Volume XXIX 2026
MBNA Publishing House Constanta 2026

Scientific Bulletin of Naval Academy

SBNA PAPER • OPEN ACCESS

Comparative Analysis of Parametric Diagnostics-Based Energy Efficiency Assessment Methods for Inland Vessels

To cite this article: Tarasenko Tetyana and Zalozh Vitalii, Scientific Bulletin of Naval Academy, Vol. XXIX 2026, pg. 19-26.

Submitted: 19.04.2026
Revised: 31.07.2026
Accepted: 04.08.2026

Available online at www.anmb.ro

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

doi: 10.21279/1454-864X-26-I1-002

Comparative analysis of parametric diagnostics-based energy efficiency assessment methods for inland vessels

Tarasenko Tetyana, Zalozh Vitalii

Danube institute of National university "Odessa Maritime Academy", Department of Engineering Sciences, Miru prospect, 15, Izmail, Ukraine, 68604
e-mail: *tarasenko@dinuoma.com.ua, zalozh@dinuoma.com.ua

Abstract. Inland vessel energy efficiency indicators for ships in operation remain poorly regulated and are still being investigated at different regulatory and research levels. This paper focuses on the ongoing efforts to define suitable forms of energy efficiency indices for self-propelled inland vessels and pusher tugs operating on inland waterways, with particular attention to the European context and the specific conditions of Danube navigation. A comparative analysis of several existing methods for assessing operational energy efficiency indices is carried out, highlighting their main assumptions and limitations. It is shown that most current approaches do not adequately account for the actual technical condition of main engines, which can significantly affect real fuel consumption, delivered power and thus operational energy efficiency. The study considers the application of parametric diagnostics of main engines to refine key working process parameters. This provides a physically grounded basis for continuous monitoring of ship energy efficiency in service. The paper further justifies the need for developing a transformation-based method that incorporates parametric diagnostics results to construct realistic fuel consumption, power and speed profiles for inland vessels, thereby improving the reliability and practical relevance of energy efficiency assessment in inland navigation.
Keywords: inland waterway transport; energy efficiency; diesel engines; parametric diagnostics; engine working process.

1. Introduction

Despite the prolonged period of effort and the considerable resources invested at various levels in emissions reduction programmes [11–13], energy transition initiatives, and the pursuit of eco-navigation and zero-emission objectives, the overwhelming majority of inland waterway transport (IWT) vessels continue to be propelled by internal combustion engines (ICE) burning fossil-derived liquid fuels. This situation stems primarily from the prohibitive cost of retrofitting the existing fleet, which – in the absence of external investment through public funds and adequate regulatory mechanisms – remains effectively unattainable for most vessel owners under the current conditions of the Danube freight market [15, 16]. The same factors account for the near-total absence of newbuilding orders, with only isolated exceptions linked to projects supported by the European Union [2].

In the foreseeable future, therefore, the principal means of transport on Europe's inland waterways will remain ICE-powered self-propelled vessels and, on the Danube in particular, push-tow convoys with equivalent propulsion arrangements [1, 14]. Fuel efficiency directly determines both the level of operating costs and the volume of harmful emissions generated during navigation [3]. Inland waterway shipping is characterised by considerable diversity – ranging from individual self-propelled vessels to large-displacement barge convoys of varying structure and configuration. Unlike ocean shipping, its energy efficiency is additionally governed by a set of variable navigational parameters: fairway depth, current velocity, hydrometeorological conditions, the nature of manoeuvring over shoals, and others [14]. Notwithstanding these complexities, inland waterway transport occupies a significant share of the European freight transport market and competes effectively with road and rail – above all in the heavy bulk cargo segment [15, 16].

Purpose. The objective of this study is a comparative analysis of existing approaches to the calculation of energy efficiency indicators for IWT vessels, and a substantiation of the potential for applying parametric ICE diagnostics to enhance the reliability of such assessment.

Literature review. The assessment of energy efficiency in IWT has attracted increasing attention from both international organisations and the research community in recent years. Drawing on the maritime Energy Efficiency Design Index (EEDI), a number of adapted approaches have been proposed for inland waterways [4], accounting for the specific conditions of restricted-water navigation – the effects of shallow water, river current, and convoy configuration.

In particular, the research group at the University of Belgrade (Kalajdžić, Momčilović et al.) proposed an approach to assessing the energy efficiency of self-propelled inland cargo vessels based on an adaptation of EEDI to the conditions of Danube navigation [5, 6]. Their work demonstrated that even within the single EEDI framework, different variants of the underlying mathematical models – with respect to engine power, water depth, draught, and current – yield substantially different energy efficiency values and may lead to contradictory conclusions regarding the compliance of existing vessels with design criteria [5].

In parallel, a study conducted by the Development Centre for Ship Technology and Transport Systems (DST) for the German Federal Ministry of Transport and CESNI proposed dedicated energy efficiency indices for inland vessels – $EEDI_{inland}$ / $EEDI_{IWV}$ – as well as an Energy Efficiency in Operation index (EEO), developed as adaptations of the maritime EEDI and EEOI to river navigation conditions [4, 7]. The study Inland waterway cargo vessel energy efficiency in operation showed that EEO, used in conjunction with design-based methods including the DST approach, is sensitive to variations in water depth, current speed, draught, and engine load, yet exhibits significant variability in results that complicates the comparison of vessels against uniform criteria [6].

A separate line of research concerns parametric diagnostics of marine ICEs, where methods have been proposed for condition monitoring based on indicator parameters, exhaust gas temperature, and emission composition, together with instrumentation systems for implementing such diagnostics under real operating conditions [10]. A growing body of work on the energy efficiency of river vessels proposes to refine index calculations through the use of corrected ICE performance curves derived from full-scale measurements, rather than the averaged specific fuel consumption values embedded in the baseline formulations of EEDI-type indices [8, 9]. These approaches demonstrate that discrepancies between modelled and actual engine operating modes – arising from variations in load, vessel speed, and shallow-water effects – can substantially alter the energy efficiency assessment. Comprehensive models of energy performance and manoeuvring of inland vessels also confirm the significant influence of hydrological conditions and operating parameters on fuel consumption and emissions [18, 19].

This provides a strong rationale for methods that combine refined ICE parameters with a decomposition of the voyage into discrete operational phases: deep-water navigation, shallow-water passage, shoal manoeuvring, split-convoy operations, and others. The prospects for alternative propulsion on the Danube remain limited in the near term [17], further reinforcing the importance of maximising the energy efficiency of existing ICE-powered fleets. However, the systematic integration of parametric diagnostics results into energy efficiency index calculation frameworks for inland vessels remains insufficiently developed in the scientific literature – and it is precisely this gap that defines the relevance, scientific novelty, and practical significance of the present study.

2. Materials and Methods

The proposed methodology for assessing the energy efficiency of inland waterway transport vessels combines two interrelated components: parametric diagnostics of the main internal combustion engine under real operating conditions, and a phase-by-phase voyage analysis accounting for the variability of navigational conditions [8, 9]. Unlike approaches that rely on averaged or nameplate engine characteristics, the proposed method involves obtaining refined load performance curves of the ICE directly during vessel operation and applying them differentially to each of the identified voyage phases.

A typical voyage of an inland vessel – whether a self-propelled cargo vessel or a push-tow convoy – is characterised by substantial heterogeneity in navigational conditions, which directly affects the load on the main engine and the specific effective fuel consumption [14]. To improve the reliability of the energy efficiency assessment, the voyage is divided into the following typical operational phases:

– deep-water navigation at full load and steady speed;

– navigation under shallow-water conditions with restricted fairway depth, accompanied by an increase in hydrodynamic resistance;

– passage over shoals with chevel manoeuvring, characterised by a variable engine operating regime and elevated fuel consumption;

– split-convoy operations involving separation of part of the barge train, which alters the displacement and hydrodynamic profile of the towed formation.

For each phase, characteristic values of vessel speed, engine rotational speed, and engine load are established, which serve as input data for the calculation of energy efficiency indicators.

Indicator diagnostics is the primary method for obtaining refined thermodynamic characteristics of the ICE working process under operating conditions. The method is based on measuring the in-cylinder pressure throughout the working cycle, followed by the construction of indicator diagrams in pressure – volume (p–V) and pressure – crankshaft rotation angle (p–φ) coordinates. The following parameters are determined from the indicator diagrams: mean indicated pressure (p_i), indicated power (N_i), and the shape and characteristics of the fuel combustion cycle. Comparison of the obtained indicator diagrams with reference diagrams enables the detection of deviations in the performance of individual cylinders and the assessment of load distribution uniformity across cylinders – a prerequisite for the correct determination of actual engine power output.

Vibrodiagnostics is employed as a supplementary and complementary method of parametric ICE diagnostics [10]. The method is based on measuring the vibration signal of the engine block or adjacent structural elements using accelerometers, followed by time – frequency processing of the acquired signal. The characteristics of the vibratory response carry information about the dynamics of the working process in the cylinders – in particular, the timing and intensity of fuel – air mixture ignition – and can be used for indirect monitoring of indicator parameters, as well as for the detection of faults in the valve train, fuel injection system, and bearing assemblies.

The results of indicator diagnostics and vibrodiagnostics are subject to a degree of variability, attributable both to the non-stationary nature of measurement conditions during operation and to the inherent cyclic variability of the ICE working process. To obtain statistically justified parameter values for each engine operating mode, the following approach is applied: for each fixed operating mode – defined by a pair of values of rotational speed n and effective power N_e – a series of measurements is performed; the sample mean, standard deviation, and confidence interval at a specified confidence level are then calculated from the series. Measurements falling outside the established confidence interval are excluded as statistical outliers. The averaged parameter values thus obtained for a set of operating modes form the basis for constructing the refined ICE load performance curves.

On the basis of the statistically processed diagnostic measurement results, refined load performance curves of the main engine are constructed – representing the specific fuel consumption (*SFC*) as a function of effective power N_e and rotational speed n – and reflect the actual condition of the engine under specific operating circumstances. These characteristics differ substantially from the manufacturer's shop-test data, as they account for engine wear and technical condition, the part-load operating regimes typical of inland navigation, and the influence of fuel quality and maintenance practices. The refined characteristics thus obtained serve as input data for the calculation of energy efficiency indicators at each of the identified voyage phases, in accordance with the transformation method described in the following section.

3. Results and Discussion

The method developed by the research group at the University of Belgrade (Kalajdžić, Momčilović et al.) [5] provides for the determination of two indicators: the attained (*Attained EEDI**) and required (*Required EEDI**) energy efficiency indices.

The attained index is calculated as

$$EEDI^* = \frac{P_{Bref} \cdot SFC \cdot CF}{m_{DWT} \cdot \upsilon}, \quad (1)$$

where P_{Bref} is the reference value of the main engine power required to achieve the design speed υ; SFC is the specific fuel consumption; CF is the conversion factor for CO_2 corresponding to the fuel type; m_{DWT} is the deadweight of the vessel or convoy; υ is the vessel speed relative to water.

In its form, this expression is almost identical to the formula of the maritime EEDI, but it differs significantly in its application: the reference power P_{Bref} is not fixed at 75 % MCR as in the IMO approach, but is defined as the power required to reach the design speed under specific navigational conditions. The method is applicable for speed ranges $\upsilon = 10 \ldots 22$ km/h, depth Froude number $Fr_H = 0.40 \ldots 0.65$ and deadweight $m_{DWT} = 100 \ldots 3000$ t.

The required index is defined by the empirical relationship

$$EEDI^*_{Req} = a \cdot m^c_{DWT}, \quad (2)$$

where a and c are empirical coefficients determined separately for deep-water and shallow-water conditions, depend on vessel type and are functions of speed υ (for deep water) or depth Froude number Fr_H (for shallow water). The original notation in Kalajdžić et al. [5] uses "$a \cdot m_{DWT}{}^{c}$"; here it is rewritten explicitly as "$a \cdot m^c_{DWT}$" to avoid ambiguity. Compliance of a vessel with the energy efficiency requirements is established by the comparison $EEDI^* \leq EEDI^*_{Req}$.

The method developed by DST (Development Centre for Ship Technology and Transport Systems, Duisburg) for the German Federal Ministry of Transport and CESNI [4, 7] likewise provides for the determination of attained and required indices.

The attained energy efficiency index for inland vessels is calculated as

$$EEDI_{IWT} = \frac{P_D \cdot SFC \cdot CF}{m_{DWT} \cdot \upsilon}, \quad (3)$$

where P_D is the delivered main engine power, calculated separately for deep-water and shallow-water conditions using a system of 33 empirical coefficients; the other symbols are as defined above.

The principal difference from the Belgrade method lies in the way the power is determined: P_D is calculated on the basis of the hull and propeller thrust characteristics for a reference vessel speed, followed by a transformation to current conditions for a given current speed υ_t. The method is applicable to vessels with draught $d = 2.0 \ldots 3.2$ m (deep water) and $d = 2.0 \ldots 2.8$ m (shallow water), length $L = 40 \ldots 135$ m, breadth $B = 5 \ldots 17$ m, deadweight $m_{DWT} = 250 \ldots 6000$ t and current speed $\upsilon_t = 2 \ldots 8$ km/h. It covers four vessel types: self-propelled dry cargo and container vessels, tankers, pushers with non-self-propelled sections and passenger vessels.

The required index in the DST method is defined as

$$EEDI_{Req} = \alpha_4 + \beta_2 \cdot \exp(\frac{m_{DWT}}{-\gamma_2}) + \upsilon_1 \cdot \exp(\frac{m_{DWT}}{-\delta_1}), \quad (4)$$

where $\alpha_4, \beta_2, \gamma_2, \upsilon_1, \delta_1$ are empirical coefficients determined separately for each vessel type and navigation zone.

It should be noted that in the DST method the energy efficiency indices are explicit functions of current speed, $EEDI_{IWT} = f(\upsilon_t)$, which is a major advantage over the University of Belgrade method, where the current is not taken into account. At the same time, the draught limitation linked to the propeller diameter as $d = 1.5D_P$ narrows the practical applicability of the method.

The transformation method proposed by the authors [8, 9] is based on a fundamentally different concept: instead of using averaged or catalogue engine characteristics, it is founded on obtaining refined engine load characteristics directly under operating conditions – by means of parametric diagnostics – and applying them in a differentiated manner to each of the identified operational stages of the voyage.

In general form, voyage fuel consumption is a continuous process described by the integral

$$EEOI_{voyage} = \frac{CF}{m \cdot d_{total}} \int_0^T N_e(t) \cdot SFC\big(N_e(t), n(t)\big)dt, \quad (5)$$

where $N_e(t)$ is the instantaneous effective power of the main engine as a function of time t; $SFC(N_e(t), n(t))$ is the specific fuel consumption as a function of power and rotational speed; T is the voyage duration; m is the cargo mass; d_{total} is the transport distance, i.e. the distance over which the cargo is carried, which may differ considerably from the actual track sailed by the self-propelled vessel, taking into account manoeuvres, split-convoy passages over shoals and pauses.

Since the voyage is divided into a finite number of typical operational stages, each characterised by statistically averaged engine parameters obtained from parametric diagnostics, the integral can be approximated by a discrete sum:

$$EEOI_{voyage} = \frac{CF}{m \cdot d_{total}} \sum_1^k N_{e_i} \cdot SFC_i\left(N_{e_i}, n_i\right) \cdot t_i, \quad (6)$$

where i is the index of the operational voyage stage; N_{e_i} is the effective main engine power at stage i; $SFC_i(N_{e_i}, n_i)$ is the specific fuel consumption at stage i, determined from the refined engine characteristics; t_i is the duration of stage i; k is the total number of voyage stages; d_{total} is the transport distance (as defined above).

Particular attention must be paid to the correct definition of the transport distance d_{total} in the denominator of formula (6). Unlike maritime shipping, where the voyage distance usually coincides with the distance of cargo transportation, these quantities may differ significantly in inland navigation – especially for pushers with barge convoys [14]. The actual track sailed by the vessel includes manoeuvres on shoals with multiple guided passages, repeated trips between the shoal section and the convoy anchorage during pauses, as well as movements of the vessel without cargo when splitting and re-assembling the convoy. In all these cases, the vessel consumes fuel and the engine performs work that is not associated with transporting the cargo over a corresponding distance. The University of Belgrade and DST methods do not distinguish these components and operate with a single "voyage distance", which may lead to systematic underestimation of specific energy efficiency indicators for pushers with large and structurally complex convoys. The transformation method explicitly distinguishes between the transport distance d_{total} and the actual vessel track, thus providing a more accurate assessment of the energy efficiency of transport work.

In contrast to the University of Belgrade and DST methods, which determine a pair of indicators (*Attained* / *Required*) and are therefore directly embedded in a regulatory framework, the transformation method first provides a reliable operational indicator (*Operational*). This is of fundamental importance: the reliability of the required indicator depends directly on the accuracy of the attained one, whereas existing methods calculate the attained index using averaged engine characteristics, which may introduce systematic errors. The transformation method eliminates this source of error and thus provides a robust basis for subsequent normalization.

The results of the comparative analysis of the three methods are summarised in Table 1. The analysis was carried out according to the following criteria: type of energy efficiency indicator, applicability to different vessel types and navigational conditions, method of determining engine characteristics, consideration of current and transport distance, presence and number of empirical coefficients, and limitations of each method [4–7].

Table 1 – Comparison of methods for calculating energy efficiency indices for inland vessels

Criterion	University of Belgrade method	DST method	Transformation method
Type of indicator	*Attained* / *Required*	*Attained* / *Required*	*Operational* (*Attained*)
Applicability	Individual self-propelled vessels; convoys with deadweight 100…3000 t	Individual self-propelled vessels; convoys with length up to 135 m, breadth up to 17 m	Individual self-propelled vessels; convoys, including large ones; validated for a self-propelled vessel with a convoy of 5 barges

Navigational conditions	Deep water and shallow water	Deep water and shallow water	Deep water, shallow water, shoals, split-convoy operations
Consideration of current	Not considered	Considered	Considered
Engine characteristics	Averaged / catalogue values of SFC	Averaged / catalogue values of SFC	Refined SFC characteristics obtained from parametric diagnostics under real operating conditions
Speed–power relationship	Used	Not used (reference speed with transformation)	Used for each voyage stage
Transport distance	Not distinguished from actual vessel track	Not distinguished from actual vessel track	Explicitly distinguished: d_{total} is the cargo transport distance
Auxiliary machinery	Not considered	Not considered	Considered (stops, manoeuvring)
Use of RIS data	Not provided	Not provided	Provided
Empirical coefficients	Present; derived for a single fairway depth value (5 m)	Numerous (33); narrow applicability	Does not require narrowly applicable empirical coefficients
Limitations	Does not consider current; empirical coefficients derived for limited conditions	Single reference draught ($d = 1.5D_P$); single reference speed	Requires verification on an extended sample of vessels and convoy types

As can be seen from Table 1, the University of Belgrade and DST methods share a common conceptual basis – the adaptation of the maritime EEDI to inland navigation – and both operate with a pair of indicators (*Attained* / *Required*) [4–7]. However, they differ significantly in their approaches to determining engine power and accounting for navigational conditions. The Belgrade method covers a wider speed range and does not require a large number of empirical coefficients for power calculation, but does not account for current speed. The DST method accounts for current and covers a broader spectrum of vessel types, but is constrained by a single reference draught and speed, which narrows its practical applicability to real Danube conditions.

A common and fundamental shortcoming of both existing methods is the use of averaged or catalogue SFC values, which do not reflect the actual technical condition of the engine under specific operating conditions. Since SFC enters directly into the numerator of the calculation formula, any deviation between the catalogue and the real specific fuel consumption leads to a systematic error in the determination of the attained EEDI and, consequently, in the conclusions regarding compliance with the required index.

The transformation method eliminates this drawback by integrating the results of parametric engine diagnostics into the calculation of the energy efficiency indicator [10]. Additional advantages of the method include: stage-by-stage voyage analysis, enabling correct representation of all characteristic engine operating modes; explicit differentiation between transport distance and actual vessel track; consideration of auxiliary machinery operation during stops and manoeuvres; and the possibility of using River Information Services (RIS) data. At the same time, the method requires verification on an extended sample of vessels and convoy types, which defines the direction of further research.

4. Conclusions

The overwhelming majority of vessels operating on Europe's inland waterways – and on the Danube in particular, where the fleet consists primarily of self-propelled cargo vessels and push-tow convoys – continue to be propelled by internal combustion engines burning fossil fuels. In the absence of realistic prospects for a mass transition to alternative propulsion in the near term, the reliable assessment of energy efficiency for such vessels acquires primary practical and regulatory significance.

A comparative analysis of two established energy efficiency index calculation methods – the University of Belgrade method [5, 6] and the DST method [4, 7] – has shown that both are founded on adaptations of the maritime EEDI to inland waterway conditions and operate with a pair of Attained / Required indicators. At the same time, both methods share significant limitations: the use of averaged or nameplate specific fuel consumption values that do not reflect the actual technical condition of the engine in service; the absence of a phase-by-phase voyage analysis accounting for the characteristic operating regimes of the propulsion plant; and the absence of an explicit distinction between transport distance and the actual path travelled by the vessel – a factor of particular importance for push-tow convoys with large barge trains under Danube navigation conditions. In addition, the Belgrade method does not account for river current velocity, while the DST method is constrained by a narrow range of draught values and a single baseline vessel speed.

The proposed transformation method addresses these limitations by integrating the results of parametric ICE diagnostics [10] – indicator diagnostics and vibrodiagnostics with statistical processing of parameter variability – into the energy efficiency index calculation. The method applies a phase-by-phase voyage analysis with differentiated use of refined engine load characteristics for each operational phase: deep-water navigation, shallow-water passage, shoal negotiation with chevel manoeuvring, and split-convoy operations. The transport distance d_{total} is defined as the distance over which cargo is actually carried, ensuring a correct assessment of the specific energy efficiency of the transport work performed.

The scientific novelty of the study lies in the first-time proposal of a methodological approach that combines parametric diagnostics of the marine ICE with a phase-by-phase voyage analysis to obtain a reliable operational energy efficiency indicator for inland vessels. Unlike existing methods, which are directly embedded in the Attained / Required regulatory framework, the transformation method provides a sound diagnostic foundation without which any form of normalisation remains methodologically vulnerable.

The results have been validated for a self-propelled vessel with a mid-sized Danube barge convoy. Further research should be directed towards verifying the method on an expanded sample of vessels of different types and convoy configurations, as well as towards developing, on its basis, a normalised indicator (Required) suitable for application in the regulatory practice of Danube inland navigation.

Author contributions:

- Conceptualization: T.T. and Z.V.
- Methodology: T.T.
- Investigation: T.T.
- Writing original draft: T.T. and Z.V.
- Writing review and editing: T.T.
- Supervision: T.T. and Z.V.

Funding: this research received no external funding

Conflict of interest: The Authors declare no Conflict of interest. The funders had no role in the design of the study, in the collection, analyses, or interpretation of data in the writing of the manuscript or in the decision to publish the results.

References

1. Guesnet, G., Deußner, R., Kirchmayr, R., Novak, R., Strasser, C., Bačkalov, I., Hofman, M., & Simić, A. (2013). *Innovative Danube Vessel: Main project results*. DST – Development Centre for Ship Technology and Transport Systems. https://www.dst-org.de

2. STC-Group. (2018). *PROMINENT – Promoting innovation in the inland waterways transport sector: Project information note*. https://www.waterborne.eu/projects/inland-navigation/prominent
3. De Vlieger, I., Panis, L. I., Joul, H., & Cornelis, E. (2004). Fuel consumption and CO_2-rates for inland vessels. *WIT Transactions on the Built Environment*, *75*, 637–646. https://doi.org/10.2495/UT040621
4. CESNI/PT. (2021). *Evaluating the energy requirement of inland vessels using energy efficiency indices*. CESNI. https://www.cesni.eu/wp-content/uploads/2021/03/cesnipt_energyindex_en.pdf
5. Kalajdžić, M., Vasilev, M., & Momčilović, N. (2022). Evaluating an inland waterway cargo vessel's energy efficiency indices. *Polish Maritime Research*, *29*(2), 27–34. https://doi.org/10.2478/pomr-2022-0014
6. Kalajdžić, M., Vasilev, M., & Momčilović, N. (2023). Inland waterway cargo vessel energy efficiency in operation. *Brodogradnja*, *74*(3), 71–89. https://doi.org/10.21278/brod74304
7. Guesnet, T. (2013, November 21). *Energy efficiency of inland water ships in the European Union Strategy for the Danube Region* [Conference presentation]. 4th Meeting of the Steering Group, EUSDR PA1a, Vienna, Austria. https://navigation.danube-region.eu/content/uploads/sites/10/2020/01/2013-11-21_EUSDR_PA1A_SG_CO2_emissions_DST.pdf
8. Tarasenko, T., Zalozh, V., & Maksymov, S. (2019). The ways to improve energy efficiency and eco-friendliness of the specific Danube inland vessels: First stage. *Journal of Physics: Conference Series*, *1297*(1), Article 012019. https://doi.org/10.1088/1742-6596/1297/1/012019
9. Tarasenko, T., Zalozh, V., Varbanets, R., & Minchev, D. (2021). Considerations regarding reducing Danube navigation emissions. *Scientific Bulletin of Naval Academy*, *24*(1), 174–183. https://doi.org/10.21279/1454-864X-21-I1-021
10. Varbanets, R., Minchev, D., Kucherenko, Y., Zalozh, V., Kyrylash, O., & Tarasenko, T. (2024). Methods of real-time parametric diagnostics for marine diesel engines. *Polish Maritime Research*, *31*(3), 71–84. https://doi.org/10.2478/pomr-2024-0037
11. CCNR. (2018). *Mannheim Declaration "150 years of the Mannheim Act for Rhine Navigation"*. Central Commission for the Navigation of the Rhine. https://www.ccr-zkr.org
12. CCNR. (2018). *CCNR roadmap for reducing inland navigation emissions*. Central Commission for the Navigation of the Rhine. https://www.ccr-zkr.org/12090000-en.html
13. European Commission. (2021). *NAIADES III: An inland waterway transport action plan for 2021–2027*. Directorate-General for Mobility and Transport. https://transport.ec.europa.eu
14. viadonau. (2023). *Manual on Danube navigation*. https://www.viadonau.org/fileadmin/user_upload/Manual_on_Danube_Navigation.pdf
15. Danube Commission. (2025). *Market observation for Danube navigation: Results in 2024*. https://www.danubecommission.org/dc/en/danube-navigation/market-observation-for-danube-navigation/market-observation-for-danube-navigation-results-in-2024/
16. Danube Commission. (2025). *Statistical yearbook 2022*. https://www.danubecommission.org/uploads/doc/2025/Stat_2022/en_stat_2022.pdf
17. Van der Linden, E. (2024). *Study on alternative propulsion on the Danube*. Aristoi / viadonau. https://www.viadonau.org/fileadmin/content/20241128_Aristoi_Study_Viadonau_final.pdf
18. Zhang, C. (2023). *Energy performance and manoeuvring modelling of inland waterway vessels* [Doctoral thesis, Chalmers University of Technology]. https://research.chalmers.se/publication/539162/file/539162_Fulltext.pdf
19. Zhang, C., Ringsberg, J. W., & Thies, F. (2023). Development of a ship performance model for power estimation of inland waterway vessels. *Ocean Engineering*, *287*, Article 115731. https://doi.org/10.1016/j.oceaneng.2023.115731