Volume XXV 2022
ISSUE no.1
MBNA Publishing House Constanta 2022

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

Approach of using a system of evaluation indicators in determining the efficiency of ships in the Danube shipping

To cite this article: T. Tarasenko, V. Zalozh and S. Maksymov, Scientific Bulletin of Naval Academy, Vol. XXIV 2021, pg. 66-74.

Submitted: 21.02.2022
Revised: 04.07.2022
Accepted: 15.07.2022

Available online at www.anmb.ro

ISSN: 2392-8956; ISSN-L: 1454-864X

doi: 10.21279/1454-864X-22-I1-008

Approach of using a system of evaluation indicators in determining the efficiency of ships in the Danube shipping

T Tarasenko, V Zalozh, S Maksymov

Danube institute of National university «Odessa Maritime Academy», Department of Engineering Sciences, Fanagoriyskaya str. 9, Izmail, Ukraine, 68607
e-mail: tarasenko@dinuoma.com.ua zalozh@dinuoma.com.ua maksimov@dinuoma.com.ua

Abstract. In modern conditions, there is an active interest in continuing research to reduce harmful emissions of marine engine exhaust gases into the atmosphere and prepare ships for the use of technologies with zero level of these emissions. It is known that the European Green Deal concept announced by the European Union is aimed not only at the modernization of the inland vessels, and coordinated qualitative change in its composition, but within this framework also at the large-scale implementation of the energy transition as the most effective way to achieve zero emissions into the atmosphere. At the same time, environmental aspects and issues of energy efficiency are considered as a complex task of transition to energy efficient eco-navigation. To date, for the European inland navigation participants, the stages of reducing harmful emissions into the atmosphere are clearly defined and regulated with established numerical standard (reference) values for each of the components (CO, HC, NOx, PM). As for energy efficiency, discussions are still ongoing at the international level about the advisability of introducing criteria according to the principle established by the International Maritime Organization for ships based on the specific mass of harmful emissions (in terms of CO_2) per unit of transport work. At the same time, there is an understanding of the specifics of navigation conditions and technologies for transporting goods, which makes us return to comparing energy efficiency and economy indicators. The team of authors made an attempt to find and offer the most comprehensive approach to assessing the energy efficiency and economy of the inland navigation vessels operation, in particular for Danube vessels, with the maximum possible consideration of the features of their operation. An integrated approach to the use of estimated indicators of the efficiency of the existing pushers with heavy convoys allows to achieve an increase in the energy efficiency of the operation of the existing fleet, as well as lead to an improvement in environmental indicators.
Keywords: energy efficiency, evaluation, indicators, emissions, existing fleet, inland vessels, environmental performance, Danube shipping.

1. Introduction

In European inland shipping, in contrast to international maritime shipping, there is a strong desire to define an integrated indicator of energy efficiency, environmental friendliness and economy. This is due to a number of features of the procuring of navigation conditions, the technologies used for transporting goods, the peculiarities of the age fleet composition and the competitive conditions of the closed market. Separately, the term "energy-efficient shipping" in the sense of the energy efficiency index established for ships by the International Maritime Organization is losing its self-sufficiency in inland navigation due to more uncertainties, constant changes in traffic patterns. At the same time, the “reduction of emissions” in itself, in the sense of emissions of polluting particles such as CO, HC, NOx, PM, in the exhaust gases of marine engines as a result of the diesel fuel combustion process is enshrined in law as a desire to gradually achieve «zero emission» eventually (Stage V [4]), for which measures are provided for the introduction of innovative technologies and the transition to alternative fuels. Obviously, this may be applicable for a new fleet and is unlikely to be fully achievable with the continued operation of existing ships. For ships built and put into operation before the start of the study of energy efficiency and environmental friendliness, the efficiency indicators of their operation were considered relevant.

2. Analyses of the Literature Data and the Problem Statement

The tasks of improving the environmental friendliness of inland navigation vessels, their modernization, fuel transition, are clearly formulated in the following fundamental documents developed within the framework of the European Commission, its special committees and international organizations:

- Directive (EC) 2016/1629 and Standard ES-TRIN (2019), Part 9;
- Regulation (EC) 2016/1628, establish level of harmful emissions in exhaust gases of the marine diesels according to Stage V; Middle Danube (sections of Hungary, Croatia and Serbia);
- Conclusions of the EU-funded project GRENDEL (2018–2020 г.г.);
- EU-funded project PLATINA 3;
- EU-funded project NAIADES III;
- Initiative working-outs of International organizations (Danube Commission, Central Commission for the Navigation of the Rhine).

At the same time, the desire of shipowners to maintain the presence on the market of existing ships of early years of construction with minimal investment in fleet modernization stimulates the continued search for an assessment of their contribution to the total amount of harmful emissions while maintaining the trend towards energy efficiency and economy. These issues are covered in publications [1, 2, 3, 5, 6, 9, 11].

3. Aims

The main purpose of this study is to analyze various indicators of the quality of the work of inland water transport and the possibilities of their adaptation, transformation for a comprehensive assessment of energy efficiency, economy, and environmental friendliness. Also to show the competitive advantages that IWT provides when transporting large quantities of goods over long distances, including safety, sustainability and economic efficiency in terms of total transportation costs and energy consumption per tonne-kilometre.

4. Observations and research

It is customary to use generally accepted indicative indicators to analyze the work of the transport fleet. Moreover, the analysis itself usually has two main directions – analysis of the use of the transport fleet in time and analysis of the use of the transport fleet in productivity.

Analysis of the use of the transport fleet can be carried out in tonnage-days, passenger-days, power-days. When analyzing the time of use of vessels, the time of stay of vessels in and out of operation is to be taken into account. Also in the course of the analysis the following indicators are estimated [7]:

- utilization rate of moving time with cargo, $URMTC$ – transport work of each ton of the capacity

$$URMTC = \frac{Capacity \cdot Time\ with\ Cargo}{Capacity \cdot Time\ in\ Operation}, \tag{1}$$

Capacity – capacity of the vessel; $Time\ with\ Cargo$ – time of moving with cargo. It's necessary to add an opinion of authors of this paper. It seems, using (1) in presented form is not informative and maybe even not very correct. We'd like to propose such a modification:

$$URMTC = \frac{Cargo \cdot Time\ with\ Cargo}{Capacity \cdot Time\ in\ Operation}, \quad (2)$$

Cargo – amount of cargo in tons in this voyage; *Capacity* – capacity of the vessel; $Time\ with\ Cargo$ – time of moving with cargo; $Time\ in\ Operation$ – time of the vessel's being in operation during the voyage.

- the average duration of the voyage turnover; characterizes the structure of the time budget for the turnover and the average duration of the completed cycle of cargo movement during the turnover:

$$TTurnover = \frac{\sum TRV(1+TAdd)}{VC}, \quad (3)$$

TRV – time of the round voyage; *TAdd* – additional time for non-transport operations; *VC* – number of subvoyages with cargo during the round voyage;

- average daily mileage of 1 ton of cargo capacity; is characterized by the ratio of the average mileage per turnover to the average duration of turnover:

$$Daily\ Distance = \frac{Average\ Distance}{Average\ Time}, \quad (4)$$

Average Distance – average distance per turnover; *Average Time* – average duration of turnover.

When analyzing the use of the transport fleet in terms of productivity, the dynamics and level of the following indicators are helpful:

- average carrying capacity (for a couple of vessels)

$$Capacity\ Average = \frac{\sum Capacity \cdot Time\ in\ Operation}{\sum N \cdot TION}, \quad (5)$$

Capacity, $Time\ in\ Operation$ – the same as in (2); *N* – number of vessels with equal time in operation; *TION* – time in operation of *N* vessels.

- average amount of cargo per 1 ton of cargo capacity as the number of tons of cargo, which is on average per 1 ton of cargo capacity per 1 km of mileage with cargo

$$CPT = \frac{\sum Cargo \cdot Distance}{\sum Capacity \cdot TMC}, \quad (6)$$

$Cargo \cdot Distance$ – freight turnover;

- capacity utilization factor (total mileage)

$$CUF = \frac{\sum Cargo \cdot Distance}{\sum Cargo \cdot Distance\ with\ Cargo + \sum Cargo \cdot Distance\ without\ Cargo}, \quad (7)$$

- average technical speed

$$ATS = \frac{\sum Cargo \cdot Distance\ with\ Cargo}{\sum Cargo \cdot Time\ with\ Cargo}, \quad (8)$$

- average operational speed

$$AOS = \frac{\sum Cargo \cdot Distance\ with\ Cargo}{\sum Cargo \cdot Time\ with\ Cargo + \sum Cargo \cdot Time\ of\ Mooring}, \quad (9)$$

In addition to these indicators, others are used, depending on the tasks to be solved, including summary indicators of the fleet:

- gross productivity;
- carrying capacity;
- profitability, etc.

All this allows the analysis of indicators and structure of use of time, productivity, carrying capacity of vessels, including comparative for vessels of different types (projects). But this technique does not take into account the specifics of inland waterway vessels.

For our study, we took as a basis the specifics of the work of ships on the Danube. The peculiarity of Danube river navigation is that most cargo is transported by non-self-propelled vessels, and the main transport work on moving cargo is performed by pushers (tugs). In addition to line towing, these vessels perform ancillary work in ports (port work), which includes work on the formation of caravans, ensuring the load of non-self-propelled fleet (preparation of cargo space, supply and removal from the berth, etc.).

The specificity of Danube shipping is that in different parts of the Danube the ship can not perform the same transport work at the same time. The reason for this is the hydro-navigation conditions, including seasonal (passage of gullies, narrows, strong currents), restrictions on the dimensions of the caravan (regulatory requirements, the size of the locks).

That is why the Conference of Directors of Danube Shipping Companies - participants in the Bratislava agreements approved the method of calculating the unit of tug (Kilat). This technique allows you to take into account the type of work performed, the characteristics of the Danube on which the tug works, the weight of the cargo, the size of the towed vessel, the time of work, distance.

$$K = \frac{(Q+1.176L(B+2T_o))\times\sum l_i k_{sec\,i}}{1000}, \qquad (10)$$

Q – amount of cargo;
L – maximum length of tugged vessel;
B – beam of the tugged vessel;
T_o – draught of empty tugged vessel;
l_i – distance of tugging for section "i" of the voyage;
$k_{sec\ i}$ – the coefficient of the section, taking into account the complexity of towing on the section "i".

At port works the actual running time of performance of work is considered.

As we can see, these indicators assess the performance of transport work in market, economic terms, but they are disparate and do not reflect the complex indicator of the use of the transport fleet, elements of energy efficiency and, accordingly, environmental friendliness.

5. The Results

To test the possibility of comparing complex indicators and energy efficiency indicators, calculations were performed based on the results of voyages of ships and caravans of several types. As an example, we propose to look at the results for the same convoys 1-4, as in paper [11], and also another convoys 5-9, as on Figure 1 (a and b) presented.

a) b)

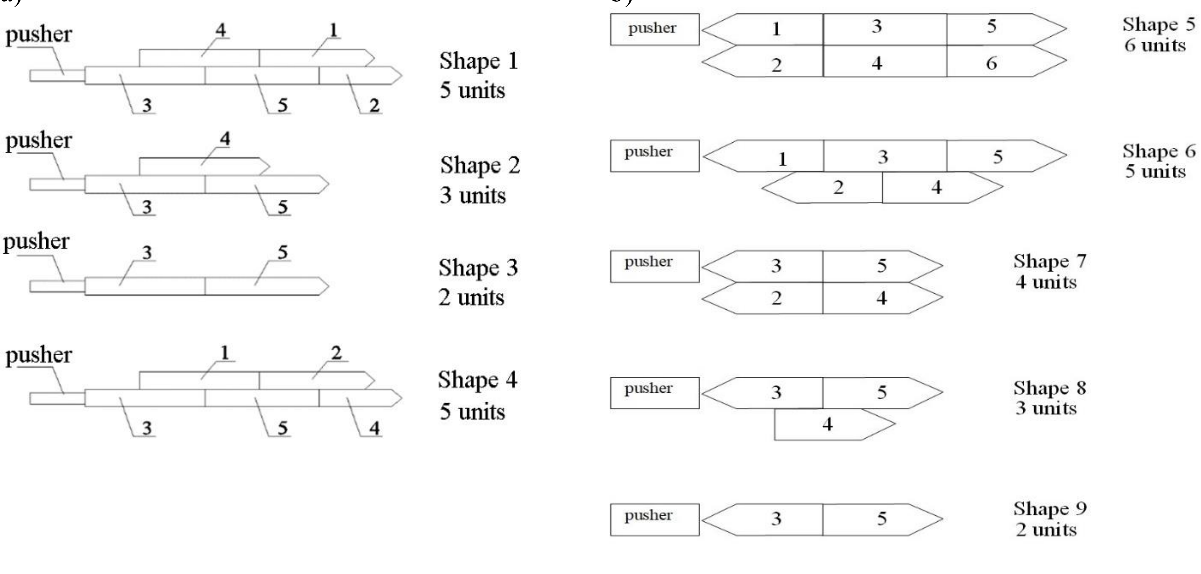


Figure 1. Shapes of convoys: a – m/v "Znamenka" with convoys 1-4 (based on the test results [11]), and b – m/v "Ivanovo" with convoys 5-9

Main dimensions and characteristics of the m/v "Ivanovo" as a pusher of convoys 5-9:

- Vessel's type – self-propelled, pusher
- Length overall – 38,5 m
- Breadth – 11,03 m
- Height – 3,20 m
- Depth moulded – 2,1 m
- Power plant – 2×852 kW
- Velocity without convoy – 19 km/h
- Crew – 7 persons.

Two 8NVD48A-2U diesel engines manufactured by SKL (Germany) are installed as main engines. Diesels are four-stroke, in-line, reversible, trunk, single-acting, with gas turbine charging and automated remote control. Main characteristics:

- rated power – 852 kW
- rotation speed – 375 min^{-1}
- number of cylinders – 8
- cylinder diameter – 320 mm
- piston stroke – 480 mm
- average effective pressure – 0.9 MPa
- specific effective fuel consumption – 220 g / kWh (max 230 g / kWh)

average consumption of lubricating oil (total) – 1500 g / h.

Caravans 1-4 (Figure 1, a) compiled from unselfpropelled barges: 1 – draught 2,0 m, cargo 895,2 tons; 2 – draught 2,0 m, cargo 888,2 tons; 3 – draught 2,3 m, cargo 1409,3 tons; 4 – draught 2,0 m, cargo 1159,7 tons; 5 – draught 2,3 m, cargo 1409,3 tons. Caravans 5-9 (Figure 1, b) also compiled from unselfpropelled barges: 1 – draught 2,1 m, cargo 1648 tons; 2 – draught 2,1 m, cargo 1623 tons; 3 – draught 2,1 m, cargo 1667 tons; 4 – draught 2,1 m, cargo 1518 tons; 5 – draught 2,1 m, cargo 1684 tons; 6 – draught 2,1 m, cargo 1653 tons.

To achieve the goals of the study, a detailed analysis of formulas (1) ... (10) was carried out. At the same time, it was found that each of the considered indicators is self-sufficient for limited use in assessing the operational performance of a particular ship, caravan or fleet as a whole. Most of them allow you to manipulate two indicators. So, the ratio "Time" - "Cargo / Capacity" forms the basis of formulas (1), (2), (3), (5); comparison "Time" - "Distance" is used in formulas (4), (7). For a more comprehensive assessment, formulas (6), (8), (9) are applicable for the reason that they take into account the ratio of three factors: "Time" - "Distance" - "Cargo". However, if we set ourselves the goal of defining a comprehensive characteristic that would make it possible to simultaneously take into account both economic factors and the applied operational technologies and navigation conditions, this is clearly not enough. That is why the authors propose an approach to the definition of indicators that determine the efficiency of ships in the Danube navigation, similarly to the energy efficiency indices adopted in international maritime navigation, but through kilat production:

$$EEI = \frac{N_e \cdot SFC \cdot CF}{K}. \tag{11}$$

In (11): N_e – main engine effective power, kWt; SFC – specific fuel consumption, g/kWt·hour; CF – type of fuel conversion factor as by IMO; K – kilat production as in (10).

The results are presented in tables and graphs (Figures 2-5). They clearly reflect the possibility of comparing the characteristics of environmental friendliness, economy and energy efficiency in order to determine the achievable optimal mode of operation and to get a general idea of the achievable level of environmental friendliness of existing vessels on the amount of harmful emissions into the atmosphere.

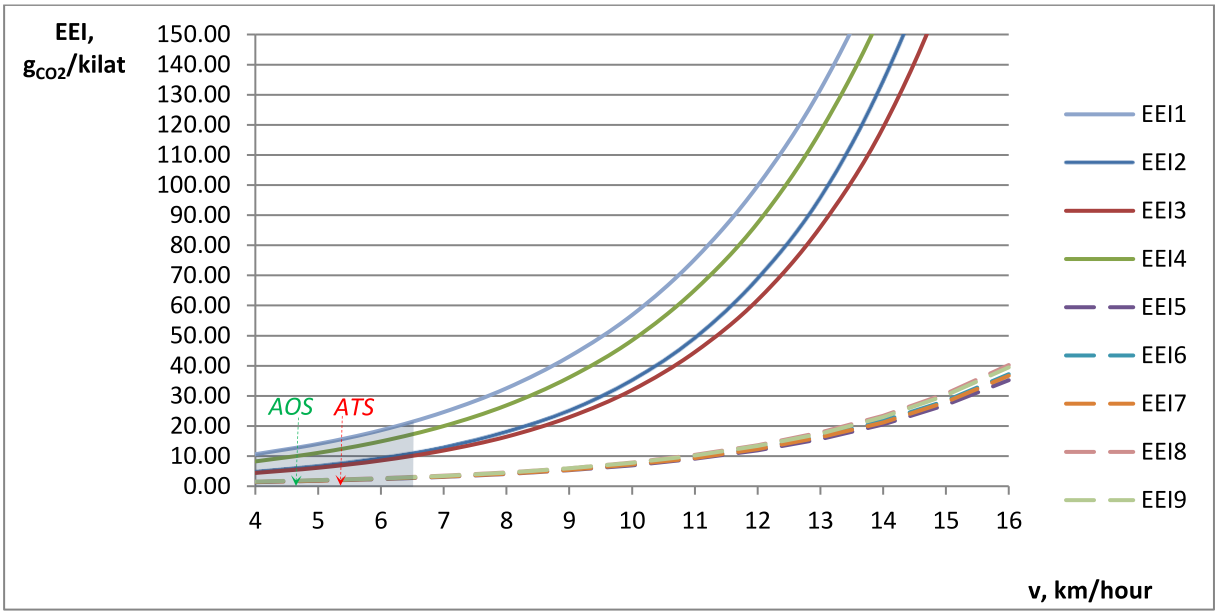


Figure 2. Results for Indices of energy efficiency per a unit of kilat production from 0 km to 861 km of the Danube: m/v "Znamenka" with convoys 1-4 (based on the test results [11]) and m/v “Ivanovo” with convoys 5-9 (calculated)

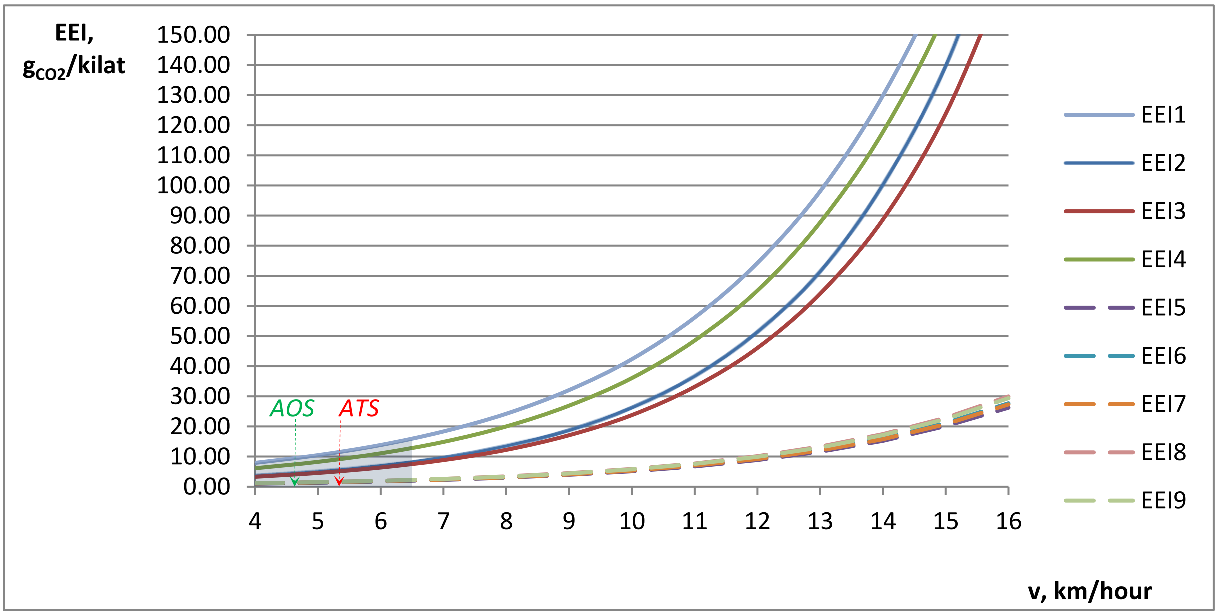


Figure 3. Results for Indices of energy efficiency per a unit of kilat production from 861 km to 1767 km of the Danube: m/v "Znamenka" with convoys 1-4 (based on the test results [11]) and m/v “Ivanovo” with convoys 5-9 (calculated)

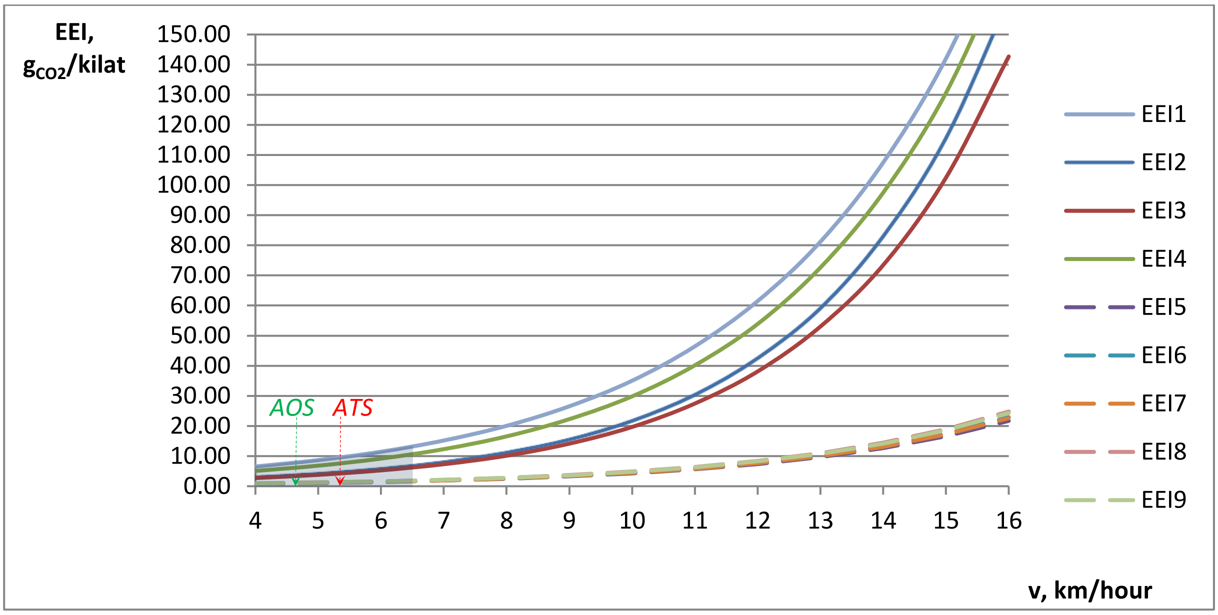
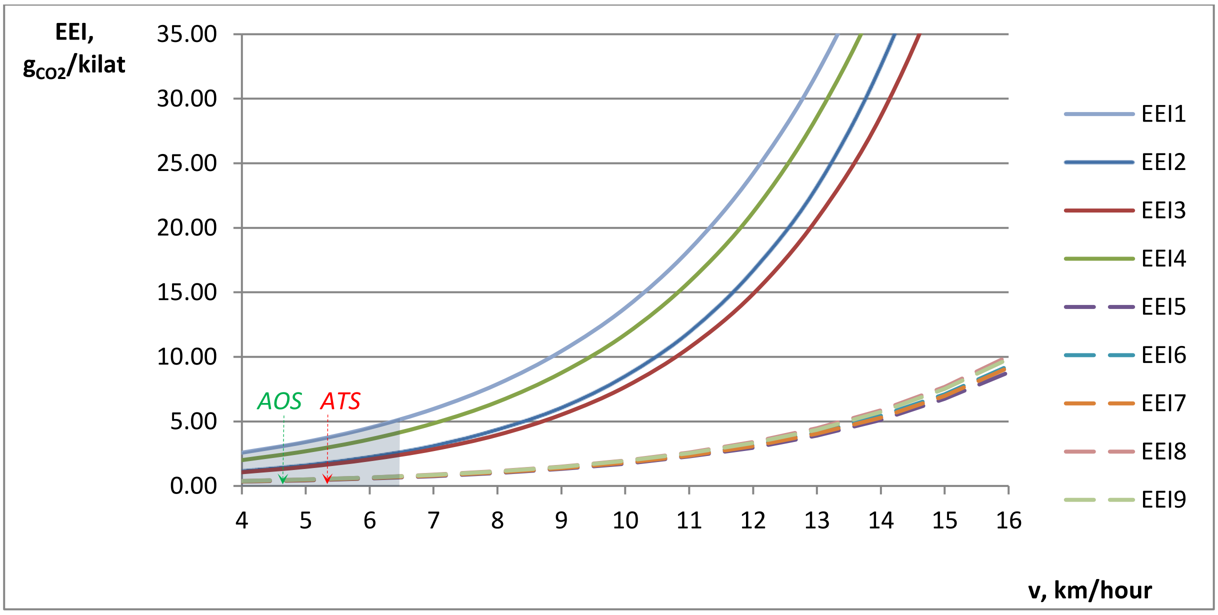


Figure 4. Results for Indices of energy efficiency per a unit of kilat production from 1767 km to 2414 km of the Danube: m/v "Znamenka" with convoys 1-4 (based on the test results [11]) and m/v "Ivanovo" with convoys 5-9 (calculated)



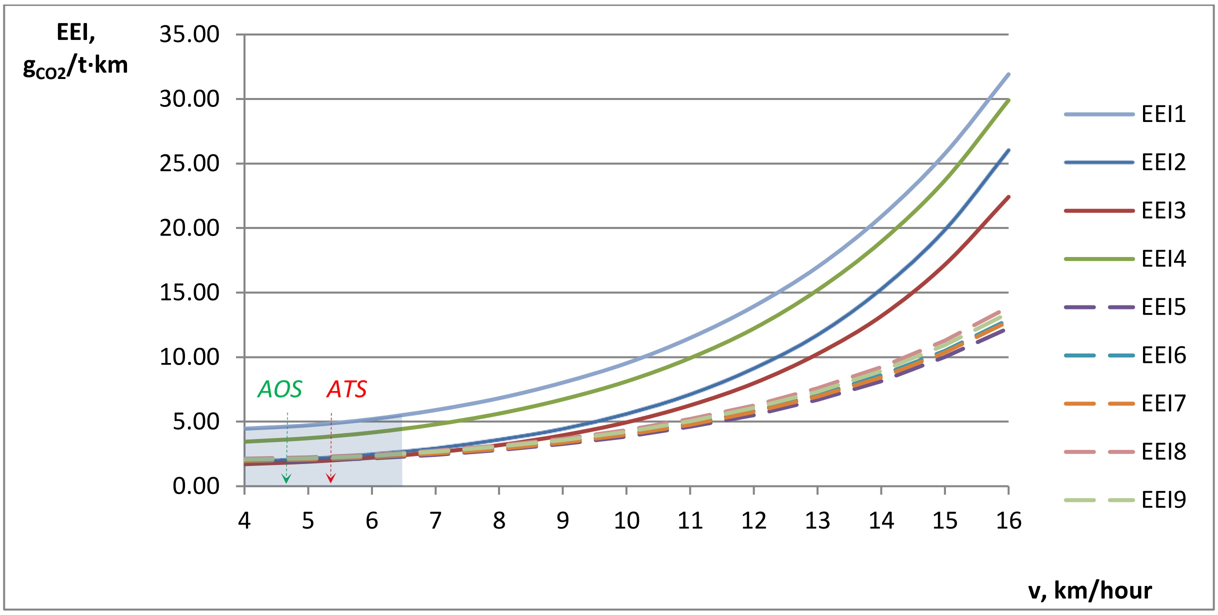


Figure 5. Comparison of the results for the whole voyage from 0 km to 2414 km of the Danube: upper graphs – Indices of energy efficiency per a unit of kilat production, below – Indices of energy efficiency by IMO

The average technical speed ATS and average operational speed AOS is marked on Figures 1…5 and also the range of preferred operational speeds highlighted. This makes it possible to obtain an estimated range of complex energy efficiency indices applicable in the forecasting / planning of the work of ships, or in reporting. In addition, this will allow the fleet to achieve foreseen values of energy efficiency indices in the fleet, the range of values of which will remain at the level of minimum values without entering the modes in which there is a sharp increase in the EEI indicators of energy efficiency indices.

Figure 5 also makes it possible to see, using the example of two tugs with caravans of various shapes, that inland water transport vessels have a clear advantage in the EEI complex energy efficiency index due to the fact that the range of operating speeds is in the region of the lowest possible values of the IMO energy efficiency index.

The way to estimate Energy Efficiency Indicators by means of kilat production gives an opportunity to consider different navigational conditions of the Lower, Middle and Upper Danube, used technologies with real reflection of pusher's transport work

6. Conclusions

Based on the results of the work done on the study of complex estimated indicative indicators and their comparison with indicators of energy efficiency and economy, the following conclusions can be drawn.

The analysis of indicators used in the work of shipping companies to assess the efficiency of inland water transport has been carried out. The possibility of adapting the form of the energy efficiency index established by IMO for marine vessels has been established in order to use it in inland navigation as one of the forecasting and reporting tools for the complex “energy efficiency - economy - environmental friendliness”. The example of two different tugs with caravans shows the range of this indicator and its normalization using the ATS, AOS values, as well as the range of operational EEI values of IMO energy efficiency indices at the lowest possible level. The latter is a weighty argument in order to relieve tension in terms of environmental requirements for existing inland waterways. We can additionally state the following.

- There is an opportunity to assess the cost-effectiveness, environmental friendliness and energy efficiency frames of existing ships.
- Calculations are rather cumbersome in terms of the amount of initial data used and time-consuming to determine some characteristics at intermediate stages.
- The need to perform such calculations for each voyage is questionable. Most likely, for a general understanding, it is enough to perform such an assessment for each vessel for the maximum and minimum voyage distances, the amount of cargo. This will make it possible to understand the feasibility of its further operation. This does not exclude the possibility of continuous or periodic monitoring of these characteristics.
- A range of values of complex energy efficiency indices can be set, applicable in forecasting / planning the work of ships, or in reporting.
- Compliance with the speed limit throughout the voyage allows you to reach the predicted (planned) time and economic performance indicators and can serve as indirect evidence of the achievement of the predicted values of energy efficiency indices, the range of values of which is at the level of the minimum values of EEI energy efficiency indices.

References

[1] Atodiresei D., Coșofreț D., Nedelcu A., Toma A., Popa C., Albayrak T., Perkovic M. The analysing energy efficiency for sailing ships in optimal travel route planning. Case study: World voyage of the training ship "Mircea". *Scientific Bulletin of Naval Academy.* 2021.Vol. XXIV, pg.211-224. DOI: https://doi.org/10.21279/1454-864X-21-I1-025.

[2] Harilaos N. Psaraftis. Shipping decarbonization in the aftermath of MEPC 76. Cleaner Logistics and Supply Chain. 2021. Volume 1, 100008. DOI: https://doi.org/10.1016/j.clscn.2021.100008.

[3] Schinas, O.; Bergmann, N. The Short-Term Cost of Greening the Global Fleet. Sustainability. 2021, 13, 9439. DOI: https://doi.org/10.3390/su13169439.

[4] Psaraftis, H.N., Kontovas C.A. Decarbonization of Maritime Transport: Is There Light at the End of the Tunnel? Sustainability. 2021, 13, 237. DOI: https://doi.org/10.3390/su13010237.

[5] NRMM STAGE V REGULATION (EU) 2016/1628 (Emission regulation for non-road mobile machinery: EU Stage V)

[6] Suvorov P., Tarasenko T., Zalozh V., Maksymov S. About Ratio of the Energy Efficiency and Ecological Compatibility for Inland Navigation Vessels. Visnik oft he Volodymyr Dahl East Ukrainian National University. - 2019. - № 3[251]. - P. 168 - 175.

[7] Analysis of economic and financial activities. Practicum : textbook / Baby`na O.A., Kovbatyuk M.V., Semenchuk T.B., Shklyar V.V. K.: KVICz, 2015. 352 p.

[8] Zalozh, V., Tarasenko, T. and Varbanets, R. 2020. Efficiency Control Improvement Of Diesel Engines Conditions By Using The Method Of Analytical Synchronization Of Monitored Data. Technium: Romanian Journal of Applied Sciences and Technology. 2, 7 (Oct. 2020), 151-159. DOI: https://doi.org/10.47577/technium.v2i7.1829.

[9] Tarasenko T, Zalozh V and Maksymov S. The Ways to Improve Energy Efficiency and Eco-friendliness of the Specific Danube Inland Vessels. First Stage. *Journal of Physics: Conference Series.* 2019. Vol. 1297, conference 1. P. 1-8. DOI: https://doi.org/10.1088/1742-6596/1297/1/012019.

[10] Danube Commission official web-site. Accessed March 14, 2021 https://www.danubecommission.org/dc/en/danube-navigation/market-observation-for-danube-navigation/ .

[11] T. TARASENKO, V. ZALOZH, R. VARBANETS and D. MINCHEV. Considerations regarding reducing Danube navigation emissions. *Scientific Bulletin of Naval Academy*, Vol. XXIV 2021, pg.174-183. DOI: https://doi.org/10.21279/1454-864X-21-I1-021.