A New Method of Determining Energy Efficiency Operational Indicator for Specialized Ships

Katarzyna Prill 1, Cezary Behrendt 1*, Marcin Szczepanek 1,* and Iwona Michalska-Pożoga 2

1 Institute of Marine Power Plants, Maritime University of Szczecin, ul. Waly Chrobrego 1-2, 70-500 Szczecin, Poland; k.prill@am.szczecin.pl (K.P.); c.behrendt@am.szczecin.pl (C.B.)
2 Department of Mechanical Engineering, Koszalin University of Technology, Raclawicka 15-17, Koszalin 75-620, Poland; iwona.michalska-pozoga@tu.koszalin.pl
* Correspondence: m.szczepanek@am.szczecin.pl; Tel.: +48-602-692-578

Received: 2 February 2020; Accepted: 24 February 2020; Published: 1 March 2020

Abstract: Limitation of CO₂ emission is one of the main goals and regulations introduced by the international institutions’ rules. In the case of ships using oil-related and gas fuels this problem is dealt with by the International Maritime Organization (IMO) introducing the methodology of Energy Efficiency Operational Indicator (EEOI) determining for ships being under exploitation. The methodology allows for determining EEOI for seven types of ships, for which the value of this index depends on the amount of transported cargo or number of passengers, type of and amount of fuel used, as well as distance travelled by the ship. Such a methodology cannot be used for the specialized ships, whose exploitation tasks are different to the ships of the trade fleet that transport the cargo or the passengers. The methodology allows for determining EEOI for seven types of ships and it does not include specialized ships. The article presents a new methodology of determining EEOI for specialized ships that takes the characteristics of their exploitation into consideration. The way of its use has been presented taking into account the results of exploitation studies carried out on the chosen research and training ship. Obtained results and their analysis allowed for energy efficiency assessment of research and training ships depending on exploitation tasks, voyage time, type of fuel used, distance travelled and ship’s speed. EEOI index value determines energy efficiency of the vessel power system that is directly connected to the amount of the liquid or gas fuel used and the amount of emitted CO₂. The aim should be to minimalize the value of EEOI index through planning of the exploitation tasks realization order and adjusting the speed of the ship as well as realization time of particular exploitation tasks, in the case of specialized ships. The analysis results can also be used when managing energy efficiency of these types of ships.

Keywords: specialized vessels; energy efficiency operational indicator; energy efficiency management

1. Introduction

The problem of the increasing level of greenhouse gases’ emission to the atmosphere which is an effect of the exploitation of ships has been analyzed by the scientific community and international institutions already for several years.

Within the last fifty years the level of significance of the marine transport branch has considerably risen and has made it earn the reputation as the most efficient and eco-friendly type of transport in the world [1]. Regardless of that opinion, it needs to be pointed out that as a result of fuel combustion in marine power systems, the emission of exhaust gases which are harmful and dangerous for living organisms and the natural environment takes place in the atmosphere. These compounds include: carbon dioxide (CO₂), sulphur oxides (SOx), nitrogen oxides (NOx), carbon oxide (CO), hydrocarbons (HC) and particulate matter (PM) [1–5].
Carbon dioxide (CO₂) belongs to a group of chemical compounds released to the atmosphere as a result of the combustion process of petroleum-derivative fuels and is classified as GHG, which contributes to changes in the natural environment, including the emergence of the phenomenon called the greenhouse effect.

The projected CO₂ emissions generated by the shipping sector amount to about 2.2%–3% of the world level, which is about 800 Mt CO₂ annually [6–8]. These values were determined on the basis of data from the global monitoring of the level of greenhouse gas emissions carried out by the International Maritime Organization (IMO) in 2012. Smith et al. [9–11] predict that in the absence of an effective policy to reduce CO₂ emissions, between 2012 and 2050, the level of CO₂ emissions may increase from 50% to 250%, as shown in Figure 1.

Figure 1. Prognosis of the CO₂ emission level to the atmosphere generated by the world shipping industry since 1990 in the perspective to the year 2050 assuming that no measures to minimize CO₂ emission level are taken [12].

Negative effects of the impact of CO₂ on the natural environment has contributed to the introduction by international institutions, including institutions directly related to the shipping sector, solutions aimed at reducing CO₂ emissions to the atmosphere, and thus reducing global temperature of the environment to the one set in the Paris Agreement [13–18] at 1.5 °C above the temperature in the pre-industrial era [19].

Legal regulations concerning limitation of emissions of harmful exhaust gases (NOx, SOx, PM) by ships to the atmosphere contain detailed guidelines referring to specific solutions aimed at reducing emissions to specific values within a given period [20–24].

In the case of CO₂, so far, the IMO has not presented particular values for emission of this compound, nor the time period in which the world shipping industry is supposed to limit the emission.

The effect of IMO’s work was development and implementation of voluntary and mandatory assessment tools and methods for improving energy efficiency, which, combined with each other, would help to reduce CO₂ emissions [25–34].

Taking CO₂ emissions from ships in operation into consideration, IMO developed the Energy Efficiency Operational Indicator (EEOI) [35,36] as a tool for determining the energy efficiency of a ship and then monitoring during its operation. EEOI was defined as the ratio of the mass of CO₂ emitted by a ship to a specific unit of work. This tool has been recommended for use for a group of seven types of ships that carry cargo and passengers [31]—this group was called a group of transporting vessels.

\[
EEOI = \frac{\text{actual CO}_2 \text{ emission}}{\text{performed transport work}}
\]  

(1)
Depending on the type of the vessel, IMO defines “performed transport work” as [31]:

- Mass of the cargo taken on board in (t), for bulk carriers, general cargo ships, tankers and gas carriers;
- Number of containers taken on board (TEU) or total weight of containers accepted on board (t), for container ships;
- Number of units (cars, railway wagons or combinations thereof) taken on board in the case of ro-ro ships);
- Number of passengers accepted on board (pcs.) or gross tonnage (GT) in the case of passenger ships, and the distance nautical miles (nm) that the ship made when carrying the cargo or passengers.

The current emission of CO\textsubscript{2} that appears in the numerator of Equation (1) is connected to the amount of fuel used on the ship and its type (liquid and gas vessel fuels have been taken into consideration). Therefore, minimizing CO\textsubscript{2} will depend on the type of the fuel used and its use, mainly depending on the power of the ship’s main engine. Thus, the shipowners introduce ship’s exploitation in slow stimming conditions, when the main engine is exploited continuously with the power below 50%–Maximum Continuous Rating (MCR). However, the performer transport work notion occurring in the denominator of Equation (1) is the product of the transported cargo in tons and travelled distance. Therefore, the shipowners should maximize the amount of transported cargo for each cruise and shorten the travelled distance by planning the route and order of ports in which the ship cargo is loaded and unloaded.

In order to determine the EEOI for one trip in accordance with [31], use the following Equation (2):

$$EEOI = \frac{\sum F_{C} C_{Fj} m_{cargo} D_j}{m_{cargo} D_j}$$

where:  
- \(j\)–type of fuel the vessel is powered with and \(F_{Cj}\), mass of fuel used during the voyage and \(C_{Fj}\)–CO\textsubscript{2} mass conversion coefficient for the fuel j, and \(m_{cargo}\)–mass of the shipped cargo or number of transported passengers and \(D_j\) a distance, in which a cargo or passengers have been transported increased by the distance during which the ship sailed “under ballast”.

The IMO has adopted the principle that the EEOI should achieve values as close to zero as possible, therefore a low EEOI relationship that defines the high energy efficiency of the ship is formed.

On the basis of the analysis of the state of knowledge in the scope of determining the level of energy efficiency, problems in determining the EEOI for specialized vessels were observed. These ships constitute about 35% of the world’s number of vessels and about 1% of world tonnage [37] and as Lützen at al. [38] proved, the application of the methodology to determine the EEOI coefficient becomes debatable due to the significant diversity of this group of vessels in terms of construction, operation and different priorities (most often economic reasons) of the shipowner or charterer [39].

The wide range of services determines the specialization of these vessels [40]. In most cases, they have been designed and built to carry out specific works such as research, assistance at drilling platforms, rescue service, training, towing assistance, dredging, etc. [41].

With regard to specialized vessels, the criteria for time, speed and distance made must be perceived differently, since they affect the amount of fuel consumed by the ship. The task of transporting vessels is to transport as much cargo as possible, as quickly as possible to the required distance, what is also associated with specific speeds set as optimal based on internal and external conditions occurring at a given time.

The purpose of specialized vessels is to perform an operational task, the result of which does not have to depend on its duration or speed. As an example of such an operation, a long-term stop at an anchor or in drift of ships assisting drilling platforms can be recalled, since they, after reaching a designated place, remain on the alert. Other vessels, such as research ships, seismic vessels or cable-ships, must move at low speeds and navigate with high precision when using, for example, a dynamic positioning system. Rescue vessels are a deviation from the aforementioned assumption,
since they remain on alert until the task is completed. This task is usually a rescue operation, during which the response time and the speed at which the ship moves are of the utmost importance. To sum up, in the case of specialist vessels, the implementation of a specific task is related to the achievement of extreme speed or time necessary for its performance in comparison with the transporting vessels, where criteria affects the level of fuel consumption.

When analyzing the applicability of the coefficient determined by Equation (2) for a specialized vessel, it was noted that it was difficult to determine the correct relationship between the loss and the profit in terms of energy efficiency. The loss of the natural environment, in the case of specialized vessels, similarly to transporting vessels, should be understood as the mass of CO\textsubscript{2} emitted. Regardless of the type of task performed, the ship uses fuel, therefore emits chemical compounds resulting from the combustion process (including CO\textsubscript{2}) to the atmosphere. In terms of profit, one should understand performed transport work. In the case of a group of specialized vessels, the term refers to the performed operational task.

The structure of tools for assessing the energy efficiency of ships, including EEOI recommended by IMO, is characterized by large autonomy of the shipowner’s decisions in the process of their design and implementation, as well as when deciding upon the appropriateness of their use in relation to a particular type of ship. The application of the methodology recommended by the IMO to determine the EEOI coefficient for specialized vessels is a problem due to the low or zero values of performed transport work, which may thus indicate inadequate values (with respect to the real ones) of the quantified level of ship’s energy efficiency.

Considering the existing gap in the definition of EEOI for specialized vessels, the EEOI research for EEOI for fishing vessels and energy audits of ships \cite{42} and research facilities in the form of a research and training vessel, which is organized by the Maritime University of Szczecin, the methodology for determining and monitoring the level of energy efficiency for specialist vessels has been developed and verified in the article.

2. The Developed Methodology for Determining Energy Efficiency Operational Indicator for Specialised Vessels (EEOI\textsubscript{SP})

The way of determining EEOI\textsubscript{SP} is based on the calculation of the ratio of the mass of CO\textsubscript{2} emitted to the atmosphere to the work performed by the ship defined as commissioned and performed the exploitation task in the time function (Equation (3))

\[
EEOI_{SP} = \frac{Z_{pi}C_{Fi}}{\sum_{j=1}^{n} w_{ij}t_{sj}}D
\]

where: \(i\)—fuel type and \(Z_{pi}\)—mass of fuel used during realization of the exploitation task and \(C_{Fi}\)—coefficient of conversion of CO\textsubscript{2} weight for type \(i\) fuel, the coefficients being indicated in the resolution IMO, MEPC.1/Circ. 684 and \(j\)—exploitation state and \(t_{sj}\)—duration of a given exploitation state, where the duration of the operational status is calculated on the basis of entries in the Ship’s Logbook or taken directly from vessel identification systems such as AIS and \(w_{ij}\)—coefficient of significance \(j\) of exploitation state and \(D\)—distance made during which a specific exploitation task was performed.

In the achieved Equation (3), the numerator’s identity was retained after the numerator from the popular formula for determining the EEOI \cite{31}, recommended by IMO i.e., no changes were made to indicate the CO\textsubscript{2} emission level, because irrespective of the type of ship and the work done by it, during exploitation, it burns fuel and emits CO\textsubscript{2} to the atmosphere.

However, a new approach has been adopted to determine the applied in the nominative formula (3) performed transport work, which refers directly to specific exploitation states and the degree of their significance for a given commissioned exploitation task carried out by a specialized vessel in a time function \cite{41,43}.
The exploitation state can be defined as "a string of instantaneous values of variable state parameters expressing the features (properties) of a given object considered to be relevant for a given problem" [44]. A. Sowa defines the exploitation state also as a descriptive attribute defining the phase of the exploitation process, that is the phase of using or operating the object [44]. The ship’s exploitation states are a key element in the implementation of the exploitation task, the correct identification of which is necessary to determine the EEOI coefficient.

The exploitation task of a specialized ship consists of a unique combination of different or repeated operating states. Each of these states has an impact on the proper implementation of the exploitation task. The degree of significance of a given exploitation state in the implementation of the task was expressed by means of the coefficient of significance of the exploitation status $w_i$.

The coefficient $w_i$ of a given exploitation state is a value defining the level of impact of a given operational status on the implementation of an exploitation task over time. Its value depends therefore on the ratio of the product of the duration of a given exploitation state and the weight significance level $p_s$ of this state to the duration of the ship’s exploitation task (4):

$$w_i = \frac{t_sp_s}{t_c}$$

where: $t_c$—duration time of exploitation state and $t_c$—total duration time of exploitation state and $p_s$—weight level of significance of a given exploitation state.

The significance level $p_s$ occurring in Equation (4) is a dimensionless value describing the degree of influence of a given exploitation state on the performance of an exploitation task by a specialized ship, whereby $p_s$ is determined by the owner or the charterer for each exploitation state for a specific exploitation task. The shipowner or specialist charterer can designate $p_s$ using two methods. The choice of method depends on the organizational structure of the owner/charterer:

- Determining $p_s$ in a subjective way by the person responsible for indicating the ship’s exploitation task;
- Determining $p_s$ by means of expert opinions (a similar method was used, for example, in [45,46]).

Under the definition of an expert, it should be understood in this case a person on behalf of the shipowner or (and) a charterer involved in the operation of a specialized vessel (including directly from the owner).

Determining $p_s$ should be preceded by a survey, but it is recommended that in the case of a shipowner or a charterer, whose organization is less than 30 employees involved in the operation of a specialized ship, consult the entire population. Taking into account the structure of the formula, it was assumed that the values of $p_s$ assigned in the course of the survey were in the range of integers from 1 to 5, where 1 is the exploitation state of the highest significance for the performance of the exploitation task, and 5 is the exploitation state of the lowest significance for realization of the exploitation task.

The adopted range of $p_s$ values was determined on the basis of two assumptions:

- The value scale should be "user-friendly", i.e., it should not be too wide and should concentrate in the integer range;
- Hierarchization of the scale should take into account the main rule related to the EEOI coefficient, i.e., the pursuit of the smallest possible values.

To determine the significance level $p_s$, the PERT method known from the literature was taken into account, including the weighted average for the beta distribution according to Equation (5) [47]:

$$p_s = \frac{n_{min} + 4n + n_{max}}{6}$$

where: $n_{min}$—minimum significance value for a given exploitation state indicated by experts and $n$—value of exploitation state significance most often indicated by experts and $n_{max}$—maximum value of significance for a given exploitation state indicated by experts.
The introduction of the scale of $p_s$ values expressed by experts allows to maintain the objectivity of the process, eliminating the subjective perception of the significance of this state for the performance of the exploitation task by experts [46].

For the purposes of further research, the method of determining $p_s$ with the help of expert opinions was used.

3. Applications of the Method for the Selected Research and Training Ship

For the purpose of validation of the presented method, a specialist research and training vessel m/s Navigator XXI, whose shipowner is the Maritime University of Szczecin, was selected. During the selection of the vessel, the following criteria were observed:

1. Tasks realization mode—m/s XXI Navigator performs tasks continuously, all year round, based on a specified schedule;
2. Independence from the value of $m_{cargo}$ coefficient—the object of the research is not a transport vessel;
3. Independence from the exploitation character on the speed—the object of the research is not exploiting for the determined, optimal speed;
4. Independence of the nature of exploitation from the distance made—exploitation activity of the object of the research is characterized by high variability of distance made during the voyage;
5. Using another way of supply in the home port—the vessel in the home port uses on-land power supply;
6. Availability—availability of the ship to conduct studies, run necessary documentation, source data and employees taking part in exploitation of the vessel.

m/s Navigator XXI is a ship with a length of 60.33 m, a width of 10.50 m, a draft of 3.15 m and a (GT) capacity of 1245 t. The speed of the ship when immersed is about 3 m in deep water and about 13 knots at 90% (MCR—Maximum Continuous Rating) of the main propulsion engine. The ship is equipped with a four-wing controllable propeller with a diameter of 2260 mm [48,49].

Power supply system of the research object includes the following elements [48]:

1. Main propulsion engine: one medium speed inline, engine SULZER HCP 8S20D type, with 8 in line cylinder, turbocharged. The maximum continuous power MCR is 1160 kW, while the speed at the MCR is 900 rpm, the unit fuel consumption at 85% MCR is 189 g/kWh with a tolerance of +3%;
2. NOVAPREX 820 type ship water boiler with rated power of 82 kW, equipped with a pressure burner with mechanical spraying, automatically controlled and in the range of heating water temperature changes of 60 °C/95 °C;
3. Two main diesel generators, each of which consists of a self-excited power generator with automatic voltage regulators and of high speed four-stroke CAT 3406 TA diesel engine with 240 kW MCR power and fuel consumption of 202 g/kWh rotational speed 1500 rpm and parameterized power output—3 × 380 V, 50 Hz;
4. Emergency generator unit—consisting of a three-phase self-excited generator, synchronous with automatic regulation, with the power of 85 kW and rotational speed 1500 rpm. The generator is powered by a four-stroke internal combustion engine, of high-speed, with a water cooled radiator system. The emergency unit is not adapted to work in parallel with other generating sets.

The vessel is authorized to conduct navigation on unlimited waters. In addition to a permanent crew of 11 people, it is able to accommodate 38 apprentices and scientists on board.

The research-training ship m/s XXI Navigator performs two types of exploitation tasks. The first task is the implementation of maritime practice, required by the International Convention of the International Convention on Standards of Training, Certification and Watchkeeping (STCW) [50], during which trainees carry out the tasks specified in this legal act and the internship curriculum.
Students of the Faculty of Navigation and Marine Engineering of the Maritime University of Szczecin during their stay on the ship perform basic, preparatory maritime practices in the on-board and machine department, curricular practices in the subject navigation (navigational cartography), ship maneuvering practices, practices related to the exploitation of marine energy systems, practices including sea rescue and fire protection. Apprenticeships take place in various conditions of the ship’s operation, i.e., when the vessel is at anchor, drifting, swimming at different speeds and changing courses at different times of the day.

The exploitation task related to the implementation of sea practices is performed after the trainees have been trained in accordance with the assumptions of the internship curriculum.

The second type of exploitation task carried out by the research object is conducting scientific research related mainly to hydrographic measurements, seabed and underwater infrastructure inspections, and the preparation of maps of the sea bottom environment. In the case of this exploitation task, it is required that the ship moves at a specified speed—up to 5 knots on the designated route, usually in a continuous mode until the measurement phase is completed (depending on the type of tests conducted, the vessel can move at a low speed from a few to several dozen hours). In the case of tests, additional energy receivers in the form of research devices are connected to the ship’s energy system. It should be noted that in the case of this exploitation task, the energy consumption on the ship increased, which resulted in increased CO$_2$ emission to the atmosphere. The implementation of this exploitation task is largely dependent on hydrometeorological conditions encountered on the tested water basin, which affects the measurement quality. In the case of a higher state of the sea than assumed or undulating, the ship does not carry out its task and waits for the weather conditions to improve, or a decision to return to the port is made.

Due to the greater number of exploitation tasks occurring in the examined time interval consisting in the implementation of maritime practices, e.g., described as training, the $EEOI_{SP}$ coefficients for these tasks were determined.

Identification of Exploitation States of the Test Object During the Realization of the Exploitation Task Training

For the needs of the research, on the basis of exploitation data obtained from the Ship’s Logbooks of the research object, exploitation states of the research and training ship were identified, the characteristics of which are presented in Table 1.

All exploitation states presented in Table 1 during exploitation of operating objects in time function. The duration of the operating system can be determined based on the following source data:

- On the basis of notes from the Ship’s Logbook;
- It can be downloaded directly from the electrical systems, which register the exploitation degree of the ship, such as Automatic Identification System (AIS), or Voyage Data Recorder (VDR).

The realization of an exploitation task is often connected with the necessity of frequent changes in exploitation states in various combinations. In this case, operating conditions can change at high frequency. Therefore, when specifying the duration of a given exploitation state, in order to avoid skipping the operating status of short duration, it is recommended to use the time (min). An additional argument in favor of using this unit of time is the situation in which, in the case of the use of registering electronic systems, the registration of operating data of the ship takes place in minute intervals.
Table 1. Exploitation states of the research and training ship m/s Navigator XXI realized during sea practice.

| Ship's Exploitation State | Power Supply System Exploitation State | Additional Information |
|---------------------------|---------------------------------------|------------------------|
|                           | Main Engine ME | Diesel Generator no.1 SP₁ | Diesel Generator no.2 SP₂ | Ship Boiler KO |                        |
| Ship maneuver m/W/E/WY     | yes           | yes                     | yes                     | yes           | Maneuvers of entry into port and leaving port, variable speed of the ship |
| Maneuver practice pMAN     | yes           | yes *                   | yes *                   | yes           | Course and speed of the ship are variable |
| Sea voyage p              | yes           | yes *                   | yes                     | yes           | Maximum speed of the ship - 11 knots |
| Stop while drifting d     | no            | yes *                   | yes                     | yes           | Ship does not realize any exploitation task |
| Stop at anchor kS          | no            | yes *                   | yes                     | yes           | Ship realizes an exploitation task i.e., trainings, classes with students, drills, etc. |
| Stop at port hS           | no            | yes *                   | yes                     | yes           | Ship realizes an exploitation task i.e., trainings, classes with students, drills, etc. |

* working, - not working. + during this exploitation state only one diesel generator is enabled, the decision on which diesel generator will be enabled is made by the chief engineer; ** CO₂ emission during realization of this state is included in the power plant emission budget.

4. Survey Results Analysis

In order to determine the EEOI_{SP} using Equation (3), it is necessary to calculate individual components of the formula.

4.1. Determining Weight of Statistical Significance Level (p_s) of Exploitation States

In order to determine the weight of the statistical significance level of exploitation states of the research object, a survey of 12 employees of the Maritime University of Szczecin was conducted. These 12 participants were the population of positions in the shipowner’s organization affecting the vessel’s exploitation tasks. The elements of the Delphi method with targeted polling were used to conduct the survey. The questionnaire form contained eight exploitation states of the research object (presented in Table 1) previously defined by the authors and the respondents were asked for a brief explanation of the motives for the evaluation of individual exploitation states.

The results of the questionnaire, contained in 12 surveys completed by the individual respondents, are presented in Table 2.

Data included in Table 2 present how important each exploitation state is for each of the respondents. Based on the results of the survey, n_{min}, n, n_{max} values were determined for each exploitation state. For example, for the m/W/E/WY state (entry/exit maneuvers from the port), according to the respondents’ opinions, the minimum value of this state is n_{min} = 1, the maximum value of n_{max} = 5, while the most frequent value was n = 1.

After determining the value n_{min}, n, n_{max} for each exploitation state and using Equation (5), the weight values of significance levels p_s for the exploitation states of the test object were calculated. The results of calculations are presented in Table 3.
Table 2. Significance levels of exploitation states in the opinions of the respondents.

| No. Surveys | 1 ** | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-------------|------|---|---|---|---|---|---|---|
| mWE/WY      | 1*   | 1 | 3 | 5*| 3 | 5 | 3 | 4 |
| pMAN        | 1    | 2 | 1 | 5 | 3 | 5 | 3 | 3 |
| p           | 1    | 1 | 2 | 3 | 2 | 5 | 2 | 2 |
| k           | 2    | 1 | 3 | 4 | 2 | 4 | 2 | 4 |
| kS          | 5    | 5 | 5 | 5 | 5 | 3 | 3 | 5 |
| h           | 5    | 5 | 5 | 5 | 2 | 5 | 2 | 5 |
| hS          | 3    | 5 | 5 | 1 | 1 | 1 | 1 | 3 |
| d           | 1    | 3 | 1 | 5 | 5 | 5 | 5 | 5 |
|             | 1    | 3 | 1 | 2 | 3 | 3 | 3 | 3 |
|             | 1    | 2 | 3 | 3 | 3 | 3 | 3 | 3 |

* 1 points represent the highest significance level, and 5 points represent the lowest significance level, ** mWE/WY—maneuvers of entry to port n leaving port, pMAN—maneuver practice, p—sea voyage, k—stop at the anchor without realization of exploitation task, kS—stop at the anchor during which exploitation tasks are realized h—stop at port without realization of exploitation task, hS—stop at port, during which exploitation task was realized, d—staying drifting.

Table 3. Weight significance level for the identified exploitation states of the research object.

| Exploitation State | Minimum Significance Level Value for a Given Exploitation State, $n_	ext{min}$ | Maximum Significance Level Value for a Given Exploitation State, $n_	ext{max}$ | Significance Level Value of the Exploitation State Most Often Point out $n$ | Weight Significance Level of the Exploitation State $p_s$ |
|--------------------|---------------------------------|---------------------------------|---------------------------------|----------------------------------|
| mWE/WY             | 1                               | 5                               | 1                               | 1.67                             |
| pMAN               | 1                               | 5                               | 1                               | 1.67                             |
| p                  | 1                               | 5                               | 3                               | 3                               |
| k                  | 1                               | 5                               | 5                               | 4.33                            |
| kS                 | 1                               | 5                               | 2                               | 2.33                            |
| h                  | 1                               | 5                               | 5                               | 4.33                            |
| hS                 | 1                               | 5                               | 3                               | 3                               |
| d                  | 2                               | 5                               | 3                               | 3.17                            |

From analyzing the values of the calculated weight significance levels of exploitation states presented in Table 3, it can be concluded that the highest values of the weight significance level, and thus the least important, are the exploitation states that have no impact on the performance of the exploitation task, i.e., stop at the anchor k ($p_s = 4.33$) and stop at the port h ($p_s = 4.33$).

4.2. Determining EEOI$_{SP}$

In order to determine the energy efficiency of the specialized ship, studies during realization of 65 exploitation tasks of the research object were conducted in the years 2015–2017.

The distance made during the implementation of the exploitation task and the duration of individual exploitation states were determined on the basis of entries in the Ship’s Logbook, whereas the fuel consumption was based on the entries in the Machine Logbooks. It was assumed that the time of the exploitation task realization starts and ends at the home port in Szczecin and takes into account the stops of the ship on anchorages, stops in the port, and in roadsteads etc. Before the voyage is started, the stay of the ship in the home port is not included, due to the fact that in this time the vessel is supplied with power from the mainland.

To indicate the $p_s$ value for each exploitation state, the values from Table 3 were used, while Equation (4) was used to calculate the value $w_i$ for each exploitation state in the task. The value of EEOI$_{SP}$ for each exploitation task was calculated in accordance with Equation (3).
5. Discussion

Table 4 presents the results of tests and calculations of individual components of Equation (3) for a selected exploitation task.

Table 4. \(EEOI_{SP}\) value and exploitation task course on the route: Szczecin–Kiel–Szczecin, realized between 17 February and 27 February 2015, exploitation task type – training.

| Date            | Time       | Exploitation State | State Duration [min] | \(p_s\) | \(w_i\) | \(EEOI_{SP}\) [tCO\(_2\)/(min/nm)] |
|-----------------|------------|--------------------|----------------------|---------|---------|-----------------------------------|
| 3 March 2015    | 14:00:00   | entry/exit         | 240                  | 1.67    | 0.02    |                                   |
|                 | 18:00:00   | voyage             | 90                   | 3       | 0.01    |                                   |
|                 | 19:30:00   | stop at anchor     | 2360                 | 2.33    | 0.3     |                                   |
| 4 March 2015    | 00:00:00   | stop at anchor     | 2360                 | 2.33    | 0.3     |                                   |
|                 | 08:50:00   | voyage             | 810                  | 1.67    | 0.07    |                                   |
|                 | 20:20:00   | stop at anchor     | 5335                 | 2.33    | 0.67    |                                   |
| 6 March 2015    | 00:00:00   | voyage             | 1500                 | 3       | 0.24    |                                   |
|                 | 09:20:00   | stop at anchor     | 1080                 | 2.33    | 0.13    |                                   |
|                 | 13:00:00   | voyage             | 1500                 | 3       | 0.24    |                                   |
| 8 March 2015    | 15:35:00   | entry/exit         | 95                   | 1.67    | 0.01    |                                   |
| 9 March 2015    | 00:00:00   | stop at port       | 4035                 | 4.33    | 0.95    |                                   |
| 10 March 2015   | 00:00:00   | entry/exit         | 70                   | 1.67    | 0.01    |                                   |
|                 | 10:50:00   | manoeuvre practice | 1280                 | 1.67    | 0.12    |                                   |
| 12 March 2015   | 09:20:00   | stop at anchor     | 770                   | 4.33    | 0.18    |                                   |

Table 5 presents an excerpt from the research results and calculations carried out in accordance with the assumptions of the new methodology for determining the \(EEOI_{SP}\) coefficient for the analyzed exploitation tasks.
Table 5. Extract from the example results of the $EEOI_{SP}$ coefficient calculation for 60 exploitation tasks performed by the research object. Own study.

| Task No. | Voyage Period | Voyage Course | Time [min] | Distance [nm] | Fuel Consumption [t] | Number of Exploitation States | $p_{sle}$ | $w_{sle}$ | $EEOI_{SP}$ [tCO$_2$/(min/nm)] |
|----------|----------------|---------------|------------|--------------|----------------------|-------------------------------|----------|--------|---------------------------------|
| 1        | 17 February–27 February 2015 | Szczecin-Kiel-Szczecin | 14,065 | 491.6 | 12.33 | 13 | 2.28 | 0.07 | $1.05 \times 10^{-5}$ |
| 2        | 3 March–13 March 2015 | Szczecin-Kiel-Szczecin | 18,390 | 646 | 11.86 | 14 | 2.38 | 0.07 | $6.50 \times 10^{-6}$ |
| 3        | 17 March–27 March 2015 | Szczecin-Ronne-Szczecin | 12,735 | 1037 | 10.87 | 16 | 2.67 | 0.08 | $6.37 \times 10^{-6}$ |
| 4        | 14 April–22 April 2015 | Szczecin-Gdynia-Szczecin | 11,245 | 480.6 | 9.07 | 10 | 2.33 | 0.11 | $6.43 \times 10^{-6}$ |
| 15       | 3 August–14 August 2015 | Szczecin–Świnoujście-Flensburg-Szczecin | 14,895 | 552.7 | 11.64 | 15 | 2.42 | 0.08 | $6.12 \times 10^{-6}$ |
| 16       | 24 August–28 August 2015 | Szczecin-Szczecin | 4495 | 168.2 | 4.45 | 5 | 2.33 | 0.21 | $2.16 \times 10^{-5}$ |
| 28       | 26 April–29 April 2016 | Szczecin–Kolobrzeg-Szczecin | 4290 | 167.4 | 4.2 | 7 | 2.24 | 0.18 | $1.66 \times 10^{-5}$ |
| 29       | 3 May–6 May 2016 | Szczecin-Szczecin | 3940 | 137.2 | 3.5 | 9 | 2.63 | 0.18 | $2.57 \times 10^{-5}$ |
| 30       | 15 May–22 May 2016 | Szczecin-Szczecin | 10,120 | 1090 | 17.3 | 7 | 2.43 | 0.16 | $5.29 \times 10^{-6}$ |
| 42       | 14 August–19 August 2016 | Szczecin–Flensburg-Szczecin-Szczecin | 6855 | 499.4 | 8.65 | 7 | 2.43 | 0.2 | $5.07 \times 10^{-6}$ |
| 44       | 5 September–07 September 2016 | Szczecin-Szczecin | 2575 | 99.3 | 2.65 | 5 | 1.8 | 0.2 | $2.28 \times 10^{-5}$ |
| 45       | 13 September–16 September 2016 | Szczecin-Szczecin | 3550 | 283.6 | 5.91 | 7 | 2.81 | 0.23 | $2.66 \times 10^{-5}$ |
| 58       | 24 April–28 April 2017 | Szczecin–Świnoujście-Szczecin | 5040 | 443 | 6.51 | 12 | 2.89 | 0.13 | $1.91 \times 10^{-5}$ |
| 59       | 8 May–11 May 2017 | Szczecin-Szczecin | 3375 | 169.5 | 3 | 7 | 2.43 | 0.22 | $1.70 \times 10^{-5}$ |
| 60       | 16 May–21 May 2017 | Szczecin-Gdynia-Szczecin | 7095 | 558.4 | 8.48 | 13 | 2.44 | 0.1 | $1.49 \times 10^{-5}$ |

Figure 2 using the data included in Table 5 presents the results of exploitation research regarding the determination of the $EEOI_{SP}$ coefficient for 60 exploitation tasks of a research and training vessel. While analyzing the quantified level of energy efficiency for individual exploitation tasks, it was found that the longer the duration of a given exploitation task, the lower the $EEOI_{SP}$ coefficient, and thus the higher energy efficiency of the ship assuming:

$$EEOI_{SP} \downarrow \text{ when } t \geq 5300 \text{ min}$$

$$EEOI_{SP} \uparrow \text{ when } t \leq 2200 \text{ min}$$

with the average values defining the duration of the exploitation task, the relationship described above does not have a clear impact. It was found that for tasks falling within the medium-term range, the value of the $EEOI_{SP}$ coefficient reached divergent values. Analyzing the test results, analogously to the impact of the duration of the exploitation task on the energy efficiency level of a specialist ship, it can be assumed that the greater distance covered by the test object during the performance of the exploitation task, the lower the value of the $EEOI_{SP}$ coefficient, and thus higher efficiency ship’s energy. However, attention should be paid to the operating characteristics of the vessel and, above all, the type of exploitation task it performs. The distance made by the ship should be analyzed in terms of its impact on the energy efficiency of the vessel only if the purpose of the task is directly related to this indicator. In other cases, it should be assumed that the distance made affects the level of the ship’s power efficiency, because it involves certain operating states, without which the performance cannot
be met, but its impact on the efficiency level is not as significant as the impact of the duration of such a task;

Based on the analysis of the results of the conducted research, the following advantages and disadvantages of the proposed methodology for determining the energy efficiency level of a specialist ship $EEOI_{SP}$ were identified.

**Figure 2.** $EEOI_{SP}$ value computed for 60 exploitation tasks of a research and training vessel analyzed between 2015 and 2017 [Own study].

Advantages of the methodology for determining the energy efficiency level of a specialized ship $EEOI_{SP}$:

1. Methodology developed for specialized vessels—the methodology takes into account the diversity and exploitation characteristics of specialized vessels;
2. The methodology does not take into account the mass of the load—the proposed methodology is different from the previous method and defines the concept of "performed transport work". It is dependent on the notion of benefit from the mass of the transported load making the notion of profit independent from the mass of transported cargo. This action avoids problems with the interpretation of the method recommended by IMO for non-transport vessels;
3. Versatility of use—thanks to the concentration of the methodology assumptions for the main purpose of specialized ships, this methodology can be applied to all specialized vessels regardless of the type of exploitation task performed, provided that exploitation states and significance levels are identified for each task;
4. Simplicity—the proposed methodology was based on the ship’s exploitation data, which are easily accessible to the owner/charterer. The methodology has been developed in such a way not to impede the work of people dealing with the energy efficiency of the ship;
5. Exploitation task—the methodology assumes an individual approach to identifying exploitation states of the vessel that are part of the ship’s exploitation task;
6. Possibility to determine energy efficiency for each exploitation state—the methodology assumes the possibility of determining the level of energy efficiency for each operating state being an
element of a combination of states in the exploitation task. Thanks to this, the owner/charterer can verify the effectiveness of the ship at every stage of exploitation;

7. Possibility of exploitation tasks’ planning—on the basis of average weight values of significance levels for the exploitation task and duration of individual exploitation states, the owner/charterer may design more effective exploitation tasks on the basis of exclusion or limitation of the duration of the low-significance state;

8. Autonomy in the decision of the shipowner/charterer—shipowner/charterer, as the structures most familiar with the operational characteristics of the vessel are responsible for identifying tasks and exploitation states and hierarchizing them relative to the level of significance for the task.

Disadvantages of the methodology for determining the energy efficiency level of a specialized ship EEOI\textsubscript{SP}:

1. Failure to take external influence into account—the methodology does not directly take into account the influence of external conditions on the energy efficiency of the ship (hydrometeorological conditions). The determination of EEOI\textsubscript{SP} with varying hydrometeorological conditions can be done after the selection of measurement data;

2. Difficulty in comparing exploitation tasks—due to the different combination of exploitation states with different significance levels occurring in the task and their course as a time function, the methodology is not recommended for comparative purposes of exploitation tasks;

3. Determining the significance levels of exploitation states—determining the value of \( p_s \) for individual exploitation states is associated with additional work;

4. Data sensitivity—exploitation data related to the exploitation of a given ship, including primarily the duration of a given exploitation state, should be carefully collected and transmitted. In another case, in relation to exploitation states of short duration, such states may be omitted in combination, which may result in a distorted picture of the ship’s energy efficiency;

5. Necessity to collect data within the prescribed time—if using the option of manual data collection (entries in the Ship Logbook and Machine Logbook), the personnel responsible for the supervision of documents should be properly trained in order to keep records in accordance with the applicable rules at appropriate time intervals.

6. Conclusions

The presented methodology of determining the energy efficiency of specialized ships fits into the EEOI\textsubscript{SP} research stream devoted to the energy efficiency of the ships. EEOI indexes developed and so far implemented by IMO concern ships transporting cargo and passengers. Applying the IMO-recommended method of determining the EEOI index with respect to specialized ships is problematic due to low or zero values of \( m_{\text{cargo}} \) index what can also depict high values of quantified level of ship’s energy efficiency level inadequate to the reality. From analyzing the EEOI index in the form recommended by IMO from the perspective of research and training ship exploitation, it has been shown that there is a distortion of the compromise between gain and loss, what in turn makes the ship seem to be ineffective energy-wise, regardless of CO\textsubscript{2} emission reducing tools and procedures used, minimization of the fuel used, or using on-land power supply during staying at port.

Applying into the formula exploitation tasks, energy system exploitation states directly connected to fuel consumption and determining weight level of exploitation states’ significance in order to determine EEOI\textsubscript{SP}, proposed in the method allowed for achieving the results that allow for Energy efficiency assessment taking into consideration exploitation specificity of this type of ship. Analyzing defined values of EEOI\textsubscript{SP} index (graphically presented in Figure 2) even a ten-fold difference between their minimum and maximum value can be observed. The analysis of cruises during which the highest values of EEOI\textsubscript{SP} have been noted showed that the reason was bad planning of exploitation tasks and order of their realization. The methodology implemented on the research and training ship, on which the studies have been carried out brings about the effects of lowering EEOI value by planning of
exploitation tasks order, their realization time, optimization of travelling routes and speed. Thanks to this a lower fuel consumption has also been noted.

The possibility of determining the level of energy efficiency for each exploitation state which is the element of a combination of states in the exploitation task allows for verification of the vessel efficiency on every stage of exploitation. This methodology can be applied to all specialized ships regardless of the type of realized exploitation task on condition that exploitation states and significance levels are identified for each task.

On the basis of average weight values of significance levels for the exploitation task and duration time of particular exploitation states one can, on the basis of excluding or limiting the duration time of low significance, develop more efficient exploitation tasks.

The scientific community dealing with a ship’s energy efficiency improvement by using EEOI focus on numerous aspects connected to this tool. For instance, the possibility of effective comparison of quantified level of energy efficiency for different travels and different ships is questioned. It is considered to be substituted by the possibility of determining the level of energy efficiency for the whole fleet. Additionally, the possibility of EEOI determining taking into consideration speed of the ship is being studied. Although, all these actions are focused on the main goal, namely limiting the amount of fuel consumed in vessel energy systems and CO₂ emission resulting from it, as well as increasing the value of performer transport work.

It is obviously justified to accept and implement in both national and international legislation all the methods of CO₂ emission limiting. It is a common practice that such new solutions are presented by the Nations—Parties at the meetings of IMO Committees, and then accepted and introduced to international and national legislation of other member states.

**Author Contributions:** Conceptualization, K.P., C.B. and M.S.; methodology, K.P., C.B. and M.S.; validation, K.P., C.B., M.S., and I.M.-P.; formal analysis, K.P., C.B., and M.S.; investigation, K.P., C.B. and M.S., and I.M.-P.; resources data curation, K.P., C.B. and M.S.; writing—original draft preparation, K.P. and C.B.; writing—review and editing, C.B.; M.S., and I.M.-P.; visualization, M.S.; and I.M.-P.; project administration C.B.; funding acquisition, C.B. and M.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** This research outcome has been achieved under the research project no. 2/S/IESO/2018 financed from a subsidy of the Polish Ministry of Science and Higher Educations for statutory activities of Maritime University of Szczecin.

**Conflicts of Interest:** The authors declare no conflicts of interest.

**References**

1. Hael, C.; Spinler, S. Capacity expansion under regulatory uncertainty: A real options-based study in international container shipping. *Transp. Res. Part E* 2018, 113, 75–93. [CrossRef]
2. Domański, T. To Nie Jest Dobra Wiadomość—Pobiliśmy Rekord Steżenia Dwutlenku Węgla w Atmosferze. 2017. Available online: https://www.spidersweb.pl/2017/05/stezenie-dwutlenku-wegla.html (accessed on 10 August 2019).
3. Giernalczyk, M. Metody redukcji emisji do atmosfery związków toksycznych oraz CO₂ przez statki. *Logistyka* 2014, 6, 655–665.
4. Jafarzeadeh, S.; Ellingsen, H. Environmental Regulations in Shipping: Interactions and Side Effects. In Proceedings of the International Conference on Ocean, Offshore and Arctic Engineering, Busan, Korea, 19–24 June 2016.
5. Mysłowski, J. *Analiza Wpływu Wybranych Parametrów Pracy Silnika Spalinowego na Zanieczyszczenie Powietrza;* Wydawnictwo Uczelniane Zachodniopomorskiego Uniwersytetu Technologicznego w Szczecinie: Szczecin, Poland, 2010; ISBN 978-83-7663-054-0.
6. Graichen, J.; Cames, M.; Cook, V. Key Issues at Stake at the 71st Session of IMO MEPC—Briefing. 2017. Available online: https://op.europa.eu/en/publication-detail/-/publication/1488b7dd-772c-11e7-b2f2-01aa75ed71a1/language-en (accessed on 12 August 2019).
7. IMO MEPC 68/INF. 24/Rev.1. The Existing Shipping Fleet's CO2 Efficiency; UCL Energy Institute: London, UK, 2015.
8. IMO ISWG-GHG 1/2/13 Consideration of How to Progress the Matter of Reduction of GHG Emission from Ships. 2017. Available online: https://www.transportstyrelsen.se/contentassets/d09234962cd4b39ab8b491bd8044c0a/1-2-5.pdf (accessed on 12 August 2019).
9. Smith, T.; O’Keeffe, E.; Aldous, L.; Agnolucci, P. Assessment of Shipping’s Efficiency Using Satellite AIS Data; Prepared for ICOT, UCL Energy Institute, University College London (UCL): London, UK, 2013.
10. Smith, T.W.P. Third IMO GHG Study 2014—Final Report, Maritime Environment Protection Committee. 2014. Available online: https://www.sjofartstidningen.se/assets/2017/06/Submission-IMO-reducing-GHG-emissions-from-ships-1.pdf (accessed on 12 August 2019).
11. Smith, T.; Rehmatulla, N. CO2 Emission Targets for Shipping, Full Report for Sustainable Shipping Initiative; UCL Energy Institute: London, UK, 2015.
12. Camens, M.; Graichen, V.; Faber, J.; Nelissen, D. Environmental Research of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety; Project No. (3711 45 104), Greenhouse Gas Emission Reduction Targets for International Shipping. 2015. Available online: https://www.oek.de/en/publications/?tx_kesearch_pi1%5Bfilter%5D%5B22%5D%5B512080%5D=Cames%20M (accessed on 24 July 2019).
13. Popkiewicz, M. IPCC o ograniczeniu wzrostu temperatury do 1.5 °C. Available online: http://naukaoklimacie.pl/aktualnosci/ograniczenie-ocieplenia-do-2c-nieralyony-otypyrmizm-naukowcow-117 (accessed on 8 June 2019).
14. Lyon, C. Complexity ethics and UNFCCC practices for 1.5 °C climate change. Environ. Sustain. 2018, 31, 48–55.
15. MacLachlan, S. Carbon Emissions All at Sea: Why was Shipping Left Out if the Paris Climate Agreement? 2016. Available online: http://oecdinsights.org/2016/05/04/carbon-emissions-all-at-sea-why-was-shipping-left-out-of-the-paris-climate-agreement/ (accessed on 25 July 2019).
16. U.N. Framework Convention on Climate Change. 1997. Available online: https://www.mos.gov.pl/g2/big/2009_04/e/e0542a9444bca0f9c7d2c2ce83d36.pdf (accessed on 5 July 2019).
17. U.N. Framework Convention on Climate Change 2016 r., DU UE L282. 2016. Available online: http://eur-lex.europa.eu/legalcontent/PL/TXT?uri=CELEX:22016A1019(01) (accessed on 9 June 2019).
18. Tobin, P.; Schmidt, N.M.; Tosun, J.; Burns, C. Mapping states’ Paris climate pledges: Analysing targets and groups at COP 21. Glob. Environ. Change 2018, 48, 11–21. [CrossRef]
19. Popkiewicz, M. Względem Okresu Przedprzemysłowego—co to Właściwie Oznacza? Available online: http://naukaoklimacie.pl/aktualnosci/wzgladem-okresu-przedprzemyslowego-co-to-wlasciwie-oznacza-236 (accessed on 12 July 2019).
20. Giernalczyk, M. Analiza możliwości redukcji emisji związków toksycznych oraz CO2 poprzez ograniczenie zużycia paliwa przez statki morskie. Zesz. Nauk. Akad. Mor. w Gdyni 2014, 83, 53–65. [CrossRef]
21. Gu, Y.; Wallace, S.W. Scrubber: A potentially overestimated compliance method for the Emission Control Area. The importance of involving a ship’s sailing pattern in the evaluation. Transp. Res. Part D 2017, 55, 51–66. [CrossRef]
22. MEPC. Amendments to the annex of the protocol of 1997 to amend the international convention for the prevention of pollution from ships, 1973, as modified by the protocol of 1978 relating Thereto. Amend. MARPOL Annex VI MEPC 2011, 70, 18.
23. MEPC.259(68)2015 Guidelines for Exhaust Gas Cleaning Systems. IMO. 2015. Available online: http://www.IMO.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/MEPC.259%2868%29.pdf (accessed on 12 July 2019).
24. International Convention for the Prevention of Pollution from Ships (MARPOL) 73/78, Consolidated Edition. 2015. Available online: http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx (accessed on 16 July 2019).
25. Szczepanek, M.; Prill, K. Process of Amendments to the Legal Acts Regarding Minimizing CO2 Emission by the Shipping Industry. In Proceedings of the 18 International Multidisciplinary Scientific Geo Conference SGEM 2018, Albena, Bulgaria, 2–8 July 2018.
26. Johnson, H.; Johansson, M.; Andersson, K.; Södahl, B. Will the IMO Ship Energy Efficiency Management Plan (SEEMP) Lead to Reduced CO2 Emissions? In Proceedings of the A comparison with ISO 5001 and the ISM Code, the IAME Conference, Taipei, Taiwan, 6–8 September 2012.
27. IMO Res. MEPC.213(63), 2012 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP). 2012. Available online: http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-%28MEPC%29/Documents/MEPC.282%2870%29.pdf (accessed on 17 July 2019).
28. IMO MEPC.233(65), 2013 Guidelines for Calculation of Reference Lines for Use with the Energy Efficiency Design Index (EEDI) for Cruise Passenger Ships Having Non-Conventional Propulsion. 2013. Available online: https://puc.overheid.nl/insi/doc/PUC_2061_14/1/ (accessed on 17 July 2019).
29. IMO MEPC.282(70), 2016 Guidelines for the Development of a Ship Energy Efficiency Management Plan (SEEMP). 2016. Available online: http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-%28MEPC%29/Documents/MEPC.282%2870%29.pdf (accessed on 19 July 2019).
30. IMO MEPC.1/Circ.212(63), Guidelines on the Method of Calculation of the Attained Energy efficiency Design Index (EEDI) for New Ships. 2012. Available online: http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-%28MEPC%29/Documents/MEPC.212%282012%29.pdf (accessed on 20 July 2019).
31. IMO MEPC.1/Circ.684, 2009 Guidelines for Voluntary Use of the Ship Energy Efficiency Operational Indicator (EEOI). 2009. Available online: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/Circ-684.pdf (accessed on 20 July 2019).
32. IMO MEPC.1/Circ.866, 2014 Guidelines on Method of Calculation of the Attained Energy Efficiency Design Index for New Ships. 2017. Available online: http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Documents/MEPC%201-CIRC%20866%20%282014%29.pdf (accessed on 20 July 2019).
33. IMO MEPC.304(72) Annex 11, Initial IMO Strategy on Reduction of GHG Emissions from Ships. 2018. Available online: http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-%28MEPC%29/Documents/MEPC.304%282018%29.pdf (accessed on 21 July 2019).
34. IMO Study on the Optimization of Energy Consumption as Part of Implementation of a Ship Energy Efficiency Management Plan SEEMP, Air Pollution and Energy Efficiency Study Series 4. 2016. Available online: http://publications.lib.chalmers.se/records/fulltext/232448/local_232448.pdf (accessed on 23 August 2019).
35. Understanding the Energy Efficiency Operational Indicator: An Empirical Analysis of Ships from Royal Belgian Shipowners Association, UCL Energy Institute. 2015. Available online: https://pdfs.semanticscholar.org/5a39/fab6ee4aa1c164c071ed6606c1b221576f753d1.pdf (accessed on 23 August 2019).
36. Tran, T.A. A research on the Energy efficiency operational indicator EEOI calculation tool on m/v NSU JUSTICE of VINIC transportation company, Vietnam. J. Ocean Eng. Sci. 2017, 2, 55–60. [CrossRef]
37. EQUASIS. The world Merchant Fleet in 2016, Statistics from Equasis. Available online: http://www.equasis.org/FichiersStatistique/ (accessed on 24 August 2019).
38. Lützen, M.; Mikkelsen, L.L.; Jensen, S.; Rasmussen, H.B. Energy Efficiency of working vessels—A framework. J. Clean. Prod. 2017, 143, 90–99. [CrossRef]
39. Poulsen, R.T.; Sørn Friese, H. Achieving energy efficient ship operations under third party management: How to ship management models influence energy efficiency? Res. Transp. Bus. Manag. 2015, 17, 41–52. [CrossRef]
40. Prill, K.; Igielski, K. Calculation of operational indicator EEOI for ships designed other purpose than transport based on a research-training vessel. New Trends Prod. Eng. 2018, 1, 335–340. [CrossRef]
41. Prill, K. Determining Specialised Vessels’ Energy Efficiency Analysis Based on the Research—Training vessel. In Proceedings of the 18 International Multidisciplinary Scientific Geo Conference SGEM 2018, Albena, Bulgaria, 2–8 July 2018.
42. Behrendt, C. Energy Efficiency Operational Indicator of the Selected Type of Polish Fleet Fishing Cutter in Dependence of the Main Engine Type. In Proceedings of the Journal of Physics Conference Series, Telangana, India, 5–6 December 2018.
43. Behrendt, C.; Prill, K.; Patsch, M. Significance analysis of ship operational states as a factor influencing the energy efficiency of a research—Training vessel. New Trends Prod. Eng. 2018, 1, 219–225. [CrossRef]
44. Sowa, A. Object State as Ambiguous Term in Contemporary Technical Operation. Mechanics—Technical Transactions. 2012. Available online: https://suw.biblos.pk.edu.pl/downloadResource&mId=515745 (accessed on 28 August 2019).

45. Deptuła, A.M.; Knosala, R. Modelowanie oceny ryzyka innowacji technicznych. Zarządzanie przedsiębiorstwem nr 2. 2015. Available online: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-f20b34e5-97bf-4ea4-b83b-70575a36096 (accessed on 28 August 2019).

46. Deptuła, A.M. Określenie wag kryteriów oceny ryzyka innowacji technicznych. XLIII Konferencja naukowa KZM w Zakopanem. 2014. Available online: http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-f20b34e5-97bf-4ea4-b83b-70575a36096 (accessed on 30 August 2019).

47. Skorupka, T.; Walczyński, M.; Siczek, R.; Kowacka, M. Application of Unmanned Aerial Vehicles for Revising Dispersion of Time of Key Undertakings. Available online: http://www.ejournals.eu/Czasopismo-Techniczne/2017/Volume-6/art/9561 (accessed on 28 August 2019).

48. Dokumentacja Projektowa Statku Badawczo—Szkolnego, m/s Navigator XXI, Sporządzona przez Przedsiębiorstwo Projektowo—Usługowe NAVICENTRUM Sp. z o.o.; Research-training ship m/s Navigator XXI; Inland Navigation Research and Design Centre NAVICENTRUM: Wrocław, Poland, 1996.

49. Instrukcja techniczno—ruchowa silników typ S20, H. Cegielski—Sulzer, wyd. B, egz. 5. Poznan, Poland. 1999. Technical instruction – engine operation type S20, H. Cegielski-Sulzer, edition B, publication 5. Poznan. Poland. 1999.

50. International Convention on standards of Training and Watchkeeping for Seafarers (STCW) 1978, Consolidated Edition. 2017. Available online: https://www.saturatore.it/Diritto/STCW95 (accessed on 30 August 2019).