TOOLS FOR THE CONTROL OF SHIP EMISSIONS AND ENERGY AND THE NEW IMO REGULATIONS

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ABSTRACT

With the fast increase in oil price, the fuel costs now account for up to 50 % of a ship operating costs in some sectors and trades. Simultaneously shipping industry is becoming under pressure to reduce GHG (Green House Gases) emissions like CO2, being already under way a number of mechanisms such as MBI's (Market Based Instruments) based on Emission Trading Schemes (a carbon tax system) and the IMO MEPC (Marine Environment Protection Committee) MEPC.1/Circ.684 from 17 August 2009. This work addresses the latest regulations but also introduces the tools ship owners need to implement such as energy and emissions reduction plans. EETI (Energy Efficiency Transport Index) is introduced as an index to effectively translate the ship energy operation efficiency, instead of EEOI that do not account for fuel quality delivered to the vessel. The paper also presents and analyses real ship energy and emissions data, gathered by VEEO (Voyage Energy and Emissions Optimizer), an author developed ship energy and emissions performance monitoring system installed on board 25 container vessels.

Keywords: CO_2, VEEO, IMO MEPC

1. INTRODUCTION

"The one that does not measure has only a vague idea."

Engine manufacturers have continuously made an effort to optimize their engines specific fuel oil consumption, e.g., through the implementation of concepts such as variable valve timing, pulsed injection, new materials metallurgies resulting in higher thermal efficiencies. However, despite the extraordinary engine technology advances more than 50% of the ship energy input is wasted Figure 1 and Table 1.

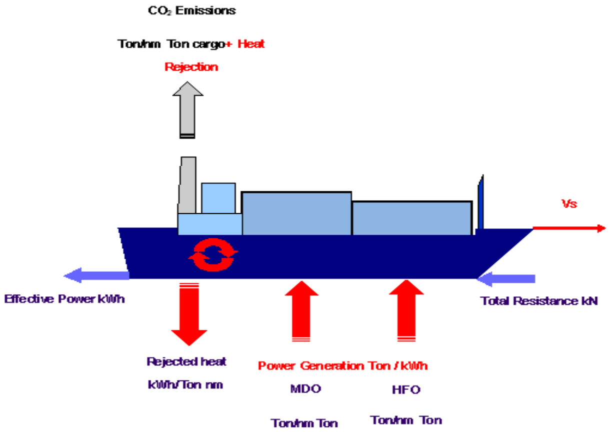

Figure 1: The whole energetic system.

Although ships are the most fuel and emissions efficient mode of mass transport see figure 2, the Second IMO GHG Study 2009 identified a significant potential for further improvements in way the energy is used on board therefore impacting on the ship operation energy efficiency mainly by the use of already existing technologies.

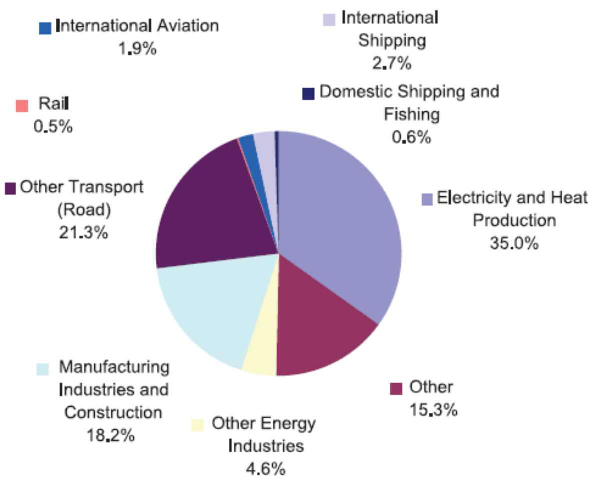

Figure 2: Emissions of CO_2 from shipping compared with global total emissions (Source, 2nd GHG Study 2009,IMO)

Additional improvements in hull, engine and propeller designs, together with reduction in operational speed, may lead to considerable reductions as illustrated in the figures below.

2. THE SHIP AS A WHOLE ENERGY SYSTEM

Looking at a ship as a "whole energy" system, and based on the recent operational data, only around 27% of the energy input for propulsion is effectively used to propel the most ships, this is illustrated in Figures 1 and 3.

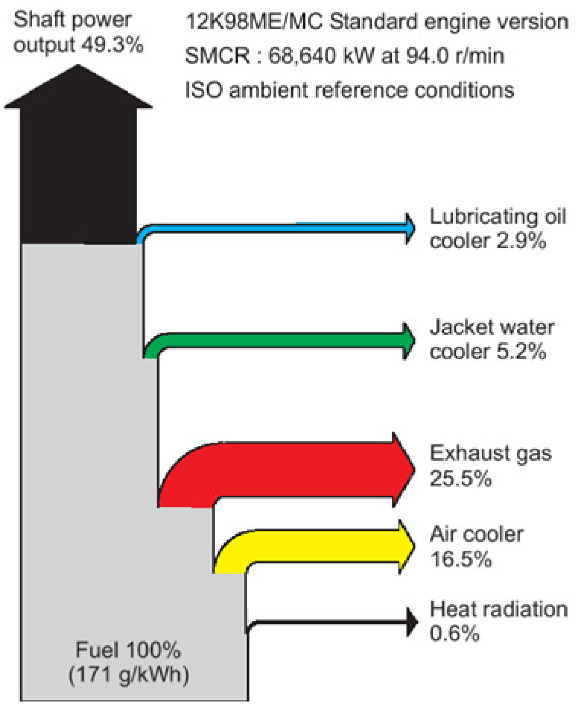

Figure 3: Sankey diagram of a two stroke 12K98ME/MC engine rated to MCR:68,640kW.

Considering the engine itself, energy flows are illustrated on the Sankey diagram of figure 2, which considers one of the most common two stroke engines in use at sea today, while table 1, summarizes the energy flows and their thermal quality.

Table 1: Heat quality and associated power

Main Engine	% Heat rate	Temperature (°C)	Heat (kW)
Lub Oil	2,9	90	1.990
Jacket water cooling	5,2	85	3.569
Exhaust gases	25,5	300	17.503
Air cooling	16,5	150	11.325
Radiation	0,6	-	835

As it is evident, from the above mentioned figures and table, approximately 50% of the energy input is available, but only a percentage of it, the one with high quality is recovered today for auxiliary ship services, or by using "power take in systems" may be recovered a maximum of 10% that may be used for propulsion purposes.

There are direct relationships between fuel consumption, carbon content and emissions as listed in table 2.

Table 2 Relationship between fuel type, fuel carbon content and resulting CO_2 emissions.

Type of fuel	Reference	Carbon Content	CF (t-CO2/t-Fuel)
Diesel/ Gas oil GO	ISO8217 Grades DMX to DMC	0.875	3.206000
Light Fuel Oil LFO	ISO8217 Grades RMA to RMD	0.86	3.151040
Heavy Fuel OIl HFO	ISO8217 Grades RME to RMK	0-85	3.114400
Liquified Petroleum Gas	Propane Butane	0.819-0.827	3.000000 3.030000
Liquified Petroluem Gas LNG		0.75	2.750000

Therefore, the ship owner will be stressed by two costs, the cost of the fuel, as it is available on the market, and the cost of the taxes over the ship CO_2 emissions. So, in case some better use of fuel consumption is achieved, the ship owner will be less penalized twice, as simultaneously becomes more competitive on his trade.

3. IMO GHG ACTIVITIES

IMO's working group on Greenhouse Gas Emissions (GHG) from ships developed a number of studies to highlight the measures to enhance energy efficiency of the shipping in general. The group defined an Energy Efficiency Design Index (EEDI) for new ships and it is already testing and debating the Energy Efficiency Operational Index (EEOI), which is focused on ships in operation. A draft for Ship Energy Management Plan (SEMP) resulted from the group meeting in March 2009 with the aim to improve the efficiency of the international shipping, by defining a number of indices.

EEDI (Energy Efficiency Design Index) objective is to stimulate innovation and the technical development of all the elements influencing the energy efficiency of a ship, thus making possible to build more energy-efficient ships in the future.

EEOI (Energy Efficiency Operational Index) objective is to enable ship operators to measure the energy efficiency of their ships. This index is expressed in tons of CO_2 per ton mile. The index translates the efficiency of specific ship, thus enabling comparisons between similar ships.

$$Average\ EEOI = \frac{\sum_i \sum_j (FC_{ij} \times C_{FJ})}{\sum_i (m_{cargo\ i} \times D_i)}$$

Where:

• j is the fuel type;

• i is the voyage number;

• FC_{ij} is the mass of consumed fuel j at voyage i;

• CF_j is the fuel mass to CO_2 mass conversion factor for fuel j;

• m_{cargo} is cargo carried (tons) or work done (number of TEU or passengers) or gross tons for passenger ships;

• D is the distance in nautical miles corresponding to the cargo carried or work done.

SEMP (Ship Energy Management Plan) objective is to incorporate the best practices into the operation of each ship, including voyage planning, speed and power optimization, optimized ship handling, improved fleet management, cargo handling and energy management.

EEOI calculation of a ship in operation has been recommended but it is not compulsory yet, and this can be calculated manually, using spread sheets and crew handled data.

SEEMP reproduces the actions taken by the ship operator to optimize the ship operation in terms of energy; however these actions can be arranged in groups according to their cost and technical and economic feasibility.

ETEI (Energy Transportation Efficiency Index) this is an author proposed index, to evaluate the energy efficiency of a ship operation. As EEOI is dependent on the fuel Net Calorific Value fuels with lower NCV, would originate higher CO_2 productions than fuels with higher NCV, therefore having an negative impact on the EEOI masking the energy efficiency of a ship.

$$Average\ ETEI = \frac{\sum_i \sum_j (FC_{ij} \times NCV_{FJ})}{\sum_i (m_{cargo\ i} \times D_i)}$$

Where:

• NCV_{FJ} is the Net Calorific Value of the fuel j;

Therefore the units of ETE would be:

$$\frac{kWh}{Ton \times NM}$$

ETEI expresses, effectively the quantity of energy used per Ton of cargo nautical mile.

In case EEOI is to be used in any carbon taxation scheme, it should be corrected and evaluated together with ETEI index to produce some type of correction for the NCV, remembering that most of the times, the fuel quality in use it is not corresponding to quality the ship operator requested, but the quality available.

Also ETE, reflects directly the results of the ship energy management effort towards a lean operation.

4. EEDI IMPLICATIONS ON THE EEOI

$$EEOI = \frac{\text{Emissions of } CO_2(CO_2\text{ton})}{\text{Volume of Transportation (ton } \times \text{ nautical mile)}}$$

From the above equation it is possible to understand that EEOI, has a strong dependence on performance and operation of the vessel, being penalized by the project decisions at the design stage taken for each ship, whereas the operation plays only a partial role.

Many authors suggested the possibility of changing some ship components and physical characteristics to obtain, the improvements that were not considered at the design stage, like propellers, and in some cases the hull forms. However, most of the existing ships exist before the quasi compulsory environmental positions, being the result of a compromise between what was requested and what was delivered.

The energy saving actions for existing ships can be categorized into three categories, the first corresponding to those actions that can be implemented without cost or very little cost, such as operation of Diesel generators, Correction of power factor, Luminaries of better quality, Good voyage planning, Slow steaming with optimization of respective engine, inside the second category may be considered the propeller re-pitch, or enhanced paint schemes, and finally on the third category fall those actions that have higher costs such as the application of heat recovery systems, or the modification of hull lines just to mention some. To decide if these actions may be taken forward, a clear knowledge of the ship operational energy profile is required to sustain the technical and economic decisions. As per Figure 4, it can be seen that a great deal of research effort has been done in areas of energy deterioration such as propeller efficiency, wave generation and air resistance, calling for costly and in most cases non feasible solutions such as hull lines modifications, having a low potential for energy recovery or optimization. However the by inspection of Figure 4, one can conclude that 57% of the ship energy input is wasted. The potential for energy recovery from these two energy flows it is much bigger than from the all other energy flows.

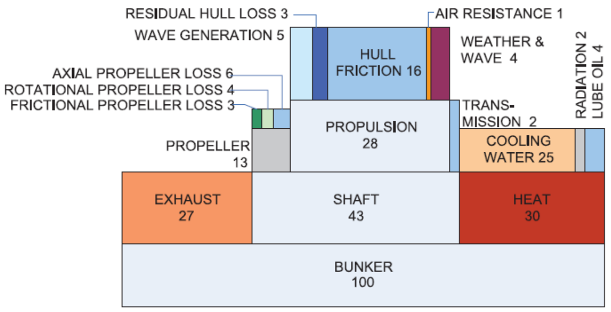

Figure 4: Use of propulsion energy on board a small cargo ship, head sea, Beaufort 6. (Source, 2nd GHG Study 2009,IMO)

To achieve reasonable energy recoveries, it is necessary to integrate the ship systems as much as possible at the design stage, and on the existing ones it is required the monitoring of the energy flows to characterize and decide in view of the ship remaining life the energy and emissions reducing actions that can be economically taken. To account to this requirement, TecnoVeritas designed ship energy monitoring system named VEEO Voyage Energy & Emissions Optimizer.

5. HOW TO GATHER THE REQUIRED DATA TO SUPPORT THE INVESTMENTS ON ENERGY ACTIONS.

"The one that does not measure has only a vague idea."

First of all, the ship operator needs to know as much as reliably how the cost of fuel will be for his ship expected future, then he needs to know how and where the energy is used on board, and therefore how it will be the impact of each energy saving action on its operational costs. Such information must be credible and for that, it must be derived from the ship itself from a period of characterization adequately long of the ship operation in its typical trade route.

To accomplish such an objective TecnoVeritas as been working with two major ship operators towards the development of a system called VEEO (Voyage Energy & Emissions Optimizer) for energy management of their fleets. The VEEO systems comprise hardware and intelligent software, acquiring data from the energy input and output flows of the various ship machinery, such as main engines generators, boilers and incinerators. One other complimentary activity has been the ship energy audits, in such a way that reliable ship operation data is always captured for further analysis and monitoring of ship improvements. The system is being installed on board 24 container vessels from APL, some of them with capacities of 4000 TEU, operating worldwide. VEEO is answering the IMO MEPC.1/Circ684 of 17 of August 2009, and it is type approved by a major classification society.

VEEO is acquiring, treating and logging the main engines fuel consumption data throughout the ship operation allowing the correct characterization of the ship energy "behavior" in its various routes, but also allowing the use of such data to base corrective actions, as well as energy improvement actions. Parameters such as propeller shaft energy transferred to the propeller, propeller thrust, power production on alternators, ship speed, nautical miles, all different fuels usage, engines performance, boiler performance, incinerators performance, trim, and weather condition, are all integrated in ship data bases. VEEO is also taking care of fuel bunkering operations and fuel management, and allows the ship's crew (once trained) to decide upon good practices on energy management actions, as the ship's crew has access to the ship´s real time ships energy consumption and emissions.

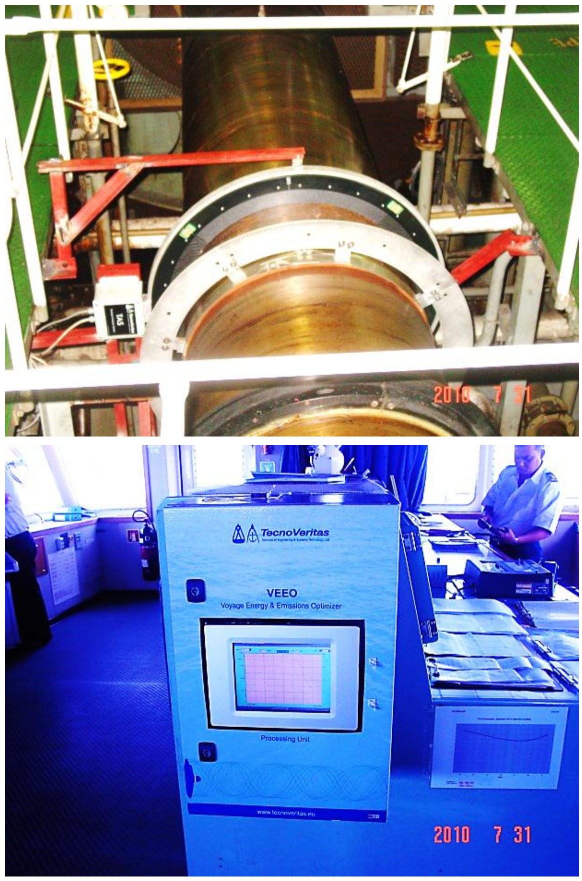

Figure 5: Bridge VEEO cabinet and shaft torque and thrust meter.

In the annex Figures 6 to 8 show typical time chart type of graphs, which are continuously displayed at the bridge and engine control room, allowing the ship officers to take energy corrective actions.

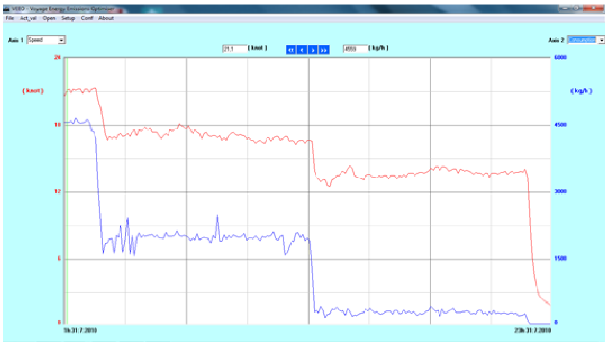

Figure 6: Ship speed and main engine fuel consumption.

Figure 7: Main engine shaft power & Hull resistance versus time.

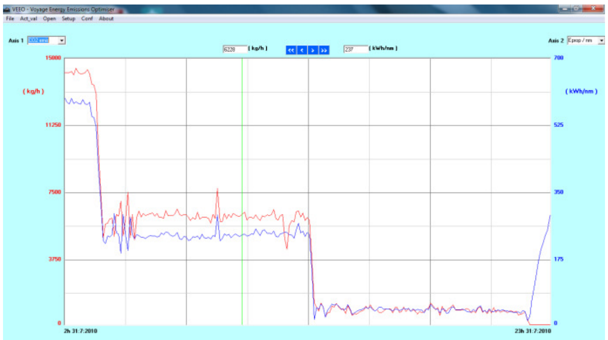

Figure 8 - CO_2 (kg/h) & Propulsion Energy per nm as a function of time.

One important factor for ship energy characterization is the called and defined by IMO Circ 684, as **"Rolling average indicator"** As a ship energy efficiency management tool, the rolling average indicator, when used, should be calculated by use of a methodology whereby the minimum period of time or a number of voyages that is statistically relevant is used as appropriate. **"Statistically relevant"** means that the period set as standard for each individual ship should remain constant and be wide enough so the accumulated data mass reflects a reasonable mean value for operation of the ship in question over the selected period.

Figures 9 and 10 and Tables 3 and 4 refer to a container ship which the main engine is developing 50MW shaft power at its MCR, displacing 50 000DWT traveling at a speed, varying between 15 and 20knots, during 16 hours of navigation. As it can be seen, the accumulated CO_2 emissions, differ for the same period of navigation time and operational conditions in as much as 22.9 Ton due to the difference in the calorific value of the fuels in use respectively of 42 000kJ/kg and 40 000kJ/kg (note that the conditions for the 42 000kJ/kg were simulated to ensure the same operational conditions). Despite the energy consumption of the ship (EETI = kWh/(TonxNM)) remains the same, the emissions increase significantly when using a fuel with a lower net calorific value. Therefore, the EEOI cannot be considered a valid energy indicator, neither should be used to charge the ship operators, as it depends on the NCV of the available fuels, unless it is corrected by the EETI or at least accompanied by the EETI. Complete and accredited fuel certificates may be a possible solution to implement to access ships energy efficiency.

The EETI expresses the energy used to transport a quantity of cargo through a distance, but also expresses how efficient is the ship operation reflecting the effort of using less energy for the same mission task.

5. CONCLUSIONS

Ship owners will be pushed to lean energy ship operation, not only because of energy costs, but also because of stringent emissions regulations but also because of emissions market mechanisms.

To achieve fuel costs reductions it is important and fundamental to properly characterize the ship in its operation profiles, that can be done during a first stage by energy audits implementation but for a long term compliance with coming maritime emissions international laws, through the installation of on line monitoring systems, that take the ship as a whole energy system, allowing the energy optimization of the ship operation at a glance. However, the need for ship energy management staff training it is of highest importance, as a fleet optimization plan, needs to handle enormous amounts of data and also decisions.

Another important aspect is that of the Net Calorific Value of the fuels has a direct impact on the quantity of the fuel being used during the voyage, and therefore on the CO_2 emission, as this is calculated based on the mass of fuel used. Therefore, fuel Net Calorific Values need also to be considered, being recommended a new index, the ETEI (Energy Transportation Efficiency Index) a ship operation energy efficiency indicator, expressed in kWh/(Ton cargo NM). This proposed index reflects the effort of the ship energy management into reach a lean operation. In case EEOI is to be used for taxation on CO_2 it should be complemented with the respective ETEI.

Ships energy costs are better controlled at the design stage with maximum integration of ship systems, and by implementation of design decisions that otherwise cannot be implemented on existing units due to excessive costs.

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Annex:

Table 3: Hourly EETI, EEOI, Fuel Consumption and CO2 Emissions displayed by VEEO (Net Calorific Value = 40 000 kJ/kg).

Hours of Navigation [h]	Conditions	EETI [kWh/(ton Carga X NM)]	EETI Rolling Average [kWh/(ton Carga X NM)]	EEOI [ton CO2/(ton Carga X NM)]	EEOI_Rolling Average [ton CO2/(ton Carga X NM)]	Fuel Consumption [Ton]	Cumulative Fuel Consumption [Ton]	Emissions of CO2 [Ton CO2]	Emissions of CO2_Cumulative [Ton CO2]
1	HFO RMK Fair Weather	0,111	-	0,000031144	-	10,0	10,0	31,14	31,1
2	HFO RMK Fair Weather	0,111	0,111	0,000031144	0,000031144	10,0	20,0	31,14	62,3
3	LFO RME Fair Weather	0,121	0,116	0,000034451	0,000032798	8,2	28,2	25,84	88,1
4	LFO RME Fair Weather	0,121	0,119	0,000034451	0,000033625	8,2	36,4	25,84	114,0
5	LFO RME Fair Weather	0,121	0,120	0,000034451	0,000034038	8,2	44,6	25,84	139,8
6	LFO RME Fair Weather	0,121	0,121	0,000034451	0,000034245	8,2	52,8	25,84	165,6
7	HFO RMK	0,111	0,116	0,000031144	0,000032694	10,0	62,8	31,14	196,8
8	HFO RMK	0,111	0,114	0,000031144	0,000031919	10,0	72,8	31,14	227,9
9	HFO RMK bad weather	0,202	0,158	0,000056504	0,000044212	12,7	85,5	39,55	267,5
10	HFO RMK bad weather	0,202	0,180	0,000056504	0,000050358	12,7	98,2	39,55	307,0
11	HFO RMK bad weather	0,202	0,191	0,000056504	0,000053431	12,7	110,9	39,55	346,6
12	HFO RMK bad weather	0,202	0,196	0,000056504	0,000054968	12,7	123,6	39,55	386,1
13	HFO RMK Fair Weather	0,111	0,154	0,000031144	0,000043056	10,0	133,6	31,14	417,3
14	HFO RMK Fair Weather	0,111	0,132	0,000031144	0,000037100	10,0	143,6	31,14	448,4
15	HFO RMK Fair Weather	0,111	0,122	0,000031144	0,000034122	10,0	153,6	31,14	479,6

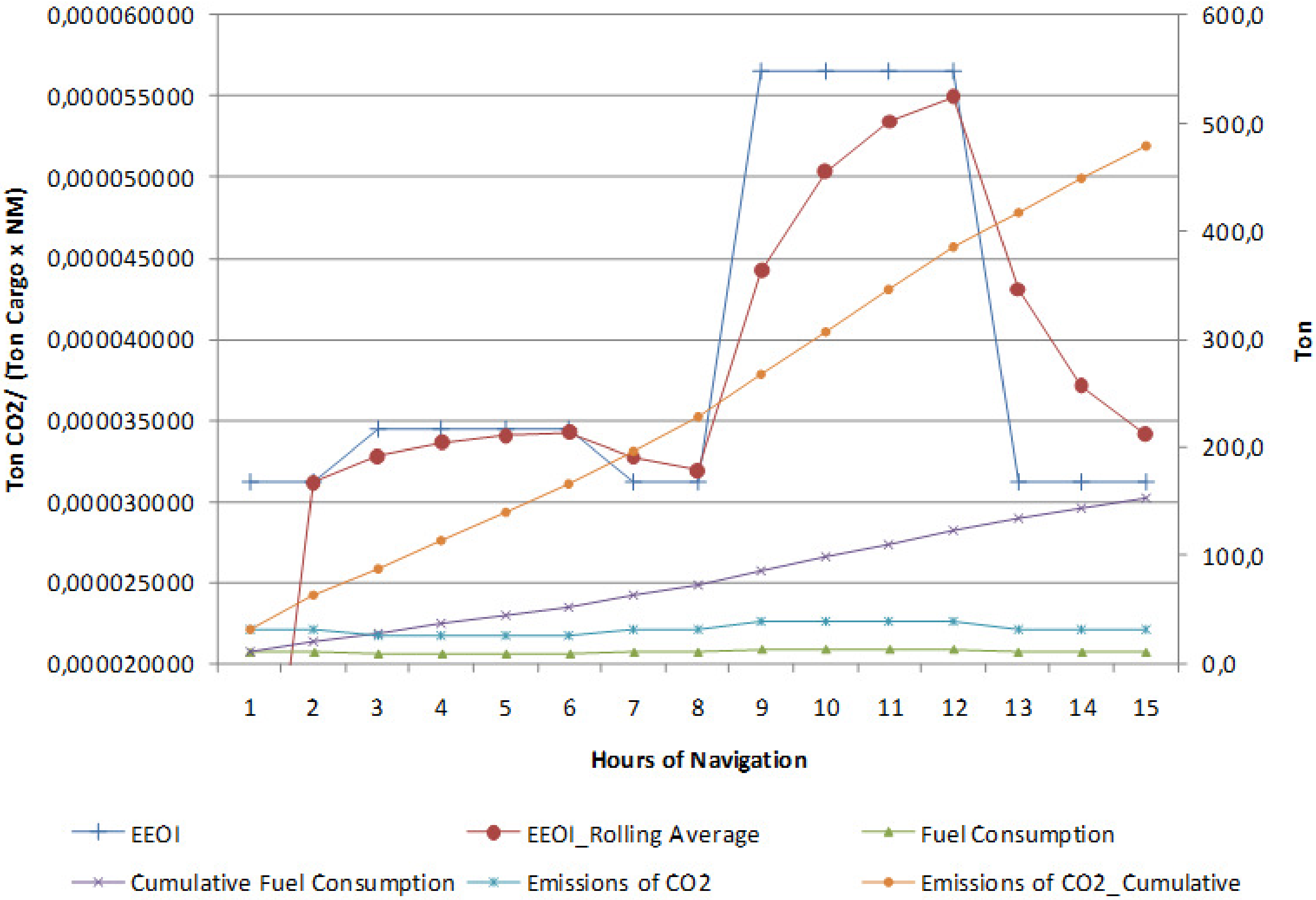

Figure 9: Hourly Specific Consumption, EEOI, Fuel Consumption and CO2 Emissions displayed as a function of time for 16 hours of navigation, (Net Calorific Value = 40 000 kJ/kg).

Table 4: Hourly EETI, EEOI, Fuel Consumption and CO_2 Emissions displayed by VEEO (Net Calorific Value = 42 000 kJ/kg)

Hours of Navigation [h]	Conditions	EETI [kWh/(ton Carga X NM)]	EETI Rolling Average [kWh/(ton Carga X NM)]	EEOI [ton CO2/(ton Carga X NM)]	EEOI_Rolling Average [ton CO2/(ton Carga X NM)]	Fuel Consumption [Ton]	Cumulative Fuel Consumption [Ton]	Emissions of CO2 [Ton CO2]	Emissions of CO2_Cumulative [Ton CO2]
1	HFO RMK Fair Weather	0,111	-	0,000029661	-	9,5	9,5	29,7	29,7
2	HFO RMK Fair Weather	0,111	0,111	0,000029661	0,0000296610	9,5	19,0	29,7	59,3
3	LFO RME Fair Weather	0,121	0,116	0,000032811	0,0000312359	7,8	26,9	24,6	83,9
4	LFO RME Fair Weather	0,121	0,119	0,000032811	0,0000320234	7,8	34,7	24,6	108,5
5	LFO RME Fair Weather	0,121	0,120	0,000032811	0,0000324171	7,8	42,5	24,6	133,1
6	LFO RME Fair Weather	0,121	0,121	0,000032811	0,0000326140	7,8	50,3	24,6	157,8
7	HFO RMK	0,111	0,116	0,000029661	0,0000311375	9,5	59,8	29,7	187,4
8	HFO RMK	0,111	0,114	0,000029661	0,0000303992	9,5	69,3	29,7	217,1
9	HFO RMK bad weather	0,202	0,158	0,000053813	0,0000421063	12,1	81,4	37,7	254,7
10	HFO RMK bad weather	0,202	0,180	0,000053813	0,0000479599	12,1	93,5	37,7	292,4
11	HFO RMK bad weather	0,202	0,191	0,000053813	0,0000508867	12,1	105,6	37,7	330,1
12	HFO RMK bad weather	0,202	0,196	0,000053813	0,0000523501	12,1	117,7	37,7	367,8
13	HFO RMK Fair Weather	0,111	0,154	0,000029661	0,0000410055	9,5	127,2	29,7	397,4
14	HFO RMK Fair Weather	0,111	0,132	0,000029661	0,0000353332	9,5	136,8	29,7	427,1
15	HFO RMK Fair Weather	0,111	0,122	0,000029661	0,0000324971	9,5	146,3	29,7	456,7

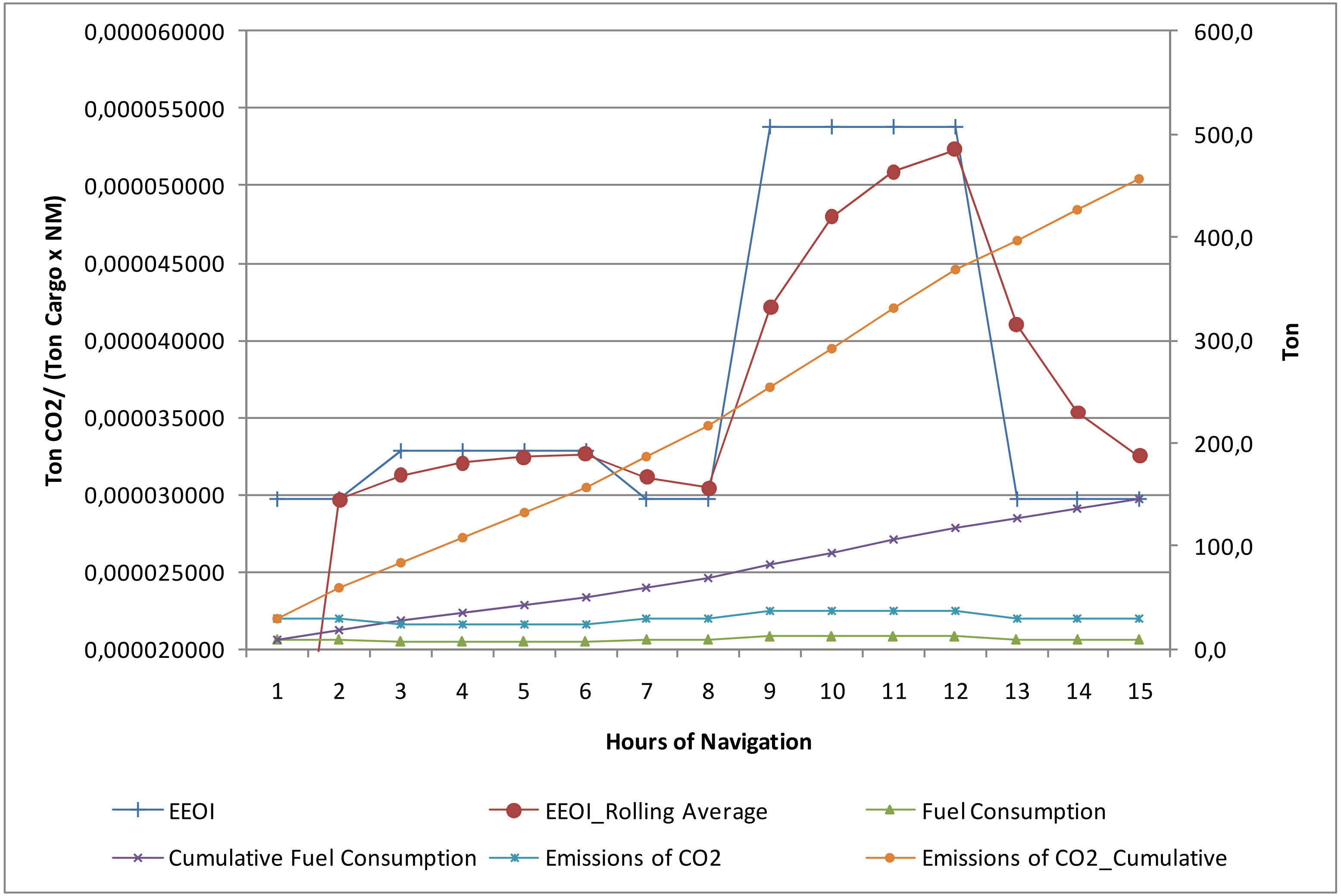

Figure 10: Hourly Specific Consumption, EEOI, Fuel Consumption and CO_2 Emissions displayed as a function of time for 16 hours of navigation, (Net Calorific Value = 42 000 kJ/kg).