Wind Angle (TWA or γ)**, also measured from the bow.

The eSAIL on a vessel, it will adapt its orientation (trim) to the existing Apparent Wind Angle (rotation) to generate Lift and Drag forces. Their direction will depend on the Apparent Wind Angle.

Those two loads can be projected on the vessel main directions, resulting in a **forward force (Driving Force, DF)** and a **side force (Heeling Force, HF)**, as follows:

$$DF = \frac{1}{2}\rho V_{ap}^2 S(C_L \sin\beta - C_D \cos\beta)$$

$$HF = \frac{1}{2}\rho V_{ap}^2 S(C_L \cos\beta + C_D \sin\beta)$$

The Driving Force is the force that helps propelling the vessel. If multiplied by vessel speed, the eSAIL propelling power (P_S) is obtained.

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$$P_s = DF \cdot V_S$$

If the eSAIL propelling power is divided by the propulsive efficiency (η_D), the engine-equivalent power delivered by the eSAIL (P_{Ds}) can be obtained:

$$P_{Ds} = \frac{DF \cdot V_S}{\eta_D}$$

Some WAPS, such as suction sails (eSAIL) or flettner rotors require an input power for operation representing a system power consumption (P_C). If this power consumption is subtracted to the engine-equivalent power delivered by the sail (P_{Ds}), the net engine-equivalent power delivered by the system is obtained as:

$$P_{D\_net} = P_{Ds} - P_C = \frac{DF \cdot V_S}{\eta_D} - P_C$$

In the current analysis, vessel speed (V_s) and propulsive efficiency (η_D) are assumed to be constant.

3.3 Reference vessel speed and engine power

The vessel's most common sailing speed ranges between 11 and 12 knot. Based on the on-board measured data for a reference day, which is plotted on Figure 12, **for an average vessel speed of 11.8 knot, the average required main engine power is 875kW**. These values are the ones selected, as reference (with no sail) condition.

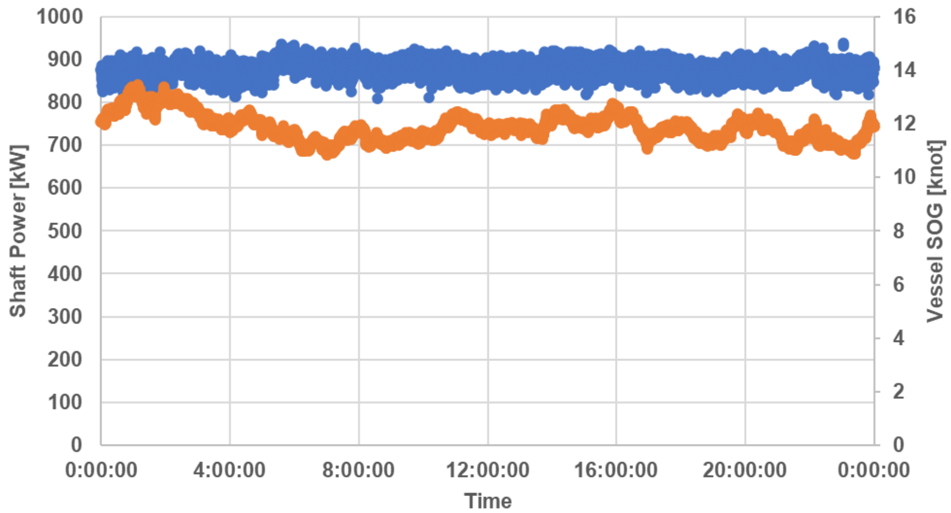

Figure 12: Eems Traveller sailing speed vs. shaft power

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3.4 Main engine heat modeling

The main engine installed on EEMS TRAVELLER went through stand testing to obtain performance information of the engine in operation at different loadings.

The results of this test, delivered as part of the engine technical documentation, is the relationship that can be obtained between the engine loading, the delivered engine power and the associated exhaust gas temperature, which is the one that can then be used by the heat recovery system.

Loadpoint	25	50	75	100	110
Time	15:25	16:50	17:35	18:55	19:45
Fuel	MDF	MDF	MDF	MDF	MDF
Engine Speed	1000	1000	1000	1000	1000
Alternator nom. Voltage [V]	550	550	550	550	550
Engine Power [kW]	360	720	1080	1440	1584
Alternator Efficiency	93,1	95,1	95,7	95,6	95,6
Alternator Output [kW]	335	684	1033	1376	1514
Load Indicator Position	15	22	28	34	37
Turbocharger A Speed [rpm]	19900	28050	33800	38200	39900
Exh. Temp. , Cyl. 1 °C	306	341	368	407	428
Cyl. 2	310	321	342	374	394
Cyl. 3	302	317	338	371	394
Cyl. 4	312	337	363	403	427
Cyl. 5	299	322	341	373	395
Cyl. 6	327	343	362	399	422
Cyl. 7	299	332	346	381	404
Cyl. 8	314	324	342	375	398
Cyl. 9					
Mean Values	309	330	350	385	408
Rack Position [mm]	11	17	23	28,5	31
Firing Press. , Cyl. 1 [bar]			144	172	
Cyl. 2			144	171	
Cyl. 3			147	174	
Cyl. 4			145	174	
Cyl. 5			146	174	
Cyl. 6			146	176	
Cyl. 7			148	176	
Cyl. 8			148	178	
Cyl. 9					
Mean Values	-	-	146	174	-
Exhaust Temp. After TC °C	299	333	323	334	348

Figure 13: Eems Traveller main engine performance characteristics.

Taking the reference operation point selected in previous section of 875kW, the expected exhaust gas temperature is 328.7 ºC, assuming linear interpolation between the closest available datapoints.

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Note that the exhaust gas temperature graph shown below (**Error! Reference source not found.**) d escribes an irregular curve, with a decrease in temperature from 720KW to 1080KW engine power. This power area will be the most likely during the vessel´s operation, therefore, the results in terms of available heat may be confusing.

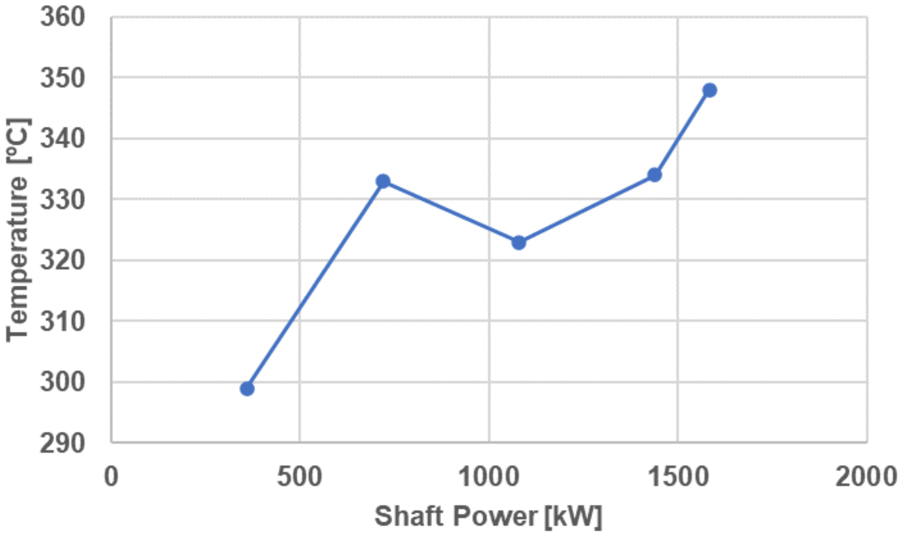

Figure 14: Eems Traveller main engine exhaust gas temperature depending on engine power.

When the eSAILs are on, they will generate a certain engine equivalent power (Pd) as seen in section 3.2 that can be be subtracted from initial engine power to keep the same vessel speed. Thus, the new engine power can be calculated as:

$$P_{eng\_new} = P_{eng\_old} - P_D$$

For the specific conditions of this analysis:

$$P_{eng\_new} = 875 - P_D$$

With the new engine power, the resulting new temperature can be calculated, from the data in **Error! R eference source not found.** by linear interpolation.

The eSAIL operation will generate two possible modifications:

- When the wind conditions are favorable, the eSAILs will deliver positive power, that can be reduced from the main engine, thus reducing the required engine power. **The initial reduction, from 875kW to 720kW will lead to an increase in available heat**. This might lead

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to an increase of exhaust gas temperature and increase of heat quality but Air Flow and fuel flow to cylinders will be lower, and in consequence the mass flow of exhaust gas will be lower. This will probably decrease the available thermal power in exhaust gases.

This increase in available heat is counter-intuitive (less engine power demanded should produce a decrease in temperature) however, as we move into the 720 to 1080 kW power range, the engine temperature tends to be reduced, as detailed in the graph above. Down from 720 kW, available heat will be reduced.

- When wind conditions are unfavorable, the eSAILs will deliver negative power, so the main engine will have to deliver more power to maintain vessel speed. In this scenario, the available heat will be increased.

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4 Performance polar plots

4.1 Introduction

This section contains the resulting performance polar plots for the selected eSAIL configuration of (2x) 17x2.85m eSAILs. The plots have been calculated for a vessel speed of 11.8 knot (V_s = 11.8 knot), with a maximum operational Apparent Wind Speed of 50 knots (AWS_{max} = 50knots) and with a fan power of 37kW installed per eSAIL ($P_{consumed\ max}$ = 37kW/eSAIL).

The plots show the engine-equivalent delivered power by the sail (P_{Ds}), the power consumed by the sail (P_C) and the resulting net engine-equivalent power saved (P_{D_net})

All these polar plots are represented for different True Wind Speeds (V_T = 10, 14, 18, 22, 26, 30 knot) with respect to:

- True Wind Speed vs. True Wind Angle
- True Wind Speed vs. Apparent Wind Angle

4.2 Engine-equivalent power delivered (P_{D_net}, P_{Ds} & P_c)

The following plots (Figure 15, Figure 16 and Figure 17) show the engine-equivalent delivered power by the sail (P_{Ds}), the power consumed by the sail (P_C) and the resulting net engine-equivalent power saved (P_{D_net}) at different True Wind Speed, with respect to **True Wind Angle**.

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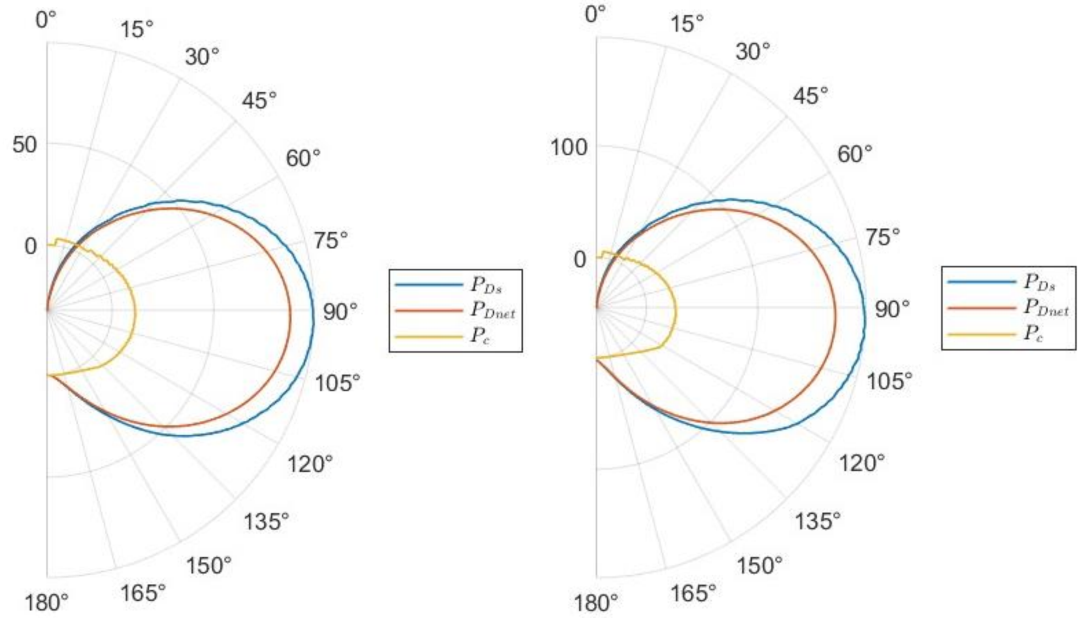

Figure 15: P_{Dnet}, P_{Ds} and P_c [in kW] for (2x) 17x2.85m eSAIL at V_S=11.8knot at V_T=10kn (left) and V_T=14kn (right), plotted wrt True Wind Angle (TWA)

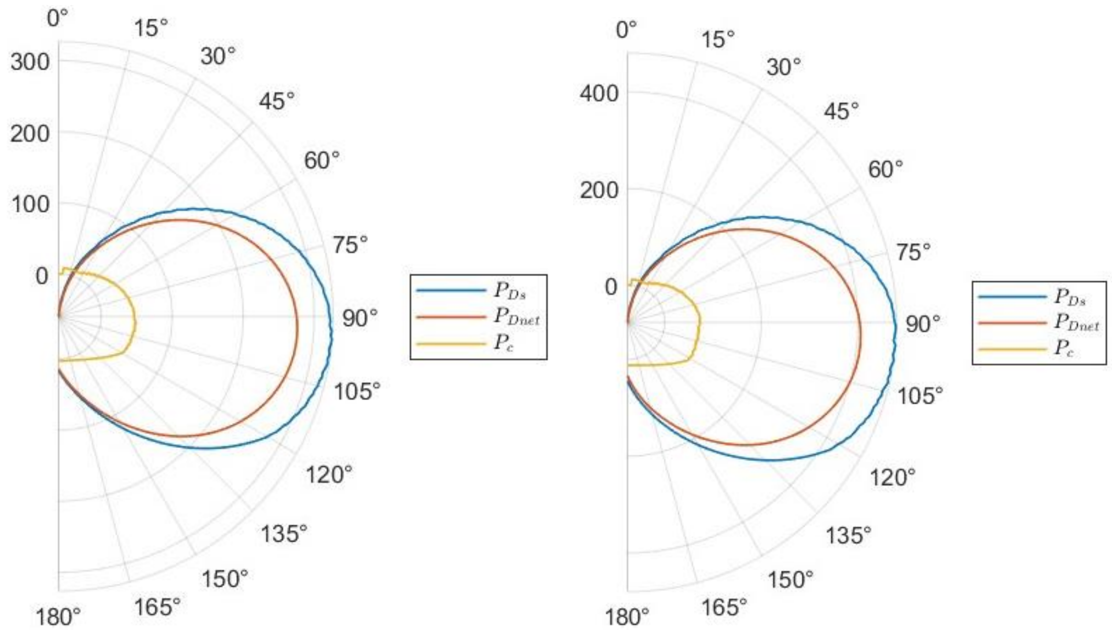

Figure 16: P_{Dnet}, P_{Ds} and P_c [in kW] for (2x) 17x2.85m eSAIL at V_S=11.8knot at V_T=18kn (left) and V_T=22kn (right), plotted wrt True Wind Angle (TWA)

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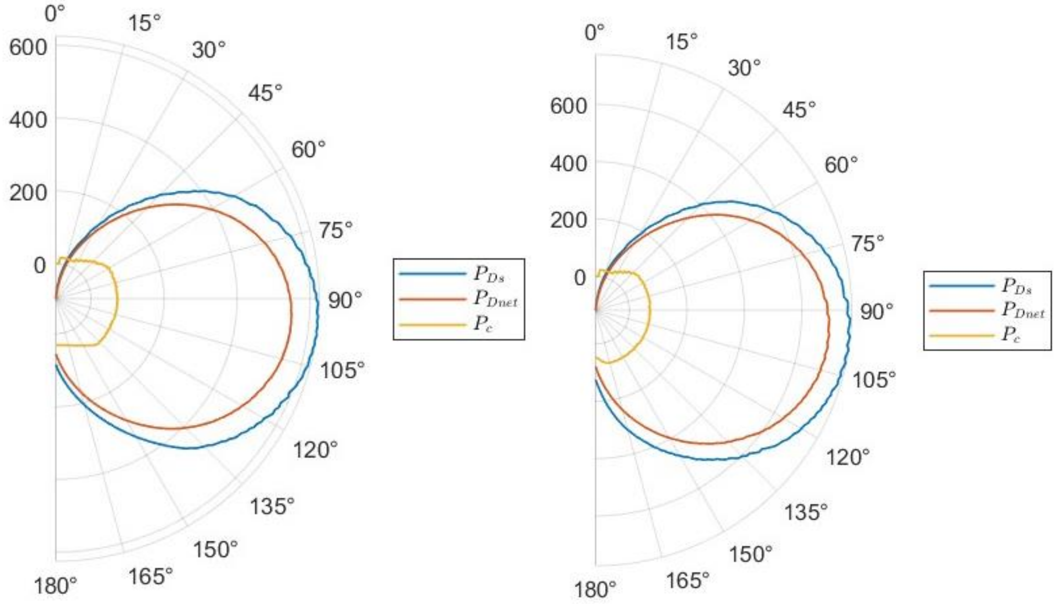

Figure 17: P_{Dnet}, P_{Ds} and P_c [in kW] for (2x) 17x2.85m eSAIL at V_S=11.8knot at V_T=26kn (left) and V_T=30kn (right), plotted wrt True Wind Angle (TWA)

The following plots (Figure 18, Figure 19 and Figure 20) represent just the same as those in the previous figures but plotted with respect to Apparent Wind Angle.

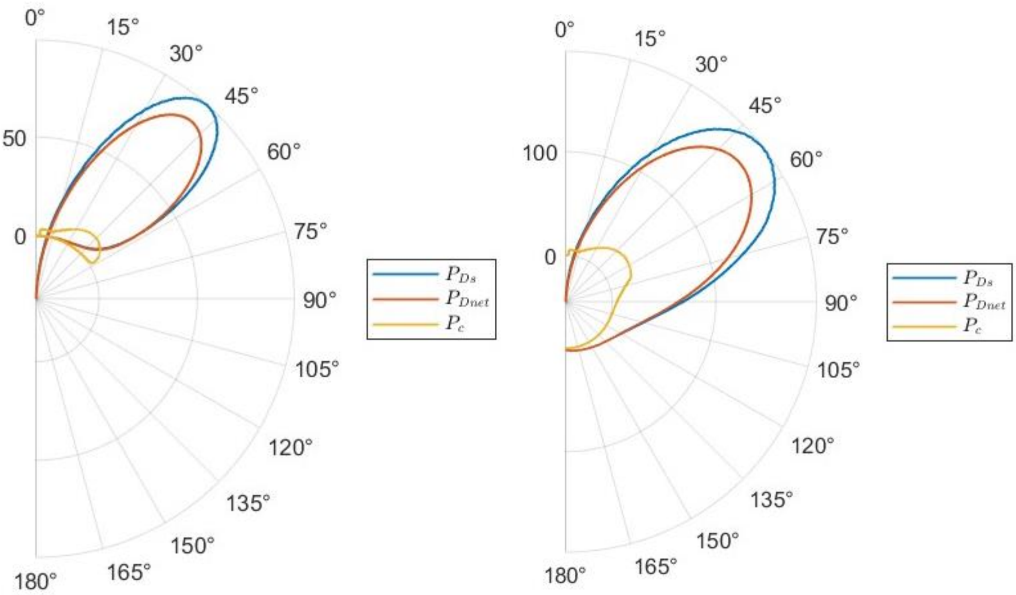

Figure 18: P_{Dnet}, P_{Ds} and P_c [in kW] for (2x) 17x2.85m eSAIL at V_S=11.8knot at V_T=10kn (left) and V_T=14kn (right), plotted wrt Apparent Wind Angle (AWA)

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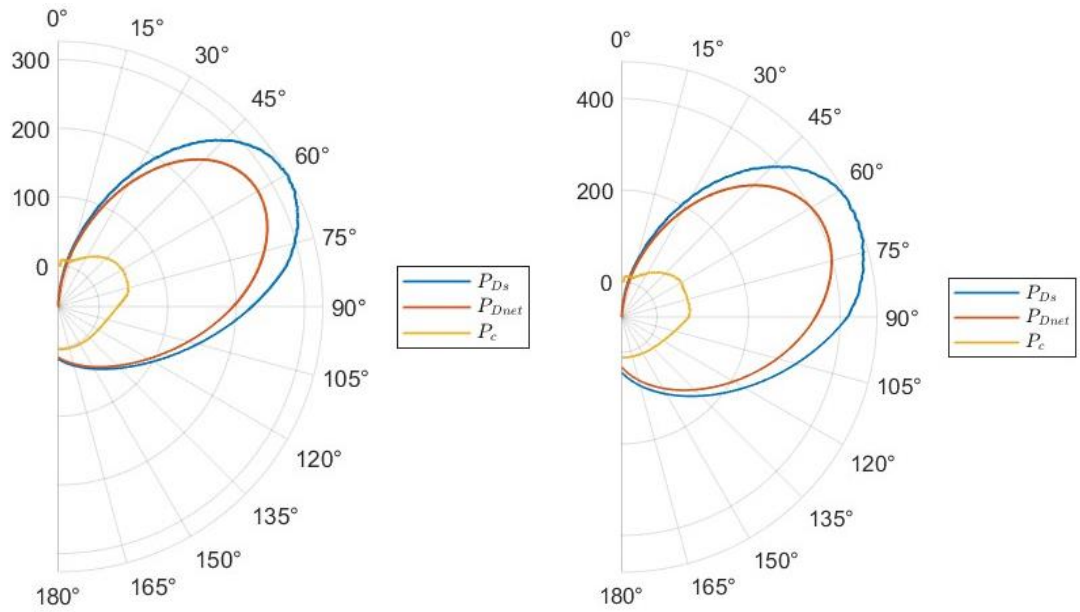

Figure 19: P_{Dnet}, P_{Ds} and P_c [in kW] for (2x) 17x2.85m eSAIL at V_S=10knot at V_T=18kn (left) and V_T=22kn (right), plotted wrt Apparent Wind Angle (AWA)

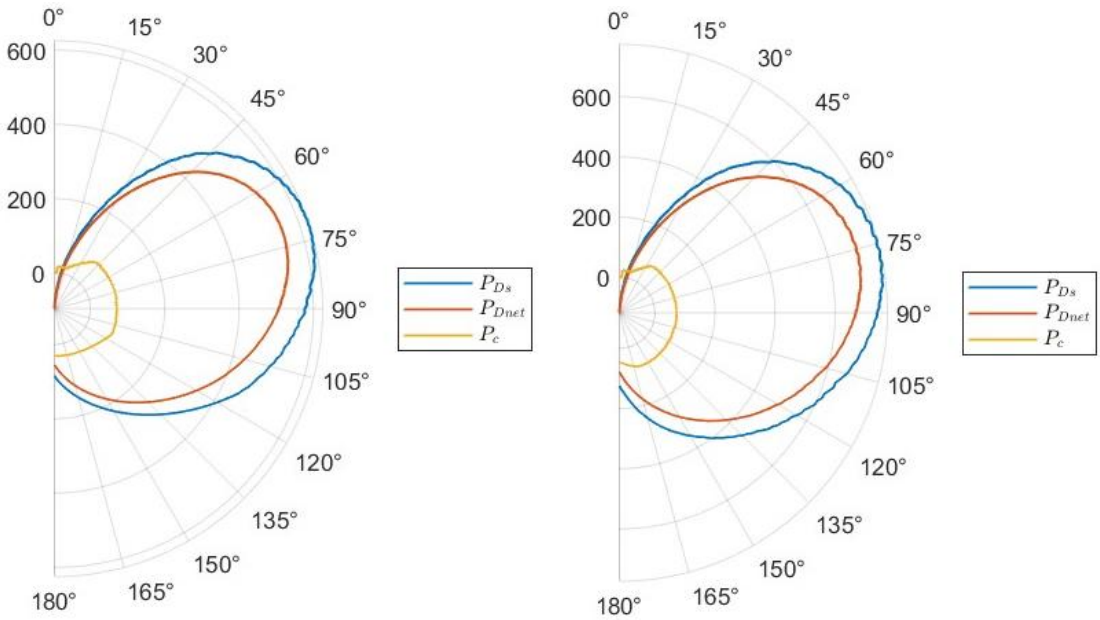

Figure 20: P_{Dnet}, P_{Ds} and P_c [in kW] for (2x) 17x2.85m eSAIL at V_S=10knot at V_T=26kn (left) and V_T=30kn (right), plotted wrt Apparent Wind Angle (AWA)

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5 Potential savings on example European trading

5.1 Selected example European trading routes

General Cargo vessels (as EEMS TRAVELLER or LA NAUMON) usually trade on short continental routes. In the case of Europe, these type of vessels trade between the different European countries.

For this performance modelisation exercise the yearly trading of an example general cargo vessel has been taken as reference. The selected trading period is from **January 2021 to December 2021**, according to Sea Net tool from Clarksons Research Database. This trading routes are displayed on the following figure.

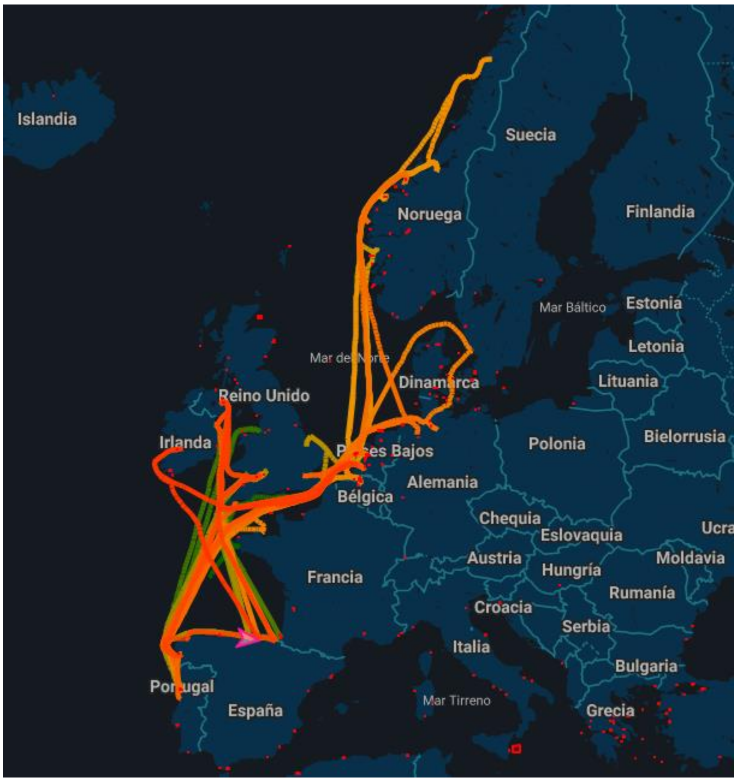

Figure 21: Trading Routes of example general cargo vessel – January2021-December2021

It can be seen that this example general cargo vessel sailed along several routes through the Atlantic Ocean (Spain, France, UK, Ireland), the English Channel and Northern Sea (Belgium, Netherlands, Germany, Denmark, Norway) and, occasionally the Baltic Sea.

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From the 1st January 2021 to the 31st December 2021, the vessel **effectively sailed for 189.5 days**, a 52% of the time.

5.2 Global savings based on 2017-21 historical wind data.

Potential fuel and emission savings can be obtained by combining:

- The performance plots of the eSAILs, as those described in section 0, for each vessel/wind speed and angle, and
- The historical wind data for 2017-2021 from the European Centre for Medium-Range Weather Forecasts (ECMWF) along the vessel's trading routes described in section 5.1

Note that the eSAIL operational limitations have been taken into account. These limitations are a maximum operational wind speed of 50 knot and a maximum fan installed power of 37kW per eSAIL.

The savings results for the selected configuration of (2x) 17x2.85m eSAIL along the trading routes followed from January 2021 to December 2021, based on historical weather data of past years, are detailed following. Note that estimations are based on the methodology described on section 3 and take into account the fuel saved, not fuel consumption. In addition, it considers Specific Fuel Oil Consumption (SFOC) constant:

Table 3: Achieved savings by eSAIL-assisted General Cargo on Jan2021 – Dec2021 European trading routes based on historical wind data with maximum fan installed power of 2x37kW

POWER CONSUMPTION LIMITED TO 25kW						
	2017	2018	2019	2020	2021	DESCRIPTION
eSAIL fuel savings (P_{Ds})	*65.2 Tn*	*84.6 Tn*	*91.0 Tn*	*95.1 Tn*	*78.6 Tn*	*Main Engine fuel savings*
eSAIL fuel consumption (P_C)	*10.7 Tn*	*13.9 Tn*	*14.7 Tn*	*15.4 Tn*	*12.9 Tn*	*Auxiliary Engine fuel consumption (suction fan)*
eSAIL Net fuel savings (P_{Dnet})	*54.5 Tn*	*70.7 Tn*	*76.3 Tn*	*79.7 Tn*	*65.7 Tn*	*Net fuel savings achieved by eSAILs*
Net CO_2 emission savings	*172.7 Tn*	*224.0 Tn*	*241.8 Tn*	*252.7 Tn*	*208.3 Tn*	*Assuming 3.17 Tn_CO_2 / Tn_fuel, according to the standard value from IMO*
Economic Savings	*54.5 k€*	*70.7 k€*	*76.3 k€*	*79.7 k€*	*65.7 k€*	*Assuming 1000 €/ton*
Daily net fuel savings	*0.287 Tn/d*	*0.373 Tn/d*	*0.403 Tn/d*	*0.421 Tn/d*	*0.347 Tn/d*	*Divided by 189.5 sailing days*
Daily net CO_2 emission savings	*0.91 Tn/d*	*1.18 Tn/d*	*1.28 Tn/d*	*1.33 Tn/d*	*1.10 Tn/d*	*Divided by 189.5 sailing days*

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5.3 eSAILs delivered power distribution.

The results in the previous section show the global averaged results accounting for all negative and positive conditions along the whole year. However, as wind conditions are variable along the year and along the trade, the instant power savings of the eSAIL can largely vary.

The following plots show the probability distribution plots of the engine-equivalent power savings (P_D) along the 5 years of wind data analyzed.

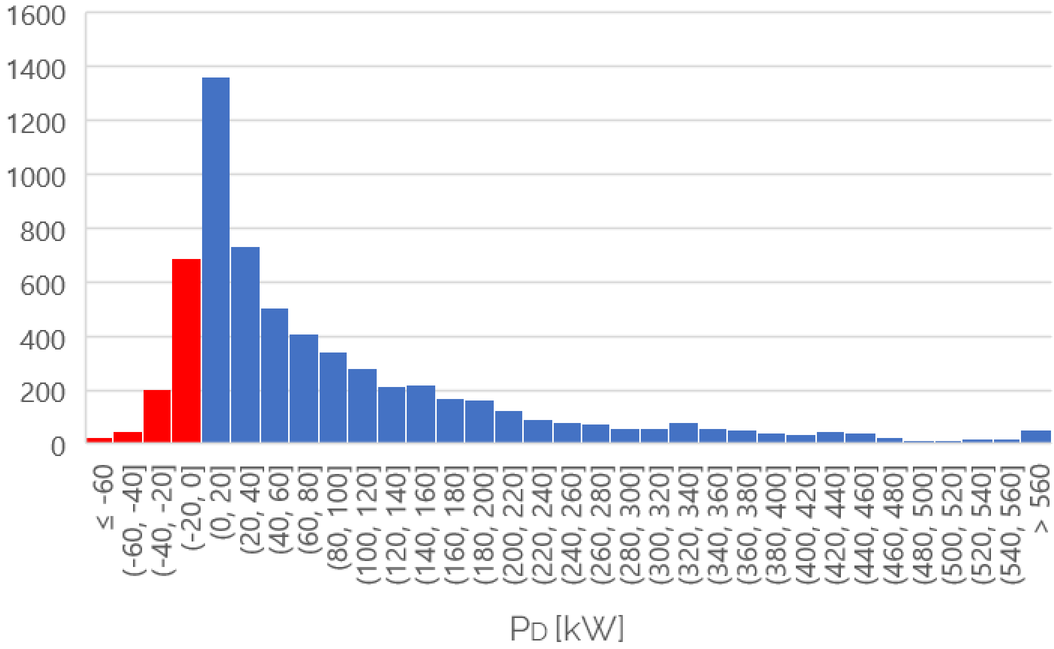

Figure 22: eSAILs engine-equivalent power savings histogram along selected example trading routes based on 2017-2021 historical wind data

It can be seen that most of the time, the **eSAIL savings are between -40kW (negative savings due to sailing into the wind) and 200kW (about 23% savings)**

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6 Analysis of the effect on available heating

Section 5.3 indicates the expected probability distribution of P_D along the vessel trades based on 5-year historical wind data. Taking the calculation approach detailed in section 3.4, the new exhaust gas temperature probability distribution can be plotted. Note that the **reference initial exhaust gas temperature was 328.7 °C.**

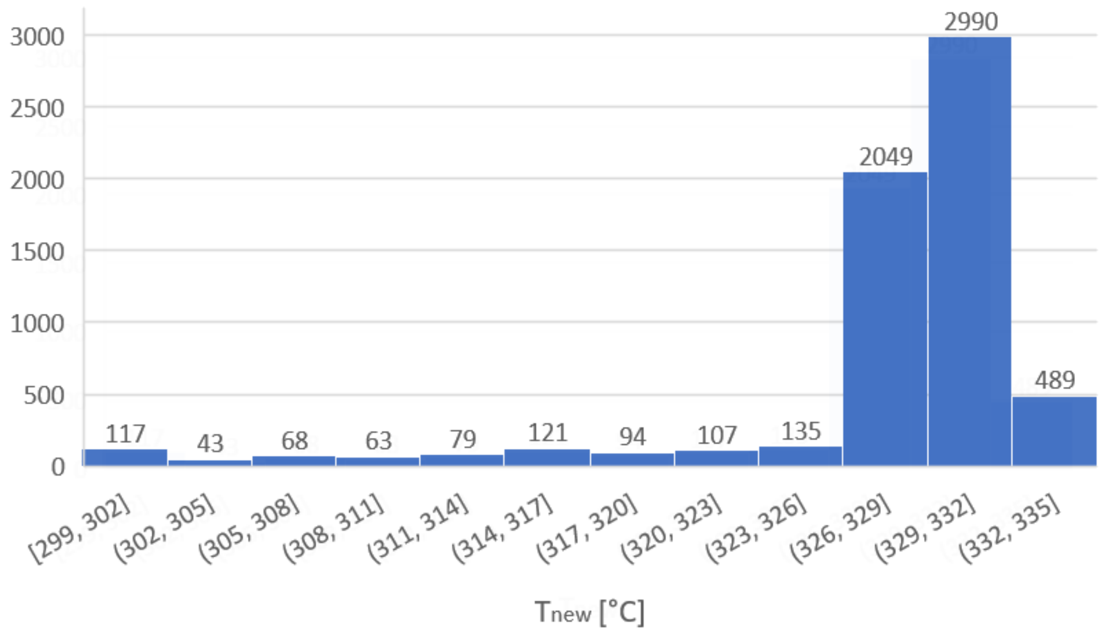

Figure 23: Resulting main engine exhaust gas temperature histogram due to the operation of the eSAILs along selected example trading routes based on 2017-2021 historical wind data.

The following picture shows the main engine exhaust gas temperature variation with respect to the reference temperature due to the operation of the eSAIL.

It can be seen that:

- Almost 70% of the time, the eSAIL operation creates a positive increase in engine exhaust gas temperature of up to 5 °C (1.5% variation).
- About 17% of the time, the engine exhaust gas temperature reduction is between 0 °C and -2 °C.
- Only 5% of the time, the exhaust gas temperature reduction is larger than a 5%.

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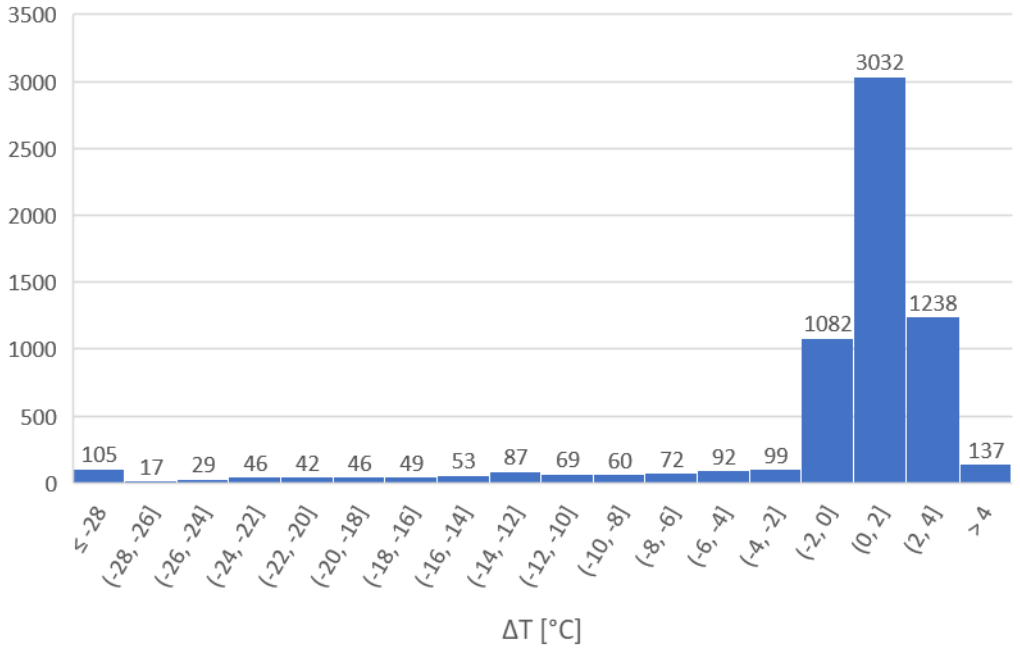

Figure 24: Variation of main engine exhaust gas temperature histogram due to the operation of the eSAILs along selected example trading routes based on 2017-2021 historical wind data.

Although this deliverable refers to a specific vessel, EEMS Traveller, the final desirable scope is to validate the approach and methodology. In a future commercial phase of the ZHENIT technologies, a specific assessment will be necessary on a case-by-case basis and considering the mix of technologies implemented on board.

The impact of a WAPS such as the eSAIL in terms of WH temperature is very limited and, again, variable depending on the vessel, the main engine characteristics, the routes sailed or the eSAIL configuration.

In terms of WH power (MW or MWh of waste heat available), the eSAIL (or any other kind of WAPS) is expected to have an impact. This impact will be proportional to the engine-equivalent delivered power by the eSAIL. The power delivered by the engine is therefore reduced of the same amount, and proportionally also the WH power availability, according to the characteristics of the main engine.

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Annexed to this deliverable, three naval engine data sheets can be consulted as a reference of the direct relation between main engine power and WH power production. This type of technical documentation should be considered for future WH availability assessments in the context of future commercialisation of ZHENIT technologies.

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7 Conclusions

In this deliverable, a comprehensive assessment of the available waste heat temperature fluctuations has been carried out for a real general cargo vessel theoretically equipped with wind-assisted propulsion technology. Due to the constraints in the available data from LA NAUMON, another general cargo vessel with operational sailing records and more detailed databases adjusted to the project needs, the EEMS TRAVELLER has been considered.

Based on the data assessed, and as a result of the operational conditions of this vessel, the most common average sailing speed is 11.8 knots, wich requires 875kW of main engine power. **This is considered a base scenario for a vessel without eSAIL. Under these conditions, the average exhaust gas temperature is 328,7 °C.**

Applying the modelization of eSAIL system for the specific trading routes over a period of 5 years, and evaluating the wind characteristics potentially observed for WAPS installed on EEMS TRAVELLER in a given configuration (x2 eSAIL model 1/17), the engine-equivalent power savings (P_D) have been estimated under the format of a probability distribution. As result of the potential savings generated by the eSAIL, which are between -40kW (negative savings due to sailing into the wind) and +200kW (about 23% savings), the impact in terms of WH has been plotted with a new temperature probability distribution.

The analysis of the probability distributions leads to the following conclusions:

- 79% of the time, the exhausting gas temperature of the hybrid vessel is between 326 and 332 °C.
- **69% of the time, the eSAIL operation creates a positive increase in engine exhaust gas temperature of up to 5 °C, whereas, the most likely temperature increase, is between 0 and 2 °C.**
- The increase in engine exhaust gas temperature in the hybrid vessel evaluated, despite the power savings generated, is due to the non-lineal relationship between the main engine exhaust gas temperature and the engine power demanded.
- In terms of WH temperature, the use of a complementary wind-assisted propulsion has no impact, nevertheless, the WH capacity availability (thermal energy) must be evaluated.
- A comparison of the results obtained in this study and the actual temperatures obtained in real sailing will be really valuable, specially as far as the engine gas exhaust temperature curve is concerned.

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References

[1] Sea Net tool from Clarksons Research Database.

[2] 2017-2021 Historical wind data. European Centre for Medium-Range Weather Forecasts (ECMWF)

[3] Technical documentation of the vessels LA NAUMON and EEMS TRAVELLER.

[4] Internal documentation of eSAIL specifications developed by B4B.

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Contact

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Diesel engine Wärtsilä 8L20			ME	AE	AE	AE	AE
Engine speed		RPM	1000	720	750	900	1000
Engine output		kW	1440	1040	1080	1360	1440
Engine output		HP	1960	1410	1470	1850	1960
Cylinder bore		mm			200		
Stroke		mm			280		
Swept volume		dm^3			70,4		
Compression ratio					15		
Compression pressure, max.		bar	167	150	150	167	167
Firing pressure, max.		bar	185	170	170	185	185
Charge air pressure at 100% load		bar			0,3		
Mean effective pressure		bar	24,6	24,6	24,6	25,8	24,6
Mean piston speed		m/s	9,3	6,7	7	8,4	9,3
Idling speed		RPM	350				
Combustion air system							
Flow of air at 100% load		kg/s	2,86	1,96	2,04	2,79	2,98
Ambient air temperature, max.		°C			45		
Air temperature after air cooler		°C			45…60		
Air temperature after air cooler, alarm		°C			75		
Exhaust gas system							
Exhaust gas flow (100% load)	3)	kg/s	2,94	2,02	2,1	2,87	3,06
Exhaust gas flow (85% load)	3)	kg/s	2,5	1,74	1,81	2,48	2,67
Exhaust gas flow (75% load)	3)	kg/s	2,18	1,57	1,62	2,24	2,41
Exhaust gas flow (25% load)	3)	kg/s	1,44	1,11	1,15	1,61	1,76
Exhaust gas temp. after turbocharger (100% load)	1) 3)	°C	350	360	360	350	340
Exhaust gas temp. after turbocharger (85% load)	1) 3)	°C	355	360	360	340	340
Exhaust gas temp. after turbocharger (75% load)	1) 3)	°C	360	360	360	340	340
Exhaust gas temp. after turbocharger (50% load)	1) 3)	°C	390	370	370	350	350
Exhaust gas back pressure drop, max.		kPa			3		
Diameter of turbocharger connection		mm			300		
Exhaust gas pipe diameter, min.		mm	400	350	350	400	400
Calculated dia for 35 m/s		mm	433	362	369	428	438
Heat balance	2) 3)						
Jacket water		kW	330	244	254	307	330
Charge air		kW	442	306	322	407	442
Lubricating oil		kW	219	162	167	204	219
Exhaust gases		kW	1057	684	708	890	943
Radiation		kW	82	55	57	74	76
Fuel system							
Pressure before injection pumps		kPa (bar)			600(6)		
Pump capacity, MDF, engine driven		m^3/h	1,92	1,48	1,54	1,73	1,92
Fuel consumption (100% load)	3)	g/kWh	199	192	192	191	192
Fuel consumption (85% load)	3)	g/kWh	198	193	193	190	191
Fuel consumption (75% load)	3)	g/kWh	198	194	194	190	192
Fuel consumption (50% load)	3)	g/kWh	203	202	202	199	199
Leak fuel quantity, clean MDF fuel (100% load)		kg/h	1,2	0,8	0,9	1,1	1,2
Lubricating oil system							
Pressure before engine, nom.		kPa (bar)			450 (4,5)		
Pressure before engine, alarm		kPa (bar)			300 (3)		
Pressure before engine, stop		kPa (bar)			200 (2)		
Priming pressure, nom.		kPa (bar)			80 (0,8)		
Priming pressure, alarm		kPa (bar)			50 (0,5)		
Temperature before engine, nom.		°C			63		

Temperature before engine, alarm		°C			80		
Temperature after engine, abt.		°C			78		
Pump capacity (main), engine driven		m³/h	50	50	50	50	50
Pump capacity (main), separate		m³/h			27		
Pump capacity (priming)	4)	m³/h			6,9/8,4		
Oil volume, wet sump, nom.		m³			0,49		
Oil volume in separate system oil tank, nom.		m³	1,9	1,4	1,5	1,8	1,9
Filter fineness, nom.		microns/60%	25	25	25	25	25
Filter difference pressure, alarm		kPa (bar)			150 (1,5)		
Oil consumption (100% load), abt.	5)	g/kWh			0,6		

Cooling water system

High temperature cooling water system

Pressure before engine, nom.		kPa (bar)			200 (2,0) + static		
Pressure before engine, alarm		kPa (bar)			100 (1,0) + static		
Pressure before engine, max.		kPa (bar)			350 (3,5)		
Temperature before engine, abt.		°C			83		
Temperature after engine, nom.		°C			91		
Temperature after engine, alarm		°C			105		
Temperature after engine, stop		°C			110		
Pump capacity, nom.		m³/h	40	35	37	39	40
Pressure drop over engine		kPa (bar)			50 (0,5)		
Water volume in engine		m³			0,15		
Pressure from expansion tank		kPa (bar)			70…150 (0,7…1,5)		
Pressure drop over central cooler, max.		kPa (bar)			60 (0,6)		
Delivery head of stand-by pump		kPa (bar)			200 (2)		

Low temperature cooling water system

Pressure before charge air cooler, nom.		kPa (bar)			200 (2) + static		
Pressure before charge air cooler, alarm		kPa (bar)			100 (1) + static		
Pressure before charge air cooler, max.		kPa (bar)			350 (3,5)		
Temperature before charge air cooler, max.		°C			38		
Temperature before charge air cooler, min.		°C			25		
Pump capacity, nom.		m³/h	48	38	40	45	48
Pressure drop over charge air cooler		kPa (bar)			30 (0,3)		
Pressure drop over oil cooler		kPa (bar)			30 (0,3)		
Pressure drop over central cooler, max.		kPa (bar)			60 (0,6)		
Pressure from expansion tank		kPa (bar)			70…150 (0,7…1,5)		
Delivery head of stand-by pump		kPa (bar)			200 (2)		

Starting air system

Air supply pressure before engine (max.)		Mpa (bar)			3 (30)		
Air supply pressure, alarm		Mpa (bar)			1,8 (18)		
Air consumption per start (20°C)	6)	Nm³			0,4		

1) At an ambient temperature of 25°C.
2) The figures are at 100% load and include the 5% tolerance on sfoc and engine driven pumps.
3) According to ISO 3046/1, lower calorific value 42 700 kJ/kg, with engine driven pumps. Tolerance 5%. Constant speed applications are Auxiliary and DE. Mechanical propulsion variable speed applications according to propeller law.
4) Capacities at 50 and 60 Hz respectively.
5) Tolerance + 0.3 g/kWh
6) At remote and automatic starting, the consumption is 1.2 Nm³

Subject to revision without notice.

0.01 Technical Data (at module)

Data at:				Full load	Part Load		Propane
Fuel gas LHV		BTU/scft		8684			2500
				100%	75%	50%	100%
Energy input		MBTU/hr	[2]	14.734	11.383	8.036	6.703
Gas volume		scfhr	*)	1.697	1.311	925	2.681
Mechanical output		bhp	[1]	2.509	1.881	1.255	1004
Electrical output		kW el.	[4]	1.790	1.326	880	713
Recoverable thermal output							
~ Intercooler 1st stage		MBTU/hr		1.339	754	218	65
~ Lube oil (with gearbox)		MBTU/hr		710	632	550	471
~ Jacket water		MBTU/hr		1.061	901	778	717
~ Exhaust gas cooled to 248 °F		MBTU/hr		3.488	2.958	2.283	1.962
Total recoverable thermal output		MBTU/hr	[5]	6.598	5.245	3.829	3.215
Heat to be dissipated							
~ Intercooler 2nd stage		MBTU/hr		340	266	198	171
~ Lube oil (with gearbox)		MBTU/hr		~	~	~	~
~ Surface heat	ca.	MBTU/hr	[7]	655	565	493	320
~ Balance heat		MBTU/hr		147	113	82	68
Spec. fuel consumption of engine		BTU/bhp.hr	[2]	5.872	6.050	6.402	6.676
Lube oil consumption	ca.	gal/hr	[3]	0,17	~	~	~
Electrical efficiency		%		41,5%	39,8%	37,3%	36.3%
Thermal efficiency		%		44,8%	46,1%	47,7%	47.9%
Total efficiency		%	[6]	86,2%	85,8%	85,0%	84.2%
Hot water circuit:							
Forward temperature		°F		194,0	170,3	167,0	
Return temperature		°F		158,0	158,0	158,0	
Hot water flow rate		GPM		366,5	366,5	366,5	

*) approximate value for pipework dimensioning
[_] Explanations: see 0.10 - Technical parameters

All heat data is based on standard conditions according to attachment 0.10. Deviations from the standard conditions can result in a change of values within the heat balance, and must be taken into consideration in the layout of the cooling circuit/equipment (intercooler; emergency cooling; ...).

Main dimensions and weights (at module)(with gearbox)

Length	in	~ 360
Width	in	~ 90
Height	in	~ 110
Weight empty	lbs	~ 46.030
Weight filled	lbs	~ 48.240

Connections

Hot water inlet and outlet	in/lbs	4"/145
Exhaust gas outlet	in/lbs	20"/145
Fuel gas (at gas train)	in/lbs	4"/232
Fuel Gas (at module)	in/lbs	4"/145
Water drain ISO 228	G	½"
Condensate drain	in/lbs	2"/145
Safety valve - jacket water ISO 228	in/lbs	2x1½"/2.5
Safety valve - hot water	in/lbs	2½"/232
Lube oil replenishing (pipe)	in	1,1
Lube oil drain (pipe)	in	1,1
Jacket water - filling (flex pipe)	in	0,5
Intercooler water-Inlet/Outlet 1st stage	in/lbs	4"/145
Intercooler water-Inlet/Outlet 2nd stage	in/lbs	2½"/145

0.02 Technical data of engine

Manufacturer		GE Jenbacher
Engine type		J 612 GS-E12
Working principle		4-Stroke
Configuration		V 60°
No. of cylinders		12
Bore	in	7,48
Stroke	in	8,66
Piston displacement	cu.in	4.568
Nominal speed	rpm	1.500
Mean piston speed	in/s	433
Filling capacity lube oil	gal	106
Filling capacity water	gal	53
Length	in	167
Width	in	74
Height	in	99
Weight dry	lbs	17.196
Weight filled	lbs	18.960
Moment of inertia	lbs-ft²	1345,01
Direction of rotation (from flywheel view)		left
Flywheel connection		SAE 21"
Radio interference level to VDE 0875		N
Starter motor output	kW	15
Starter motor voltage	V	24

Thermal energy balance

Energy input	MBTU/hr	14.734
Intercooler	MBTU/hr	1.679
Lube oil (with gearbox)	MBTU/hr	710
Jacket water	MBTU/hr	1.061
Exhaust gas total	MBTU/hr	4.449
Exhaust gas cooled to 356 °F	MBTU/hr	2.876
Exhaust gas cooled to 212 °F	MBTU/hr	3.692
Surface heat	MBTU/hr	379
Balance heat	MBTU/hr	147

Exhaust gas data

Exhaust gas temperature at full load	°F [8]	804
Exhaust gas mass flow rate, wet	lbs/hr	23.296
Exhaust gas mass flow rate, dry	lbs/hr	21.819
Exhaust gas volume, wet	scfhr	310.401
Exhaust gas volume, dry	scfhr	280.354
Max.admissible exhaust back pressure after engine	psi	0,870

Combustion air data

Combustion air mass flow rate	lbs/hr	22.582
Combustion air volume	SCFM	4.929
Max. admissible pressure drop in front of intake-air filter	psi	0,145

base for exhaust gas data: natural gas: 100% CH4; biogas 65% CH4, 35% CO2

Output / fuel consumption

ISO standard fuel stop power ICFN	bhp	2.509
Mean effe. press. at stand. power and nom. speed	psi	290
Fuel gas type		Natural gas
Based on methane number	MN d)	70
Compression ratio	Epsilon	11,00
Min. fuel gas pressure for the pre chamber	psi	43.5 - 58.0
Min./Max. fuel gas pressure at inlet to gas train	psi	1.2 - 2.9 c)
Allowed Fluctuation of fuel gas pressure	%	± 10
Max. rate of gas pressure fluctuation	psi/sec	0,145
Maximum Intercooler 2nd stage inlet water temperature	°F	104
Spec. fuel consumption of engine	BTU/bhp.hr	5.872
Specific lube oil consumption	g/bhp.hr	0,22
Max. Oil temperature	°F	176
Jacket-water temperature max.	°F	203

c) Lower gas pressures upon inquiry
d) based on methane number calculation software AVL 3.1

Sound pressure level

Aggregate b)	dB(A) re 20μPa	100
31,5 Hz	dB	90
63 Hz	dB	88
125 Hz	dB	100
250 Hz	dB	95
500 Hz	dB	94
1000 Hz	dB	93
2000 Hz	dB	91
4000 Hz	dB	91
8000 Hz	dB	94
Exhaust gas a)	dB(A) re 20μPa	116
31,5 Hz	dB	104
63 Hz	dB	121
125 Hz	dB	124
250 Hz	dB	116
500 Hz	dB	111
1000 Hz	dB	110
2000 Hz	dB	108
4000 Hz	dB	104
8000 Hz	dB	86

Sound power level

Aggregate	dB(A) re 1pW	121
Measurement surface	ft²	1.324
Exhaust gas	dB(A) re 1pW	124
Measurement surface	ft²	67,60

a) average sound pressure level on measurement surface in a distance of 3.28ft according to DIN 45635, precision class 2.
b) average sound pressure level on measurement surface in a distance of 3.28ft (converted to free field) according to DIN 45635, precision class 3.
Operation with 1200 rpm see upper values, operation with 1800 rpm add 3 dB to upper values.
Engine tolerance ± 3 dB

0.03 Technical data of generator

Manufacturer		STAMFORD
Type		LVSI 804 R2
Type rating	kVA	2.750
Driving power	bhp	2.477
Ratings at p.f.= 1.0	kW	1.790
Ratings at p.f. = 0,8	kW	1.772
Rated output at p.f. = 0,8	kVA	2.214
Rated current at p.f. = 0,8	A	2.663
Frequency	Hz	60
Voltage	V	480
Speed	rpm	1.800
Permissible overspeed	rpm	2.160
Power factor lagging		0,8 - 1,0
Efficiency at p.f.= 1.0	%	96,9%
Efficiency at p.f. = 0,8	%	95,9%
Moment of inertia	lbs-ft²	1774,12
Mass	lbs	11.449
Radio interference level to VDE 0875		N
Construction		B3/B14
Protection Class		IP 23
Insulation class		H
Temperature rise (at driving power)		F
Maximum ambient temperature	°F	104
Total harmonic distortion	%	1,5

Reactance and time constants

xd direct axis synchronous reactance	p.u.	2,13
xd' direct axis transient reactance	p.u.	0,19
xd'' direct axis sub transient reactance	p.u.	0,14
Td'' sub transient reactance time constant	ms	15
Ta Time constant direct-current	ms	66
Tdo' open circuit field time constant	s	3,95

0.03.01 Technical data of gearbox

Manufacturer		EICKHOFF
Type		ANO - 090
Gearbox ratio		1:1.2
Efficiency	%	98,73
Mass	lbs	2.282

0.04 Technical data of heat recovery

General data - Hot water circuit

Total recoverable thermal output	MBTU/hr	6.598
Return temperature	°F	158,0
Forward temperature	°F	194,0
Hot water flow rate	GPM	366,5
Design pressure of hot water	psi	145
Pressure drop hot water circuit	psi	18,13
Maximum Variation in return temperature	°F	+5/-36
Max. rate of return temperature fluctuation	°F/min	18

Mixture Intercooler (1st stage)

Type	gilled pipes	
Design pressure of hot water	psi	145
Pressure drop hot water circuit	psi	3,63
Hot water connection	in/lbs	4"/145

Mixture Intercooler (2nd stage) (Intercooler separate)

Type	gilled pipes	
Design pressure of hot water	psi	145
Pressure drop hot water circuit	psi	3,63
Hot water connection	in/lbs	2½"/145

Heat exchanger lube oil

Type	plate heat exchanger	
Design pressure of hot water	psi	145
Pressure drop hot water circuit	psi	5,80
Hot water connection	in/lbs	4"/145

Heat exchanger engine jacket water

Type	plate heat exchanger	
Design pressure of hot water	psi	145
Pressure drop hot water circuit	psi	5,80
Hot water connection	in/lbs	4"/145

Exhaust gas heat exchanger

Type	shell-and-tube	
PRIMARY:		
Exhaust gas pressure drop approx	psi	0,22
Exhaust gas connection	in/lbs	20"/145
SECONDARY:		
Design pressure of hot water	psi	87
Pressure drop hot water circuit	psi	2,90
Hot water connection	in/lbs	4"/145

0.10 Technical parameters

All data in the technical specification are based on engine full load (unless stated otherwise) at specified temperatures as well as the methane number and subject to technical development and modifications. For isolated operation an output reduction may apply according to the block load diagram. Before being able to provide exact output numbers, a detailed site load profile needs to be provided (motor starting curves, etc.).

All pressure indications are to be measured and read with pressure gauges (psi.g.).

(1) At nominal speed and standard reference conditions ICFN according to DIN-ISO 3046 and DIN 6271, respectively
(2) According to DIN-ISO 3046 and DIN 6271, respectively, with a tolerance of + 5 %
(3) Average value between oil change intervals according to maintenance schedule, without oil change amount
(4) At p. f. = 1.0 according to VDE 0530 REM / IEC 34.1 with relative tolerances
(5) Total output with a tolerance of +/- 8 %
(6) According to above parameters (1) through (5)
(7) Only valid for engine and generator; module and peripheral equipment not considered
(8) Exhaust temperature with a tolerance of +/- 5 %

Radio interference level
The ignition system of the gas engines complies the radio interference levels of CISPR 12 and EN 55011 class B, (30-75 MHz, 75-400 MHz, 400-1000 MHz) and (30-230 MHz, 230-1000 MHz), respectively.

Definition of output
- ISO-ICFN continuous rated power:
  Net break power that the engine manufacturer declares an engine is capable of delivering continuously, at stated speed, between the normal maintenance intervals and overhauls as required by the manufacturer. Power determined under the operating conditions of the manufacturer's test bench and adjusted to the standard reference conditions.
- Standard reference conditions:

Barometric pressure:	14.5 psi (1000 mbar) or 328 ft (100 m) above sea level
Air temperature:	77°F (25°C) or 298 K
Relative humidity:	30 %

- Volume values at standard conditions (fuel gas, combustion air, exhaust gas)

Pressure:	1 atmosphere (1013.25 mbar)
Temperature:	60°F (15.56°C)

Output adjustment for turbo charged engines
For plants installed at >1640.5 ft (500 m) above see level and/or intake temperature > 86 °F (30 °C) the reduction of engine power is determined for each project.

If the actual methane number is lower than the specified, the knock control responds. First the ignition timing is changed at full rated power. Secondly the rated power is reduced. These functions are done by the engine management.

Parameters for the operation of GE Jenbacher gas engines

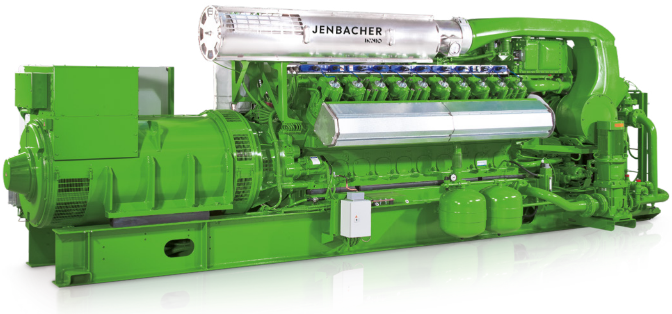
The following "Technical Instruction of GE JENBACHER" forms an integral part of a contract and must be strictly observed: **TI 1100-0110 – TI 1100-0112**

JENBACHER INNIO

JENBACHER TYPE 4

An efficiency milestone

Based on the proven design concepts of types 3 and 6, the modern Jenbacher type 4 engines in the 800 to 1,500 kW power range are characterized by a high-power density and outstanding efficiency. The enhanced control and monitoring provide easy preventive maintenance, high reliability and availability.

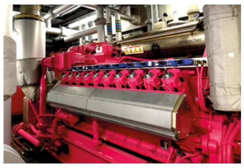


Reference installations

J420 St Bart's Hospital in London, United Kingdom

Energy Source	Engine type	Electrical output	Thermal output	Commissioning
Natural gas	1 x J420	1,480 kW	1,624 kW	2015

Since 2015, one of the oldest hospitals in the UK has obtained cooling, heat and power from a single J420 unit. The 1.4 MW cogeneration unit includes a 250 kW absorption chiller that delivers cooling water to the hospital. The J420 engine is the cornerstone of a new energy center that has provided the facility with financial savings by boosting its energy efficiency, reliability and durability.



J420 Ashford Power Peaking Plant in Kent, United Kingdom

Energy Source	Engine type	Electrical output		Commissioning
Natural gas	14 x J420	21 MW		2018

The electricity generating peaking plant at Ashford Power, Kings North Industrial Estate in Kent is operating 14 containerized Jenbacher J420 engines. When not in operation, the engines of this fully-automated plant wait on standby, prepared to be called upon and ramped up in less than two minutes.

J420 SV.CO Strijbisverbeek Greenhouse in Maasdijuk, the Netherlands

Energy Source	Engine type	Electrical output	Thermal output	Commissioning
Natural gas	1 x J420	1,501 kW	1,996 kW	2018

The Strijbisverbeek Greenhouse in Maasdijuk, Netherlands, is relying on a total greenhouse CHP solution consisting of a Jenbacher J420, a complete exhaust gas system incl. catalytic reactor for CO_2 and acoustical enclosure. The energy generated in this greenhouse is used to operate its grow lights. Additionally, they are using the heat of the CHP to heat up their greenhouse in colder periods and at night.

J420 Biogas Plant in Nakornrachasrima, Thailand

Energy Source	Engine type	Electrical output		Commissioning
Biogas	5 x J420	7,105 kW		2012

The Chok Yuen Yong facility profits from its five J420 engines that provide reliable on-site power while also reducing electrical and energy costs. The excess electricity produced is supplied to the public grid.

Technical features

Feature	Description	Advantages
Heat recovery	Flexible arrangement of heat exchanger, two stage oil plate heat exchanger on demand	- High thermal efficiency, even at high and fluctuating return temperatures
Gas dosing valve	Electronically controlled gas dosing valve with high degree of control accuracy	- Very quick response time - Rapid adjustment of air / gas ratio - Large adjustable calorific value range
Four-valve cylinder head	Enhanced swirl and channel geometry using advanced calculation and simulation methods (CFD)	- Reduced charge-exchange losses - Central spark-plug position resulting in optimal cooling and combustion conditions
Crack connecting rod	Applying a technology—tried and tested in the automotive industry—in our powerful stationary engines	- High dimensional stability and accuracy - Reduced connecting rod bearing wear - Easy to maintain

Technical data

Configuration			V 70°
Bore (mm)			145
Stroke (mm)			185
Displacement / cylinder (lit)			3.06
Speed (rpm)			1,800 / 1,200 (60 Hz) 1,500 (50 Hz)
Mean piston speed (m/s)			7.4 (1,200 1/min) 9.3 (1,500 1/min) 11.2 (1,800 1/min)
Scope of supply			Generator set, cogeneration system, generator set / cogeneration in container
Applicable gas types			Natural gas, flare gas, biogas, landfill gas, sewage gas. special gases (e.g., coal mine gas, coke gas, wood gas, pyrolysis gas)
Engine type	J412	J416	J420
No. of cylinders	12	16	20
Total displacement (lit)	36.7	48.9	61.1

		Dimensions l x w x h (mm)
Generator set	J412	5,400 x 1,800 x 2,200
	J416	6,200 x 1,800 x 2,200
	J420	7,100 x 1,900 x 2,200
Cogeneration system	J412	6,000 x 1,800 x 2,200
	J416	6,700 x 1,800 x 2,200
	J420	7,100 x 1,800 x 2,200
Container	J412	12,200 x 3,000 x 2,700
	J416	12,200 x 3,000 x 2,700
	J420	12,200 x 3,000 x 2,700

		Weights empty (kg)
Generator set	J412	11,200
	J416	13,500
	J420	17,200
Cogeneration system	J412	11,800
	J416	14,100
	J420	17,800

Outputs and efficiencies

Natural gas		1,500 1/min | 50 Hz					1,800 1/min | 60 Hz					1,200 1/min | 60 Hz				
NOx <	Type	Pel (kW)[1]	Pt (kW)[2]	ηel (%)[1]	ηth (%)[2]	ηtot (%)	Pel (kW)[1]	Pt (kW)[2]	ηel (%)[1]	ηth (%)[2]	ηtot (%)	Pel (kW)[1]	Pt (kW)[2]	ηel (%)[1]	ηth (%)[2]	ηtot (%)
500 mg/m³N	J412	901	928	43.4	44.6	88.0	851	960	41.6	46.9	88.5	630	618	42.8	41.9	84.7
	J416	1,202	1,244	43.4	44.9	88.3	1,141	1,281	41.8	46.9	88.7	846	824	43.0	41.9	85.0
	J416	1,000	1,029	43.3	44.6	87.9										
	J420	1,561	1,656	43.7	46.3	90.0	1,429	1,602	41.9	46.9	88.8	1,057	1,029	43.0	41.9	84.9
	J420	1,561	1,833	42.4	49.7	92.1										
250 mg/m³N	J412	901	967	42.1	45.2	87.4	851	1,003	40.6	47.9	88.5	630	641	41.8	42.5	84.4
	J416	1,202	1,285	42.3	45.2	87.5	1,141	1,338	40.8	47.9	88.7	846	856	42.1	42.6	84.7
	J416	1,000	1,046	42.7	44.7	87.4										
	J420	1,502	1,606	42.7	45.6	88.3	1,429	1,648	41.2	47.5	88.7	1,057	1,085	41.7	42.8	84.6
	J420	1,561	1,906	41.4	50.5	91.9										

Biogas		1,500 1/min | 50 Hz					1,800 1/min | 60 Hz				
NOx <	Type	Pel (kW)[1]	Pt (kW)[2]	ηel (%)[1]	ηth (%)[2]	ηtot (%)	Pel (kW)[1]	Pt (kW)[2]	ηel (%)[1]	ηth (%)[2]	ηtot (%)
500 mg/m³N	J412	749	750	42.1	42.2	84.3					
	J412	901	919	42.6	43.5	86.1	851	916	41.1	44.2	85.3
	J412	934	914	43.3	42.3	85.6					
	J416	999	993	42.3	42.1	84.4					
	J416	1,202	1,221	42.8	43.5	86.2	1,141	1,220	41.3	44.2	85.5
	J416	1,248	1,225	43.3	42.4	85.7					
	J420	1,498	1,524	42.7	43.4	86.2	1,429	1,527	41.4	44.2	85.7
	J420	1,561	1,548	43.3	42.9	86.2					
250 mg/m³N	J412	889	922	42.0	43.6	85.6	851	933	40.4	44.3	84.7
	J416	1,190	1,229	42.2	43.5	85.7	1,141	1,237	40.6	44.0	84.7
	J420	1,487	1,537	42.1	43.6	85.7	1,429	1,556	40.7	44.3	85.0

[1] Technical data according to ISO 3046
[2] Total heat output with a tolerance of +/- 8%, exhaust gas outlet temperature 120°C, for biogas gas outlet temperature 180°C

All data according to full load and subject to technical development and modification. Further engine versions available on request.

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