Journal of civil engineering and transport **transEngin**

2021, Volume **3** Number **1** **ISSN 2658-1698, e-ISSN 2658-2120**

DOI: 10.24136/tren.2021.004

ANALYSIS OF INLAND WATERWAY VESSEL PROPULSION BY CRITERION EFFICIENCY, ECOLOGY AND SAFETY

Zbigniew **Łosiewicz** [1,*], Waldemar **Mironiuk** [2], Magdalena **Kaup** [3], Dorota **Łozowicka** [4], Wojciech **Ślączka** [5]

[1] West Pomeranian University of Technology in Szczecin Faculty of Maritime Technology and Transport, al. Piastów 17, 70-310 Szczecin, Poland, e-mail: zbigniew.losiewicz@zut.edu.pl, https://orcid.org/0000-0001-9327-418X

[2] Polish Naval Academy of the Heroes of Westerplatte, Faculty of Navigation and Naval Weapons, Śmidowicza Street 69, 81-127 Gdynia, Poland, e-mail: w.mironiuk@amw.gdynia.pl, https://orcid.org/0000-0001-7931-3680

[3] Maritime University of Szczecin, Faculty of Navigation, Wały Chrobrego 1-2, 70-500 Szczecin, Poland, email: m.kaup@am.szczecin.pl, https://orcid.org/0000-0002-9384-8144

[4] Maritime University of Szczecin, Faculty of Navigation, Wały Chrobrego 1-2, 70-500 Szczecin, Poland, email: d.lozowicka@am.szczecin.pl, https://orcid.org/0000-0001-8031-762X

[5] Maritime University of Szczecin, Faculty of Navigation, Wały Chrobrego 1-2, 70-500 Szczecin, Poland, email: w.slaczka@am.szczecin.pl, https://orcid.org/0000-0003-3265-9726

* Corresponding author

Reviewed positively: 29.03.2022

Information about quoting an article:
Łosiewicz Z., Mironiuk W., Kaup M., Łozowicka D., Ślączka W. (2021). Analysis of inland waterway vessel propulsion by criterion efficiency, ecology and safety. Journal of civil engineering and transport. 3(1), 39-47, ISSN 2658-1698, e-ISSN 2658-2120, DOI: 10.24136/tren.2021.004

Abstract – The paper analyses the propulsion systems of inland waterway vessels according to the criteria of economic efficiency, ecology and safety. The professional experience of the authors and their expert knowledge indicate that always the increase of safety level as well as ecological solutions are realized at the expense of economic efficiency. Therefore, arguing for the result of such analysis, the features of water bodies, port infrastructure and elements which should influence the selection of propulsion systems, features of various types of power and fuels with their energy value guaranteeing the swimming range were described. Types of propulsion systems were characterized and a model of selection of propulsion system to the type of sailing was presented. The analysis presented in the article is necessary for a reliable assessment of the accuracy of the selection of the propulsion system for the actual conditions of operation of sea and inland waterway vessels, i.e. for the type of the vessel and its suitability to perform operational tasks on specific waterways.

Key words – analysis of propulsion systems, inland waterway vessels, drive system selection criteria

JEL Classification – Q42, R40

INTRODUCTION

As a fundamental branch of the world economy, transport has a significant impact on every area of human life, as well as on the entire environment. This impact is not only positive but also negative, which makes it necessary to interfere with its functioning. The EU is working to reduce or neutralise the negative effects of transport. The result of this work are the established legal acts, which define the basic assumptions for development plans, action strategies or indicate the principles of conduct and guidelines for the proper functioning of individual transport branches in unimodal and integrated systems.

Inland waterway transport is recognised as an efficient and environmentally friendly alternative to road and rail. Therefore, the acts European Agreement on Main Inland Waterways of International Importance (AGN) of 19 January 1996 (UNECE Transport Agreements and Conventions No. 6) and The Commission's White Paper 1 "Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system" (European Agreement on Main Inland Waterways of International Importance

(AGN), Geneva, 19 January 1996) are among the most important legal regulations of the European Union. This fits into the idea of sustainable development as an ecological understanding of technical life, including means of transport, from their design, production, operation and disposal. With a view to unifying European legislation on inland waterway transport, the following was adopted. Directive (EU) 2016/1629 of the European Parliament and of The Council of 14 September 2016 laying down technical requirements for inland waterway vessels, amending Directive 2009/100/EC and repealing Directive 2006/87/EC.[10]. Under this Directive, EU Member States, when implementing its provisions, shall at the same time carry out studies and implementation activities aimed at increasing the efficiency of inland waterway transport and her greater involvement in freight traffic. Protection of the marine environment is a very important element in the development of equipment and machinery. It should be stressed, however, that each propulsion system of each vessel should be adjusted both to the basin and to the type of vessel constructed adequately to the operational tasks. Therefore, in spite of the research on development of alternative propulsion systems, studies are still being carried out on improvement of the efficiency of the so-called traditional propulsion systems fuelled with petroleum-derived hydrocarbon fuels which, being very effective, are the reference point for new, so-called "green" design solutions. Publication [14] presents the possibility of rational control of diesel engines with the application of a semi-markov model. On the other hand, publication [15] presents the results of calculations of distribution functions and average statistical values of propeller, rotational speed and efficiency as well as propulsion engine power and specific diesel oil consumption occurring on selected shipping routes, i.e. the criteria useful in designing ship propulsion systems. The historical development of the Diesel-electric (DE) propulsion system, an important component of today's Electrical Propulsion Systems (EPS), is presented in [13]. The performance of this type of propulsion system was analyzed in terms of NO_X, SO_X and CO_2 emission reduction, energy efficiency, fuel consumption, life cycle and cost. At the same time, attention has been drawn to the high investment cost of the DE system. The topic of drive efficiency, environmental protection of hybrid propulsion systems is taken up by researchers in the publication [5]. The concept of using alternative configurations of propulsion systems for inland waterway vessels to reduce their carbon footprint is presented, as well as models for assessing emissions and related costs over their lifetime (life-cycle assessments - LCAs) of a propulsion system using an internal combustion engine and electricity-powered engines in various configurations (including batteries and photovoltaics), where the economic viability of both solutions according to the life-cycle cost assessment (LCCA) is compared using the GREET 2020 program. In publication [5], due to the specificity of river navigation, the authors proposed the concept of diesel-hydraulic and hybrid propulsion system for inland waterway vessels. The solution of the hybrid design with a pumping system driven by a battery bank in the aspect of energy efficiency is also presented. Publication [6] presents research on the efficiency of two propulsion systems installed in parallel: hybrid and diesel-electric, controlled by an intelligent "smart propulsion" system. The tests were carried out on a vessel in real operating conditions. Optimization of propulsion on a river passenger ship is presented in [7]. Based on the measurements, the authors analyzed the fuel consumption and investment costs of four alternative propulsion systems. A simplified method of cost and savings analysis is presented. A solution of "green propulsion" on a passenger ship in the "green shipping" concept was presented in [8]. A small hybrid ferry powered by an energy-efficient, emission-free propulsion system powered by lithium batteries, which can be controlled remotely, was designed. In publication [9], the cost-effectiveness of a COGES (COmbined Gas turbine Electric and Steam) propulsion system as an alternative to diesel-electric propulsion on a passenger ship was analyzed. Since the three key issues (topics) contained in the idea of sustainable development are efficiency, ecology and safety, it should be noted that the work on the implementation of this idea requires compromises and establishing an appropriate hierarchy of importance. The measurable economic returns associated with the efficiency of inland waterway transport depend on the specific navigational conditions on the inland waterways, the technical and operational parameters of the vessels, and the logistics (TSL) activities associated with the operation. At the same time, the increase in the level of efficiency must ensure the imposed high level of safety of inland waterway transport and effective protection of the natural environment [8]. Assuming the above criteria and their mutual relations, the analysis should take into account the specificity of inland waterway transport, the parameters of vessels [1, 3] and, consequently, the type and properties of the propulsion systems applicable on them, consisting of drive units and propellers.

On the other hand, the selection of propulsion units should be guided by rational decisions based on data characterising the features of these propulsion units both at the stage of their design, application and assessment of the possibility of their modernisation.

The paper proposes a decision support model useful in selection of inland waterway vessel propulsion systems in terms of efficiency, ecology and safety. The rational choice of vessels is part of the process of optimising integrated transport chains.

1. NAVIGABILITY CHARACTERISTICS OF WATER AREAS

The definition of a water body is any water area with characteristic features.

General division of water bodies:

– open - such as seas, oceans - with large areas, strong winds, long distances to a safe place of refuge,
– closed - seas, e. g. Caspian Sea, lakes - with surfaces on which there is limited wind action and less wave action than in open waters, easier access to a safe place of refuge or receiving help from the land,
– saltwater - seas, oceans
– freshwater - inland lakes, rivers, reservoirs,
– navigable,
– non-navigable,
– warm water - year-round navigability,
– cold water - temporary possibility of icing,
– other
– The functions that bodies of water perform e. g. transport, industrial and municipal, agricultural, energy, sports and recreation or tourism.
– The operating conditions of a watercraft are influenced by elements such as:
– the vessel's cruising range,
– power demand of the main propulsion and auxiliaries resulting from e. g. water waves, water depth, currents, flora, fauna,
– corrosiveness of structures and components of propulsion systems, deck systems, auxiliary systems, etc.
– hull structure,
– design of auxiliary systems needed to operate the drive and auxiliary equipment.

During the realization of transport tasks, the characteristics of bodies of water allowing navigation and maneuvering are: the depth of water, type of shore, type of bottom, dimensions of the surface of the body of water of known depth. When navigating rivers, current strength, eddies, width of waterways to ensure one-way or two-way traffic, passing of vessels, possibility of side-by-side mooring, turning the vessel or standing at anchor are important.

Inland navigation is carried out on waterways of appropriate navigability class (in Europe 7 main classes) defining specific parameters and dimensions of vessels, including: length - *L* [m], width - *B* [m], draught - *T* [m], load capacity - *P* [t] and clearances under bridges or other elements of point infrastructure, located above water surface.

Point infrastructure, its quantitative and qualitative dimensions, is also crucial. Given that ship propulsion requires energy, which is supplied either in a transformed form (e. g. electricity) or in a primary form as fuel (chemical energy of the fuel), adequate berths should be provided, which should:

– provide a safe berth for waiting units,
– meet safety requirements when refuelling or replenishing e. g. electrical power,
– provide simultaneous service to several units, which will significantly reduce the downtime,
– ensure that maintenance of varying degrees of complexity (welding, replacement of equipment or machinery, docking, etc.) can be carried out.

Fuel points should provide:

– liquidity of supply and the possibility of storing or reloading fuel,
– standardized, safe connections.
– Electricity points should provide:
– transmission of electricity with appropriate parameters,
– substations enabling adaptation of the technical parameters to the requirements of the vessel,
– standardized connections and protection against electric shock and fire safety, waste management and other activities of importance to ship operation and crew as specified by the relevant documents and legislation.

2. SELECTED PROPULSION EVALUATION CRITERIA FOR INLAND WATERWAY VESSELS

The small dimensions of the engine room/ power plants of inland waterway vessels cause that the most frequently used for their propulsion are the propulsion units fuelled with liquid petroleum, internal combustion engines, two - and four-stroke piston engines, anhydrous, medium and fast, whose efficiency is about 35%.

They can be upgraded to gaseous fuel *LPG* (propane-butane) and *NG* (methane as *LNG* or *CNG*), alcohol, or vegetable oil, equipped with waste heat utilization systems or combined systems. This increases the complexity of the propulsion system and requires high crew qualifications and higher operating regimes.

On newly built and modernized units, classic electric drives supplied with direct or alternating current or in combined combustion-electric *DE*, *gas* turbine-electric GTE systems are applied, which reduces or eliminates the emission of harmful NO_x, SO_x, CO_x.

They are characterized by low noise and vibration levels and greater flexibility in engine placement. Another solution are innovative propulsion systems based on renewable solar energy (PV - *PhotoVoltaic*), chemical energy converted into electricity - fuel cells (FC - Fuel Cell), and e. g. in Stirling engines using heat from various sources, which may also be used on remotely operated or autonomous craft. These are the vessels of the future and must be designed in accordance with environmental policies, including the use of low- or zero-emission propulsion.

From the comparison, according to the economic calculation of the cost of energy production, hydrocarbon energy is cheaper than innovative energy.

Figure 1. shows the factors influencing the choice of propulsion for a vessel.

However, it should be noted that there are also non-measurable factors in the selection of energy sources such as health, comfort, awareness of environmental degradation. Therefore, the rational selection of power units involves the need to evaluate their properties according to selected criteria, such as those proposed in this paper. These criteria can include:

Technical factors (*TechFac*), including:

– *Cruising range (CR)* - time of continuous operation of the propulsion system, fuel reserve,
– *Energy supply of the drive (ESD)* - energy value, type of energy carrier,
– *Reliability (R)* - the ability to operate without failure between overhauls - *TBO (Time Between Overhauls),*
– *Harmful Emission (HE)* - harmful chemical compounds, heat emission, noise emission,
– *Durability (Dur)* - service life - the period during which an object retains its service properties.
– *Technical drive structure (TDS)* - design, construction materials used,
– *Time between technical inspections (TBTI)* - inspection time resourses,

***Economic factors (EcFac)*, including:**

– *Investment costs (IC)* - the purchase price of the drive unit and the required installation,
– *Operating costs (OC)* - costs of fuel, consumables, spare parts, overhaul costs,

Social factor (SocFac), including:

– *Social costs (SC)* - higher food prices caused by biofuel production, threat to birds posed by wind power plants, noise, disturbance of ecological balance, reduction of landscape values,

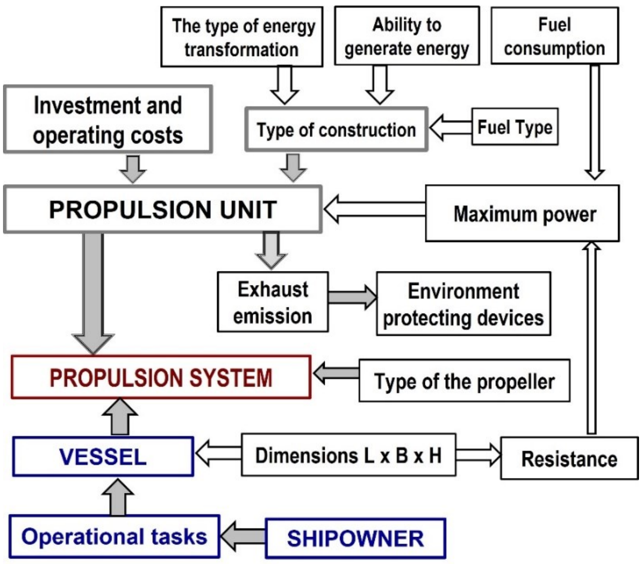

Fig. 1. The factors influencing the choice of propulsion system for a vessel [source: author's own elaboration]

- Social benefits (*SB*) - ecological point of view, reduction of diseases caused by harmful emissions,
- *Application optimization (AO)* - justification of the selection of a given drive according to measurable and non-measurable criteria [3],

Particular characteristics of the vessel (PChV) - characteristics specific only to a particular unit, specifics of construction, working environment and operational quality.

The concept of sustainable development, apart from measurable values, e. g. economic factor (*EF*), also includes non-measurable factors, which include: social factor (*SF*) (cultural conditions, level of technical culture, level of unemployment, educational values, e.g. ecological point of view. This results in increased financial outlays and the need for society to accept these costs.

Considering the above analysis, the following criteria should be considered in the *Concept Selection Matrix (CSM)* of the inland waterway vessel propulsion (1), (2):

$$\{\mathbf{CSM}\}:\{\mathbf{EcFac}, \mathbf{SocFac}, \mathbf{PChV}, \mathbf{R}\} \quad (1)$$

$$\{\mathbf{CSM}\}:\{\text{CR, ESD, R, HE, Dur, TDS, TBTI, IC, OC, SC, SB, AO, PChV, } \mathbf{R}\} \quad (2)$$

Where: *R* - stands for mutual relations and interaction of matrix elements with each other.

Depending on the drive type application, the values listed are variable and the values of the individual factors must be estimated, as well as the proportions of their importance in relation to each other.

The exemplary units have been analysed according to the criteria given above:

- Diesel engine fuelled by hydrocarbon liquid fuel (*DEFHLF*).
- Diesel engine fuelled by liquid vegetable oil fuel (*DEFLVO*).
- Steam turbine fuelled by liquid hydrocarbon fuel (*STFLCF*).
- Steam turbine fuelled by a gaseous hydrocarbon fuel (*STFGHF*).
- Gas fuelled diesel engine (*GFDE*) with methane - *LNG, CNG*, propane-butane - *LPG, CPG*.
- Diesel engine fuelled liquid alcohol (*DEFLA*).
- Diesel engine - electric motor (*DE-EM*) powered by the chemical energy of a hydrocarbon fuel converted to electricity through a generator.
- Diesel engine – powered by ammonia burned in the engine (*DE-BAm*) [11]
- Electric motor - fuel cells *FC* fuelled by ammonia (*EM-FCAm*) [11]
- Electric motor - fuel cells *FC* (*EM-FC*)
- Styrling engine- (SEPHS) powered by any heat source.
- Electric motor - photovoltaic *PV (SE-PV)* cells.

3. Propulsion selection for inland waterway vessels

The main factor on which the efficiency of inland waterway transport depends is the depth of the waterway. It affects the size of the vessel, the speed at which it can perform the transport tasks, the punctuality and reliability of deliveries, the fuel consumption which also depends on the speed of the vessel. Each drive unit has its own design and operating characteristics depending on the design of the drive unit, the energy conversion method and the type of fuel used. Usually the lowest fuel consumption is designed for 60 - 85 % of the effective power (Ne). The load reserve is anticipated for deteriorating swimming conditions or the need to increase the speed of the vessel. Therefore, a speed is sought at which the efficiency of the vessel is highest e.g. priority short delivery time for vessel cargo, even at the expense of the efficiency of the power unit.

The choice of the type of propulsion depends on the draught of the ship, the required manoeuvrability, the amount of power the propeller should transfer to overcome the resistance, as well as its efficiency and cost. An example process for optimizing the drive selection process depending on the selected criteria was developed by the authors in earlier publications, which is briefly presented below.

When a solution is selected and marketed, its value in use meets the needs of the market. After a period of time, the value in use corresponds to its aging dynamics. Important considerations in the choice of propulsion type are to maximise their service value and minimise the probability of loss of safety over the entire life cycle of the inland waterway vessel. The very process of its exploitation can be written in the form of a set of individual states of its structural-functional parameters (3):

$$X_{kf}(t) = \{x_{1f}(t) x_{2f}(t) \ldots x_{kf}(t)\} \quad (3)$$

whereby:

$k=\overline{1,m_f}$

$f=\overline{1,m_f}$

Where:

$X_{kf}(t)$ - the vector of structural and functional propulsion parameters of the inland waterway unit in the k-th state of its capacity to perform f-th transport task at time t;

in the course of each transport task with specified by working conditions loads, the wear of ship structure elements and ship equipment, including elements of propulsion system, takes place, and with each task the wear will be bigger. It will cause quantitative and qualitative change of constructional and functional parameters values,

m_f - the number of possible propulsion states of the inland waterway unit when performing f-th transport task;

the propulsion state of a drive unit, including torque load or thermal load, depends on the unit's operating conditions, i.e. the effect of the operating environment and the operational decisions of the decision-makers,

f_m - the complete set of transport tasks which an inland waterway unit can be involved;

each transport task is performed under different environmental conditions and requires different operational measures and thus different costs, different fuel consumption and different stresses on the vessel's structure and propulsion.

Assuming that each component of the vector $X_{kf}(t)$ is assigned some number K_k from the K-th set of real numbers, then it can be written (4):

$$K[X_{kf}(t)] = \{K_1 K_2 \ldots K_k\} \tag{4}$$

Each of these numbers is a value of the drive quality-of-use index, and the value-of-use index can be evaluated by assessing functional effectiveness.

In Figure 2. factors affecting the selection of fuel and driving unit are presented, while Table 1 gives an exemplary classification of characteristics of hydrocarbon-fuelled drives as well as alternative solutions.

Each of the terms grading the described criteria can be assigned measurable values, e. g. numbers from 1-5, or weights determined by mathematical relations.

In Table 1. the characteristics of hydrocarbon and alternative propulsion systems are presented according to selected criteria.

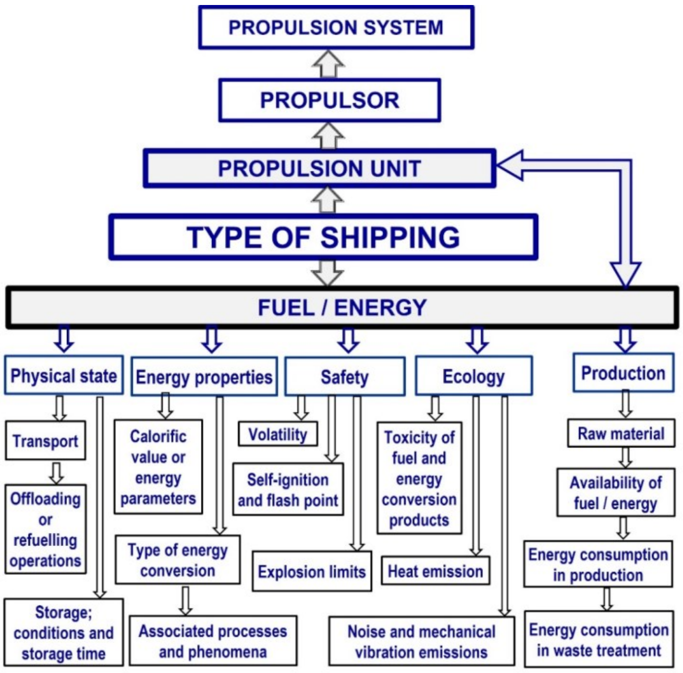

Fig. 2. Factors affecting fuel and power unit selection [source: author's own elaboration]

Table 1. Features of HC and alternative drives [source: author's own elaboration]

L.p.	PROPULSION COMPARISON CRITERIA	TYPES OF INLAND WATERWAY VESSEL PROPULSION				
		DEFHLF	*DEFLA*	*SE-PV*	*EM-FC*	*(DE-Am/DE-BAm)*
1.	**Energy supply/fuel**	HC fuel	Alcohol	Solar radiation	Hydrogen compounds, oxygen	Ammonia
2.	**Achieved power**	Very high	Very high	Very low	Low	High
3.	**Range, fuel and energy storage**	Very high	High	Small	High	Medium
4.	**Harmful emissions**	high	low	No	No	Possible CO_2 and NO_x emissions
5.	**Utility values**	Easy to handle, flexible use in the power range small - very large	Easy to handle, flexible use in the power range low - very high	No harmful products of energy conversion, no oxygen required	Clean energy, quiet operation	High service qualifications, flexibility of application in the power range small - large
6.	**Restrictions**	High oxygen consumption	High oxygen consumption	Limited solar radiation, low energy storage capacity	Small capacity, difficult fuel storage	Difficult fuel storage, CO_2 emissions
7.	**Maintenance required**	Easy replacement of parts	Easy replacement of parts	Minimal maintenance	Specialised service	Specialised vessel crew and service personnel
8.	**Economic**	Low operating costs, high efficiency 35 – 65 %	Low operating costs, high efficiency of 35 - 65 %	High investment costs, very low efficiency 10 -30 %	High investment costs, very high efficiency 50 -90 %	High investment costs, efficiency depending on the technical solution
9.	**Applicability**	Long-term operation without replenishing the energy source	Long-term operation without replenishing the energy source	Complementary to other propulsion systems when large environmental regime is required	Clean energy, quiet operation, no air	Clean energy
10.	**Operational suitability**	Very large power range, great flexibility in application	Very wide power range, high application flexibility	Small for commercial shipping, large surface area required	Small due to low power for shipping conditions	One of the target solutions experimental/high

In Figure 3. the factors affecting the rational selection of propulsion units depending on the specifics of the basin and on planning the type of sailing or the environmental protection policy were presented.

The most commonly used drive selection algorithms are based on measurable metrics.

In contrast, aspects such as safety or environmental protection have non-measurable values in addition to measurable costs, which are described in the paper.

Always in the process of selection of the propulsion system of an inland waterway vessel several variants are taken into consideration and the one which most satisfies the requirements and criteria selected by the designer is selected.

When selecting compared and evaluated multi-criteria variants possible to implement in operating conditions, the effects and consequences of the selected solutions are also taken into account. This process can be described by mathematical relationships in a specified admissible solution space between independent variables and their constraints. The mathematical form of the decision process requires the definition of: parameters, decision variables, constraints, criterion function.

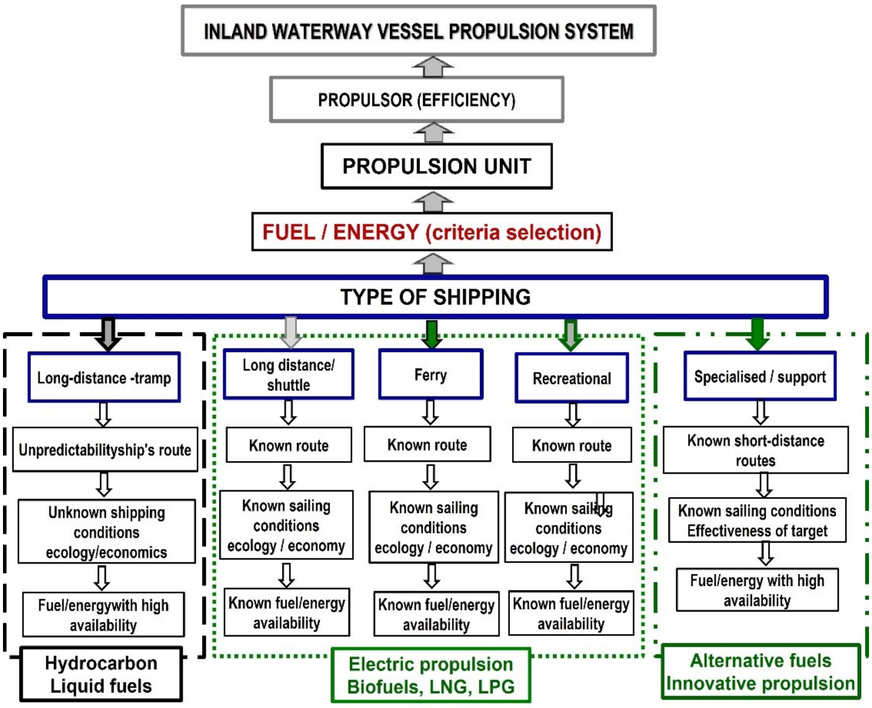

Fig. 3. Factors affecting the rational selection of propulsion units depending on the specifics of the basin and planning of the type of navigation [source: author's own elaboration]

Most often in practice, a combination of multiple methods and mathematical solutions is also used with methods based on expert knowledge. This is aimed at creating a decision-making model allowing to make an accurate decision, adequate to the expectations of e.g. a shipowner, whose vessel is to perform operational tasks safely for the crew and the society, effectively and safely for the environment.

CONCLUSIONS

The introduction of innovative solutions on inland waterway vessels recommended by the EU requires high investment and operating costs and a change in the environmental awareness of the public.

The size of inland waterway vessels shall depend on the parameters characterising the waterways in which the vessels perform their operational tasks.

Therefore, the process of selection of vessels and propulsion units should be carried out during the design of newly built means of transport, adapting them to the existing and planned infrastructure, providing them with adequate service.

Modernization of the already existing solutions is very limited due to the necessity of making major changes in the technical structure of the facilities and thus incurring high costs.

On larger inland waterways, the use of renewable energy PV, FC or waste heat propulsion such as Stirling engines is possible to a very limited extent in long distance shipping. These solutions can be used in coastal waters, harbours, with sufficiently developed infrastructure to ensure easy energy or fuel refuelling, or on recreational craft using less Energy.

Also in the proposed selection process for inland waterway vessel propulsion systems based on multi-criteria analysis, appropriate weights should be assigned to economically unquantifiable values, depending on the application of the vessels.

Innovative ship propulsion solutions fuelled by alternatives to fuels or energy, e.g. natural gaseous or gaseous and oil liquids hydrocarbons crude oil-derived, must be used on newly designed manned vessels or may be used on remotely operated or autonomous vessels, which as vessels of the future and must be designed in accordance with environmental policies, including low- or zero-emission propulsion.

Despite many promotional activities and technical, legal and economic solutions, the use of innovative technologies (requiring huge costs and research) requires the support of government programs just as in the development of for example, electromobility in other branches of transport [12].

ANALIZA NAPĘDU ŚRÓDLĄDOWYCH JEDNOSTEK PŁYWAJĄCYCH WEDŁUG KRYTERIUM EFEKTYWNOŚCI, EKOLOGII I BEZPIECZEŃSTWA

W artykule dokonano analizy napędów śródlądowych jednostek pływających we-dług kryteriów efektywności, ekologii i bezpieczeństwa. Doświadczenie zawodowe autorów i ich wiedza ekspercka wskazują, że zawsze wzrost poziomu bezpieczeństwa jak i rozwiązania ekologiczne realizowane są kosztem efektywności. Dlatego też, argumentując wynik takiej analizy opisano cechy akwenów, infrastruktury portowej oraz elementy, które powinny mieć wpływ na dobór napędów, cechy energii zasilającej i paliw z ich wartością energetyczną gwarantującą zasięg pływania. Scharakteryzowano typy napędów oraz przedstawiono model doboru napędu do typu żeglugi. Analiza przed-stawiona w artykule jest niezbędna do rzetelnej oceny trafności doboru napędu do rzeczywistych warunków eksploatacji jednostek pływających, czyli do typu jednostki oraz jej zdatności do wykonania zadań eksploatacyjnych na określonych akwenach.

Słowa kluczowe: napędy śródlądowych jednostek pływających, kryteria efektywności ekonomicznej, ekologii i bezpieczeństwa, dobór układu napędowego do warunków rzeczywistych

REFERENCES

[1] Abramowski T. (2008). "Application of artificial neural networks to assessment of ship manoeuvrability qualities". Polish Maritime Research, 2(56), Vol. 15, pp 15-21. https://doi.org/10.2478/v10012-007-0059-0

[2] WHITE PAPER Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system, (COM/2011/0144 final)

[3] Cepowski T. (2007). "Approximation of the index for assessing ships sea-keeping performance on the basis of ship design parameters". Polish Maritime Research, 3(53), Vol. 14, pp 21-26. https://doi.org/10.2478/v10012-007-0014-0

[4] Percic M., Vladimir N., Korican M. (2021). „Electrification of Inland Waterway Ships Considering Power System Lifetime Emissions and Costs", Energies, 14, 7046. https://doi.org//10.3390/en14217046

[5] Piątek D. (2019). "New Concept of Hybrid Propulsion with Hydrostatic Gear for Inland Water Transport", Polish Maritime Research, 2(102), Vol. 26, pp 134-141. https://doi.org/10.2478/pomr-2019-0033

[6] Litwin W., Leśniewski W., Piątek D., Niklas K. (2019). "Experimental Research on the Energy Efficiency of a Parallel Hybrid Drive for an Inland Ship", Energies 2019, 12(9), 1675. https://doi.org/10.3390/en12091675

[7] Zalacko R., Zöldy M., Simongáti G., (2021). "Comparison of alternative propulsion systems a case study of a passenger ship used in public transport", Brodogradnja, 72(2). http://dx.doi.org/10.21278/brod72201

[8] Kunicka, M., Litwin, W. (2019). "Energy Demand of Short-Range Inland Ferry with Series Hybrid Propulsion Depending on the Navigation Strategy". Energies, 12, pp 1-14. https://doi.org/10.3390/en12183499

[9] Mrzljak V., Mrakovčić T. (2016). "Comparison of COGES and Diesel-Electric Ship Propulsion Systems", Pomorski zbornik , Vol. Special edition No. 1, pp 131-148. https://doi.org/10.18048/2016-00.131

[10] European Commission: Guidance document on Inland waterway transport and Natura 2000, Ecosystems LTD under contract to the European Commission (2012) (contract N° 070307/2010/ 513837/SER/B2)

[11] https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX%3A32016L1629

[12] https://www.wartsila.com/insights/article/successful-tests-pave-the-way-for-ammonia-as-a-future-marine-fuel

[13] Pamik M., Nuran M. (2021). "The historical process of the diesel electric propulsion system" Dokuz Eylül University, Maritime Faculty Journal, 13(2), pp 299-316. https://doi.org/10.18613/deudfd.932650

[14] Jerzy Girtler J.(2017). "Features of load and wear of main propulsion devices on sea-going ships with piston combustion engines and their impact on changes in technical states of the systems", Polish Maritime Research, 4(96), Vol. 24; pp 57-66. https://doi.org/10.1515/pomr-2017-0136

[15] Szelangiewicz T., Żelazny K. (2007) "Mean long-term service parameters of transport ship propulsion system - Part I - Screw propeller service parameters of transport ship sailing on a given shipping route", Polish Maritime Research, 4(54), Vol. 14; pp 18-23. https://doi.org/10.2478/v10012-007-0035-8