EXPERIMENTAL RESEARCH ON REED HARVESTING WITH "ERBA" ELECTRIC BOAT
/
CERCETĂRI EXPERIMENTALE PRIVIND RECOLTAREA STUFULUI CU AMBARCAȚIUNEA ELECTRICĂ "ERBA"

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ABSTRACT

The article presents the results obtained from experimental research conducted with an electric equipment (a watercraft) for harvesting aquatic biomass (reed, cattail, water lily, etc.), remote controlled, symbolized as ERBA. This equipment was designed and built in Romania by researchers from INMA Bucharest and ICPE-CA, at the level of experimental model. The purpose of this equipment is to develop a national system of machines for cleaning lakes, navigable canals, and specific areas of the Danube Delta Biosphere Reserve from excess biomass that needs to be removed for the proper functioning of aquatic ecosystems. The harvested biomass is used as raw material for the production of liquid and gaseous fuels, as well as biofertilizers, which can be utilized as inputs in the bioeconomy. The phenological characteristics of the harvested biomass, the structural and functional characteristics of the vessel, the laboratory experimental records, the nautical indices, the exploitation indices, and the energy consumption were measured under different working conditions and regimes, and with different types of biomass.

REZUMAT

Articolul prezinta rezultatele obținute in cadrul cercetărilor experimentale ale unui echipament electric (ambarcațiune) de recoltat biomasa acvatica (stuf, papura, zambila de balta, etc.), controlat de la distantă, simbolizat ERBA, echipament proiectat și realizat în Romania, de cercetătorii de la INMA București și ICPE-CA, la nivel de model experimental. Echipamentul a fost realizat in scopul dezvoltării pe plan național a sistemei de mașini destinată curățării lacurilor, canalelor navigabile și a zonelor specifice Biosferei Delta Dunării, de biomasa în exces care trebuie înlăturată pentru buna funcționare a ecosistemelor acvatice. Biomasa recoltată poate fi folosită ca materie prima pentru obținerea de combustibili lichizi, gazoși și biofertilizatori, produse care pot fi utilizate ca inputuri în bioeconomie. Au fost măsurate caracteristicile fenologice ale biomasei recoltate, caracteristicile constructive și funcționale ale ambarcațiunii, înregistrate la experimentările de laborator, indicii nautici, indicii de exploatare și consumul de energie, realizate in diferite condiții și regimuri de lucru și diferite tipuri de biomasă.

INTRODUCTION

Aquatic weed control is a critical aspect of maintaining the health and balance of aquatic ecosystems. There are studies about various methods and strategies for effectively managing and controlling aquatic weeds. These studies provide valuable insights into the challenges associated with aquatic weed control and offer potential solutions to mitigate their negative impacts.

One common approach discussed by *Siemering and Hayworth, (2005), and Hofstra and Clayton, (2001)* is the use of herbicides and surfactants for aquatic weed control. The paper evaluates the efficacy and environmental impacts of different herbicides, considering factors such as target weed species, application methods, and potential non-target effects. The research aims to identify herbicides that effectively control aquatic weeds while minimizing harm to non-target organisms and the aquatic ecosystem.

Another area of focus is the use of biological control methods for aquatic weed management exploring the use of natural enemies, such as insects or fish, to control the growth and spread of invasive aquatic weeds. The research investigates the effectiveness of different biological control agents, their impact on non-target species, and the long-term sustainability of such approaches. These studies provide valuable insights into the potential benefits and limitations of biological control as a strategy for aquatic weed management *(Torawane and Mookat, 2019)*.

Additionally, there is a discussion about the importance of integrated weed management approaches for effective and sustainable aquatic weed control. *Clayton (1996)* and *Lavergne and Molofsky, (2006),* emphasize the need to combine multiple control methods, such as mechanical removal, herbicide application, and biological control, to achieve optimal results. The research explores the effects of integrating different control strategies and assesses their long-term effectiveness in preventing weed resurgence and maintaining the ecological balance of aquatic ecosystems.

Reed, often considered a weed, has emerged as a valuable resource for biofuel production and is seen as a highly promising and sustainable option. Reed, also known as Phragmites communis, is a tall perennial grass that grows in wetlands and marshy areas. It has gained attention as a potential feedstock for biofuel production due to its high biomass yield and ability to grow in diverse environmental conditions *(Obreja et al, 2023; Sciuto et al, 2023).*

One of the key advantages of using reed as a source of biofuels is its abundance. It is widely available in various regions around the world, making it a readily accessible and cost-effective feedstock. This availability reduces the dependency on traditional fossil fuels and contributes to a more sustainable energy future *(Piccitto et al, 2022, Shahrukh et al, 2021).*

Furthermore, reed is a highly efficient plant in terms of biomass production. It has a rapid growth rate and can yield a significant amount of biomass per unit area. This makes it an attractive option for biofuel production, as it can provide a substantial feedstock supply without requiring excessive land use.

In addition to its high biomass yield, reed also offers environmental benefits. It has the ability to absorb and store large amounts of carbon dioxide during its growth, thereby acting as a carbon sink. By utilizing reed as a source of biofuels, greenhouse gas emissions can be effectively reduced and climate change impacts mitigated *(Ivan et al, 2016).*

Moreover, reed can be cultivated in marginal lands or areas unsuitable for traditional agriculture. This means that it does not compete with food crops for arable land, ensuring food security while simultaneously supporting biofuel production. This aspect makes reed a sustainable and socially responsible choice for biofuel feedstock.

Chao at al. investigates the physical and mechanical properties of mature reed stalks grown in the Yangtze River region. The experiments revealed various parameters, including stress resistance intensity, pulling resistance intensity, bending resistance intensity, shearing resistance intensity, and modulus of elasticity. The results showed that the reed stem material exhibited significant anisotropy and non-linearity, suggesting the need for an anisotropic constitutive relationship when establishing reed mechanical models.

Furthermore, the article presents the differences between the physical and mechanical properties of reed compared to other crops such as *Arundo donax L.,* ramie, and wheat. These differences indicate that traditional agricultural machines used for cutting and processing other crops may not be suitable for reed harvesting. Therefore, it is recommended the adoption of a new cutting technology that aligns with the specific physical and mechanical properties of reed.

In conclusion, reed holds great potential as a source of producing biofuels. Its abundance, high biomass yield, environmental benefits, and ability to grow in diverse conditions make it an attractive option for sustainable energy production. By harnessing the power of reed, the reliance on fossil fuels can be reduced, climate change can be mitigated, and a contribution to a greener future can be brought.

Aquatic reed harvesters are specialized machines designed for the efficient and sustainable harvesting of reeds from wetland areas. These machines are specifically engineered to navigate through water bodies, such as lakes, ponds, and marshes, where aquatic biomass typically grow *(https://headdredging.com;https://relong-tech.com;https://aquarius-systems.com/equipment/aquatic-weed-harvester/; Ștefan et al, 2022; Tudor et al., 2023).*

The modern harvesters are innovative machines that have been specifically designed to efficiently harvest biomass while incorporating sustainable practices such as utilization of renewable energy sources and electrically power, making them environmentally friendly alternatives to traditional harvesting methods. They are equipped with converters that efficiently convert renewable energy into usable electrical power.

With integrated converters and electric motors, these harvesters eliminate the need for additional external equipment, streamlining the harvesting process *(Tudor et al. 2022; Popovici et al., 2022).*

The primary purpose of aquatic reed harvesters is to collect reeds in a controlled and systematic manner. They are equipped with cutting mechanisms, typically in the form of rotating blades or sickle bars, which can efficiently cut the reeds at the desired height. The harvested reeds are then collected and stored on board the machine for further processing. One of the key advantages of using aquatic reed harvesters is their ability to minimize environmental impact. These machines are designed to operate with minimal disturbance to the surrounding ecosystem. They are equipped with low ground pressure tracks or pontoons, which distribute the weight of the machine evenly and prevent damage to the wetland habitat.

Aquatic reed harvesters also offer increased efficiency and productivity compared to manual harvesting methods. They can cover large areas in a relatively short period, allowing for faster and more cost-effective reed collection. Additionally, these machines are often equipped with advanced features such as GPS navigation and automated cutting systems, further enhancing their efficiency.

Huang et al, (2022), analyses the development and optimization of a reed harvester for efficient and effective reed harvesting. It highlights the current limitations of domestic reed harvesters, such as the lack of mature technology, versatility, and mass production. The study focuses on designing a reed harvester that integrates cutting and conveying processes, analyzing key components, and determining optimal working parameters. Through a quadratic orthogonal rotation combination test and regression mathematical modeling, the study identifies the optimal combination of operation parameters for the reed harvester. The results demonstrate that with a forward speed of 0.85 m/s, cutting speed of 1.40 m/s, and chain conveying speed of 1.33 m/s, the harvester achieves a failure rate of 4.17%, cutting efficiency of 44.21 plants/s, and conveying rate of 93.60%. These optimized parameters were further validated in field tests, where the relative errors with the optimized values were within an acceptable range.

Overall, the study provides a theoretical basis for controlling operating parameters and improving the design of reed harvesting implements. The developed reed harvester effectively addresses challenges such as uneven stubble, low cutting efficiency, and blockage during the conveying process. The optimized parameters ensure that the harvester meets the requirements for reed harvesting, with satisfactory performance in terms of failure rate, cutting efficiency, and conveying rate.

Due to the rising number of internal-combustion automobiles that rely on non-renewable conventional fuels, there has been a surge in energy-related concerns and environmental problems (*Tudor et al, 2022; 2023)*. Consequently, numerous countries have introduced electric vehicles as substitutes for traditional automobiles, aiming to decrease reliance on oil and mitigate the air pollution associated with conventional *vehicles (Wenbo et al, 2016; Hu etal, 2018; Calotă et al, 2022; Suvac et al, 2019, Culcea et al, 2023).*

Furthermore, the use of aquatic reed harvesters can contribute to the sustainable management of wetland ecosystems. By selectively harvesting reeds, these machines can help control the growth and spread of invasive species, maintain biodiversity, and promote the overall health of the wetland habitat.

The aquatic reed harvesters are specialized machines that play a crucial role in the efficient and sustainable harvesting of reeds from aquatic environments. Their ability to minimize environmental impact, increase productivity, and contribute to the sustainable management of wetland ecosystems make them valuable tools in the reed harvesting industry.

MATERIALS AND METHODS

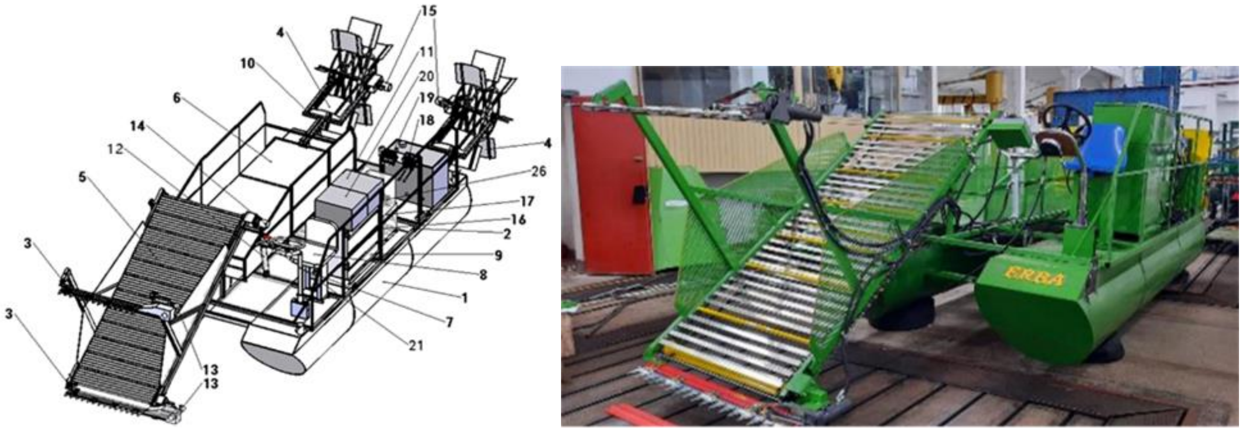
The researchers are faced with a technical challenge in developing an electric vehicle harvester for aquatic vegetation. This challenge arises from the specific requirements of the harvester, such as the need for high torque at low speeds, maneuverability, high load capacity, low draught, and affordability. To address these requirements, the authors proposed an electro-hydraulic architecture that utilizes paddles driven by hydraulic motors for propulsion and auxiliary services, also powered by motors and hydraulic actuators.

For conducting the tests, the ERBA electric equipment was used. This machine was developed within a larger research project that aimed to utilize the harvested biomass as a source of liquid biofuel. The equipment for harvesting aquatic biomass, ERBA (Fig.1 a, b), is a self-propelled device powered by a hydrostatic electric motor, remotely controlled.

It performs the cutting of the biomass, stores it in a collection bin, and transports it to the unloading area. The biomass is unloaded either into another aquatic transport vehicle or in a nearby temporary storage area.

The key components of the equipment presented in Fig.1a are identified as: *1* - assembled floats, *2* - welded frame, *3* - double-blade cutter bar, *4* - paddle wheel, *5* - conveyor, *6* - biomass collection bin, *7* - steering system with rudder, *8* - user seat, *9* - electric batteries, *10* - plate indexing, *11* - electrical elements, *12* - hydraulic actuator, *13* - hydraulic knife drive motor, *14* - conveyor chain drive hydraulic motor, *15* - paddle drive hydraulic motor, *16* - electric motor, *17* - double pump, *18* - Proportional distributor, *19* - sectional distributor, *20* - electronic control, *21* - remote control, *26* - converter.

For the energy source of the harvester, the authors have developed a system of 33 kWh Li-Ion batteries connected in parallel. These batteries supply an electronic converter and a 14.5 kW rated power electric motor, which in turn drives a hydraulic double-circuit pump. Additionally, this vehicle can be controlled remotely.



a) b)

Fig. 1 – Reed harvester experimental model (ERBA):
a) key components design b) manufactured equipment

The *float assembly* consists of two floats, each measuring 4.5 meters in length, with a diameter of 0.8 meters at the bottom and a straight section with a width of 0.7 meters at the top. Each float is made up of three sections, each measuring 1.5 meters in length, welded together with metal, and sealed tightly.

The *paddle wheel, two in number, provides* propulsion for the vessel. The active part of each paddle wheel consists of 8 curved blades arranged radially, driven by a hydraulic motor. The role of the paddle wheels is both for forward movement and for left/right turns. The control is achieved using a proportional distributor, which ensures independent operation of each paddle wheel and the variation of speed, depending on the need, by adjusting the oil flow transmitted to the hydraulic motor.

The equipment for harvesting aquatic biomass performs the cutting of aquatic biomass, especially reeds, in deep water conditions exceeding 1 m. The equipment for harvesting aquatic biomass is intended for the collection of aquatic biomasses, in the Danube Delta, as well as other areas of interest such as ponds, navigable canals, lakes, recreational areas, etc.

The *cutting system* is equipped with two double-blade cutting devices, with guide plates and triangular lamellar blades, which have an alternating rectilinear motion and are individually driven by a hydraulic motor. The guide plate cutting device includes a main bar, guides, guide plates, blade rail carriers, knife blades, and detachable assembly elements. The knife blades are riveted to the blade rail carriers and have two sharp, smooth edges. The aquatic biomass harvesting equipment, performs the cutting of low-lying biomass at water level using only the lower blade (Fig. 2b), while reeds, cattails, or other tall plants are cut into two fractions using both blades, with the upper blade positioned 1.5 m above the lower blade (Fig 2 a). The upper blade, which cuts the stem above the water, is positioned 100 mm horizontally in front of the lower blade, performing the first cut.

The harvested biomass is then taken up by the conveyor belt and discharged directly into the *collection bin area,* which is a fixed metal structure welded to a frame, with a useful volume of approximately 2.5 m^3. Both the walls and the floor of the bin are secured with self-drilling screws and made of perforated sheet metal to allow easy drainage of water.

The *hydraulic system* assembly provides the necessary hydrostatic energy for the equipment movement and the operation of all functional systems of the vessel. It consists of a dual gear pump that supplies two hydraulic circuits (the first circuit operates the flaps through two hydrostatic motors and the second circuit operates the hydrostatic motors that drive the conveyor, cutting blades, and the two hydraulic cylinders that lower and raise the conveyor).

The *electronic control* system assembly allows remote operation of the vessel or operation by an operator on board, depending on the control mode.

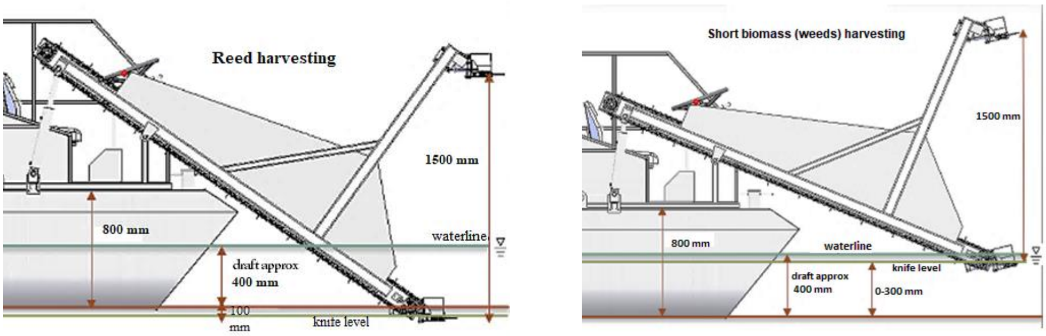


Fig. 2 – Biomass cutting possibilities for

a) tall biomass (reed); b) short biomass

When measuring a vessel, there are several nautical indices that are commonly measured to assess its performance, stability, and overall operational characteristics. Some of the key nautical indices include: draft, length overall, beam (maximum width), displacement, freeboard, speed, etc.

The total length *(L)* of the equipment is measured from its forwardmost point (bow) to its aftmost point (stern), including any extensions or overhanging parts. This measurement is used to quantify vessel size and is often a governing factor for regulations and restrictions.

Beam is the maximum width *(l)* of the vessel measured at its widest point. Beam provides an indication of a vessel stability and carrying capacity.

The experimental research focused on determining the state of buoyancy and equilibrium of the vessel, calculating the inertia at rest and determining the characteristics and operational indices of the vessel.

Buoyancy is defined as the tendency of a body to float or rise when submerged in a fluid. The resultant force acting on a submerged body by the fluid is called the *buoyant force.* For a boat to float in equilibrium, it is necessary that the weight of the displaced water be equal to the weight of the ship. If the body weighs more than the fluid - it sinks; if the body weighs less than the fluid - it floats.

Two forces act on the vessel floating on the water: the weight of the ship P and the weight of the volume of water displaced by the ship's body (floats) D, according to Archimedes' principle. Forces P and D are equal in magnitude, opposite in direction, and act along the same line normal to the basal plane. P has its point of application at center of gravity of the ship, and D has its point of application at center of gravity of the hull. The weight of water displaced by the ships body (floats) D is determined, according to equation of flotation, eq. (1).

$$D = \gamma \cdot V_s = P \tag{1}$$

where: P is the weight of the ship, including operator weight, (N); D is the weight of the volume of water displaced, (N); $\gamma = \rho \cdot g$ is the specific weight of water, (N/m^3), ρ is the density of water (kg/m^3), g is acceleration of gravity (9.81 m/s^2), V_s is the volume of the submerged part of the floats, (m^3).

Another nautical parameter that needs to be measured is the *draft (h).* Draft is represented by the vertical distance from the vessel waterline to the deepest part of its hull and is important for determining the vessel immersion level, load-carrying capacity, and maneuverability in shallow waters. The volume of fluid displaced can be estimated by multiplying the draft *(h)* by the cross-sectional area (A) of the submerged part of the vessel hull:

Working capacity, *W,* measures the proportion of reeds effectively harvested by the electric reed harvester. It takes into account factors such as the cutting mechanism, collection system, and overall design of the harvester. Higher harvesting efficiency indicates a more effective harvester.

Working capacity, W, is represented by the area harvested in a unit of time at a certain speed of travel established, according to relation (10).

$$W = \frac{v \cdot l_f \cdot t}{10^5} \tag{2}$$

where W is the work capacity, (ha/h); v is the boat speed, (km/h); l_f is the furrow width, (m); t is harvesting time, (h).

The energy efficiency has to be measured to evaluate the autonomy of the vessel, using the power consumption during various tests, including the trip using solely the paddlewheels, and the harvesting of various types of crops. The targeted autonomy of this vessel was 2 hours of harvesting within a 10 km trip.

For the different operation regimes of the vessel, maximum autonomy can be computed from the maximum available energy by dividing to the power level absorbed during that task.

$$A_{trip} = \frac{E_{max} - E_{min}}{P} \left[\frac{kWh}{kW}\right] \tag{3}$$

To compute the A_{trip} for various operations, it is necessary to know the storage capacity of the battery and the average power consumption during various modes of operation, like the power consumption during movement using only the paddlewheels, or during harvesting using knives, loader and paddlewheels.

The real autonomy computed is evaluated using the hourly consumption Q, which has to be determined in the same way the Electric Vehicles are used to, by measuring the initial and the final energy stored in the battery pack, by using the SOC (State of Charge) values, and the operating time t_{op}.

$$Q = \frac{E_{init} - E_{act}}{t_{op}} \left[\frac{kWh}{h}\right] \tag{4}$$

where E_{init} is the energy at the beginning of the daily trip, [kWh]; E_{act} is the actual remaining energy, [kWh] and t_{op} is the operating time, [hours]. The value of the hourly consumption, Q, is used to compare the efficiency of the drive and to compute the remaining time of operation, also called the autonomy of the vessel, A, [h]. The remaining range (expressed in operating hours) is an estimate based on reporting the remaining energy to average hourly consumption Q of that day.

$$A = \frac{E_{act} - E_{min}}{Q} [h] \tag{5}$$

where E_{act} is the actual remaining energy, expressed in kWh, E_{min} is the minimum energy (usually 20% of the total stored energy) in kWh and the average hourly consumption Q is expressed in kWh/h.

Test time and movement time are reported by the GPS tracking system. The initial and final energy levels were deducted from the battery pack voltages using the voltage state-of-charge dependency curve as measured in the laboratory. No temperature correction was used for the real storage capacity.

RESULTS

The experimental research in the real environment took place from February 2023 to April 2023 at the Fish Farm in the locality of Săbiești, Dâmbovița County, Romania. On this occasion, the equipment was launched into the water, and the first demonstrations in the real environment were conducted.

Before this, measurements were carried out at idle to verify the correspondence between the technical execution documentation and the physically constructed equipment within the execution department, recording its constructive characteristics. The constructive characteristics of the aquatic biomass harvesting equipment are shown in Table 1. The overall functional verification was checked to observe the proper operation without noises and vibrations, tightness of the hydraulic system and floaters or any unauthorized heating of moving components. All the necessary adjustments were performed and the equipment was prepared for the real environment tests.

Table 1

The constructive characteristics of ERBA harvester

Parameters	Values
Overall dimensions size (length×width×height) /mm×mm×mm	7800x2500x1800
Electric engine power/kW	14,5
Battery storage capacity/kW	33
Cutting width/mm	1100
Machine weight/kg	1880
Paddlewheel diameter/mm	1300
Float dimension (length×width×height) /mm×mm×mm	4500x800x750

The experimental research began with determining the buoyancy of the vessel, considering its own weight and then with various loads. The buoyancy and the depth of immersion (draft) are correlated and were determined taking into account the constructive characteristics shown in Table 1.

Under these conditions, the draft of the vessel (Fig. 3) could be observed, with its mass of 1880 kg (without load and people on board), being 0.35 m (out of the total 0.75 m float height, of which 0.40 m are above the waterline). The draft of the vessel with people on board is shown Fig. 4. *Draft* is the vertical distance measured from the baseline to the waterline.

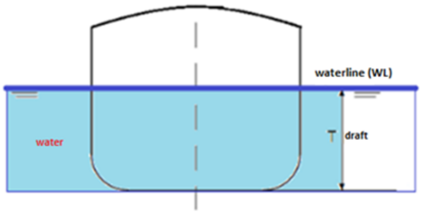


Fig. 3 – Draft measurement

Fig. 4 - Measuring the draft of the boat in different conditions

The correlation between equipment total mass (own mass+ load) and the deep of immersion (draft) is very important for the equipment not to sink. The obtained results can be read in Fig. 5. It is recommended that the overall mass does not exceed 80% of total load capacity, meaning a total maximal load of 1720 kg.

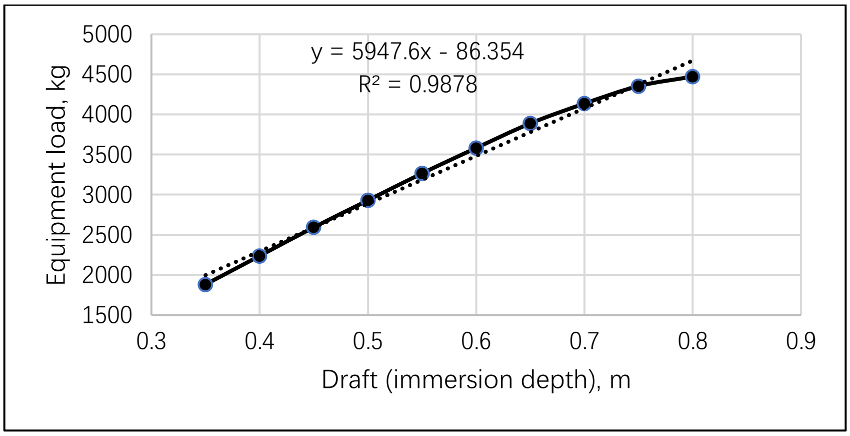


Fig. 5 - The correlation between equipment total mass and draft

It also has been measured the *turning circle* which refers to the path followed by a vessel when making a turn. It's a critical consideration for ship maneuverability, provides vital information about the ship's maneuverability and ability to navigate in narrow or crowded waters. It helps determining how much space a ship needs to execute turns safely and efficiently, which is critical for avoiding collisions and safely navigating through channels, and other confined areas. The nautical indices measured or calculated are presented in Table 2.

Table 2

Nautical indices

Parameters	**Values**			
	Test 1	**Test 2**	**Test 3**	**Average**
Buoyant force for equipment owns mass (1880 kg), N	18639	-	-	-
Buoyant force at the operating mass of the equipment (2500 kg), N	25702	-	-	-
Draft at its own mass (1880 kg), m	0.34	0.36	0.35	0.35
Draft at load and operators' mass (2500 kg), m	0.45	0.46	0.48	0.463
Inclination around the longitudinal axis without load, °	1 (towards the front)	1	1	1
Inclination around the longitudinal axis with load, °	1.5	1.5	1.5	1.5

Parameters	Values			
	Test 1	Test 2	Test 3	Average
Turning circle diameter with one propeller engaged (pivot turn), m	8	8	8	8
Duration of the pivot turn, s	21	19	20	20
Turning circle diameter with both propellers in operation, m	16	15.5	16.5	16
Duration of the turn with both propellers in operation, s	34	35	33	34

Inertia represents the ability of the vessel to continue its movement through water after a change in the regime of the ship propulsion, such as stopping or reversing. For example, if a ship is moving at full speed forward and the engines are suddenly stopped, the ship does not immediately come to a halt but continues to move due to its inertia. The characteristics of inertia are the distance traveled and the time taken to cover that distance. These can be determined when the moment of engine stoppage and the moment of the vessel final stop are known, and if the moment of changing the direction of travel is known, the distance and the time required to stop from that moment can be determined.

The time to stop the equipment with its own mass was t_1 = 2.76 s and with load and operators' mass was t_2=2.56 s, when the equipment speed was 7.46 km/h. These values help calculating the distance that the equipment is doing until the final stopping, being 2.09 m respectively 1.94 m.

During the tests, the speed of the vessel, from shore to the harvesting area, was determined and also the speed when the equipment was performing the harvesting. The average and maximum speed of the vessel was determined with a GPS application – (Strava), as shown in Fig. 6. Speed is critical for travel planning, fuel consumption analysis, and estimating time of arrival. A maximum speed of 12.5 km/h was reached, with an average speed of 4.2 km/h.

Avg Speed 4.2 km/h
Max Speed 12.5 km/h
Moving Time 8:30
Elapsed Time 1:30:28

Distance 0.60 km
Avg Speed 4.2 km/h
Elapsed Time 1:30:28

Distance 2.10 km
Pace 1:17:48 /km
Time 2h 43m
Nicely done! Keep moving by joining a challenge

Avg Pace 1:17:48 /km
Moving Time 2:43:42
Avg Elapsed Pace 1:24:35 /km
Elapsed Time 2:57:57
Fastest Split 39:07 /km

Fig. 6 - Travel speed and routes travelled

After the nautical tests were carried out, the exploitation indices were measured. These tests were done to determine the main qualitative working indicators.

The working capacity of the equipment is determined based on the results obtained during tests under operating conditions. During the determination of the working capacity, no adjustment is made to the machine. Three measurements are made for each sample.

The noise was determined using a sound level meter. The noise level is an important factor to consider for environmental impact, crew comfort, and potential disturbance to marine life.

The width of the harvested furrow, is measured in one pass with the harvesting equipment and the value is presented in Table 3. By knowing the width of the harvested furrow, it can be calculated how much area the harvester can cover in a given time, which is essential for planning and optimizing the harvesting process.

The working capacity was determined taking into account the following characteristics of the equipment and operating regimes: v = 1.51 and 3.05 km/h (minimum and maximum working speed); l_f = 1.03 m (furrow width).

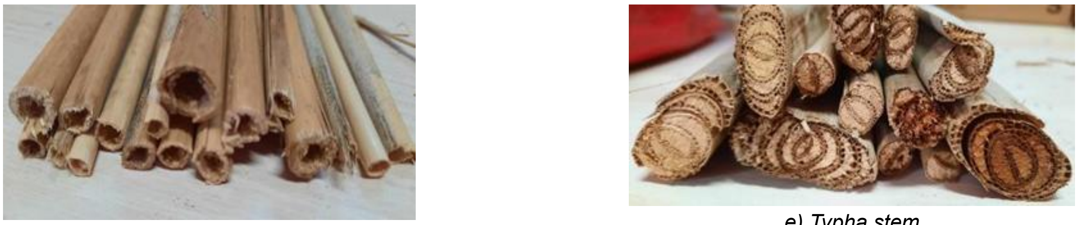
Table 3

The working parameters of the equipment

Parameters	Values			
	Test 1	**Test 2**	**Test 3**	**Average**
Minimum working speed, km/h	1.5	1.52	1.51	1.51
Maximum working speed, km/h	3	3.05	3.1	3.05
Transport speed with the load and operators, km/h	7.1	7.5	7.8	7.46
Conveyor belt speed at 600 motor rpm, m/s	0.23	0.22	0.24	0.23
Conveyor belt speed at 1250 engine rpm, m/s	0.66	0.68	0.59	0.64
Furrow width, m	1.1	0.96	1.05	1.03
Minimum hourly working capacity, ha/h	0.1545	0.1545	0.1545	0.1545
Maximum hourly working capacity, ha/h	0.305	0.305	0.305	0.305
Noise level, dB	70.1	74.8	77.86	74.25

On the lake where the equipment was tested, two areas of biomass were identified, namely *sedge* (rest of rushes) with a maximum height above the water of 0.9 m and *reed* with a height of approx. 3 m above the water level. The reed was cut, in the first phase of the tests, from a depth of approx. 100 mm below the water level, to check the operation of the cutting knives. Later it was cut 400-500 mm below the water level. Some aspects during the experiments are presented in Fig. 7 a-e.

a - Harvesting reeds *b - Rush harvest* *c - Noise level measurement*



d) Reed stem *e) Typha stem*

Fig. 7 - Some aspects during the experiments

Biomass samples were taken and laboratory measurements were done, the results of the phenological characteristics determined by the harvested biomass are recorded in Table 4.

Table 4

The phenological characteristics of biomass

Parameters	Numerical value Reed (*Phragmites communis*)	Numerical value Typha (*Typha latifolia)*
Stem thickness, mm	5-15	6-40
Crop height (from the root), mm	3500-4000	1250-1550
Steam length cut between bottom and the top blade, mm	1000-1500	200-900
Steam length cut above the top blade, mm	1200-1500	0
Volumetric mass, kg/m^3	58	56,4
Estimated biomass mass stored in the 2.5 m^3 bin, kg	145	141

The harvesting operation went normally, meaning that the electric systems operated according to the operator's commands, with three operational speeds available, using the electric motor adjusted to 600 rpm speed for normal operation, and switching at 1250 rpm when higher power is needed.

The hydraulic oil heating and functionality testing regime is carried out with the machine running and the speed set at the level of 300 rpm. The transition from the dock to the harvesting place can be completed with the Driving Mode which can imply a 600 rpm speed of the electric motor.

For harvesting, depending on the need, the speed for the electric motor can be selected to be 1250 rpm or 600 rpm, as appropriate, using the buttons located on the remote control. Thus, using two independent and linear power control over the two paddlewheels, high manoeuvrability of the vessel is obtained.

The temperature of the electric motor has not exceeded 104°C, compared to the maximum permissible value of 150°C. For safety reasons, the converter has a threshold for limiting the output power when the internal temperature of the electric motor is above 125°C. The temperature of the electric converter did not exceed 38.7 ºC, compared to the maximum allowable value of 100ºC, which is also the protection threshold for the power converter. The energy consumption is shown in Table 5.

Table 5

Energy consumption of each operated equipment, measured on the lake

Operation	Time	Pack voltage	Current consumption	Power consumption	Motor speed
	h.min	V_{dc}	A_{dc}	kW	r/min
Oil pre-heating	12.2	62.57	9.43	0.6	300
Lower cutter	12.49	62.47	21.45	1.3	600
Positioning actuator	12.49	62.47	11.32	0.7	600
Both paddle wheels	12.49	62.38	63	3.9	300
Both paddle wheels & Lower cutter & Conveyor on	13.27	62	140	8.7	1250
Both paddle wheels & both cutters & Conveyor on	13.31	61.9	80	5.0	600
Both paddle wheels & both cutters & Conveyor on	13.45	61.28	180	11.0	1250
Both paddle wheels & Lower cutter & Conveyor on	14.01	60.94	132	8.0	1250
Both paddle wheels	14.31	60.35	80	4.8	600
Both paddle wheels & Lower cutter & Conveyor on	15.01	60.11	180	10.8	600

During the tests performed on the lake, the initial State of Charge (SOC) was 98% of the available capacity. At the end of the tests, the measured State of Charge was 70%. As measured during the dry reed harvesting, the current absorbed from the batteries has values between 130 and 180 A_{dc}, values corresponding to an instantaneous energy consumption of about 7–12 kW.

For the different operation regimes of the vessel, maximum autonomy is computed from the maximum available energy by dividing by the power level absorbed during that task, using Equation 6 and values from Table 5 for the harvesting and the trip operation.

$$A_{harv} = \frac{E_{max}-E_{min}}{P_{harv}}\left[\frac{kWh}{kW}\right] = \frac{33-6.6}{12} = 2.2\ [\mathrm{h}] \tag{6}$$

where E_{max} is the maximum stored energy in the three Li-Ion batteries, 33 kW, expressed in kWh, E_{min} is the minimum energy (20% of the total stored energy of 33 kWh) and for P_{harv} was used the maximum measured value of 12 kW.

For the trip, when only the two paddle wheels were used for propulsion, was measured a consumption P_{trip} of about 3.9 kW (see Table 5), for an average travel speed of 10 km/h.

$$A_{trip} = \frac{E_{max}-E_{min}}{P_{trip}}\left[\frac{kWh}{kW}\right] = \frac{33-6.6}{3.9} = 6.77\ [h] \tag{7}$$

The A_{trip} for movement using only the paddle wheels is 6.77 h, and during harvesting using both knives, loader and paddle wheels, is 2.2 h. Using the up results, it can be concluded that the maximum trip distance is 67 km, with the average speed of 10 km/h.

During the tests, the energy consumption from the batteries, the test duration, the real trip, as well as the average speed and maximum speed were measured. The data was collected over 6 test sessions, each one being presented in Table 6.

Table 6

Energy consumption during tests on the lake

Date	**Initial energy E1**	**Final energy E2**	**DC initial voltage V_1**	**DC final voltage V_2**	**Test time t_g**	**Trip time t_{op}**	**Real trip dx**	**Average speed v_{med}**	**Max Speed v_{max}**	**Energy cons. CE_{21}**	**Remaining range t_{rem}**
	kWh	kWh	V	V	h	h	km	km/h	km/h	kWh/h	h
01.03.23	32.44	32.13	65.48	64.40	1.50	0.15	0.60	4.0	12.5	2.09	12.21
08.03.23	32.12	31.06	64.40	63.70	1.78	0.36	0.93	2.6	13.6	2.94	8.31
20.03.23	31.06	30.44	63.70	63.35	1.33	0.38	1.28	3.4	12.5	1.62	14.76
20.03.23	30.44	29.04	63.35	62.60	0.68	0.27	0.72	2.7	9.6	5.17	4.34
10.04.23	29.04	28.05	62.56	62.26	1.08	0.22	0.81	3.7	10.4	4.50	4.77
10.04.23	27.98	23.17	61.9	60.11	1.05	0.45	3.20	7.1	10.5	10.71	1.55
Total	**32.44**	**23.17**	**65.48**	**60.11**	**7.42**	**1.83**	**7.54**	**4.1**	**13.6**	**5.07**	**3.27**

The energy efficiency was measured to evaluate the autonomy, as described in Eq. 4 and Eq. 5. The energy consumption is evaluated as the hourly consumption and was to be determined by measuring the initial and the final energy stored in the battery pack by using the SOC (State of Charge) values, and the operating time t_{op}.

$$Q = \frac{E_{init}-E_{act}}{t_{op}} = \frac{27.99-23.17}{0.45} = 10.71 \left[\frac{kWh}{h}\right] \tag{8}$$

The value of the hourly consumption Q, computed in the Equation 8, is the maximum value obtained durring harvesting the crop, and was used to compute the worst time of operation, also called the autonomy of the vessel. The remaining range (expressed in operating hours) is an estimate based on reporting the remaining energy to that day's average hourly consumption Q.

$$A = \frac{E_{act}-E_{min}}{Q} = \frac{23.17-6.60}{10.71} = 1.55\ [h] \tag{9}$$

where E_{act} is the actual remaining energy, expressed in kWh, E_{min} is the minimum energy (20% of the total stored energy of 33 kWh). Total autonomy, $A_{max,}$ can be computed using the maximum available energy and the maximum hourly consumption.

$$A_{max} = \frac{E_{max}-E_{min}}{Q} = \frac{33-6.60}{10.71} = 2.46\ [h] \tag{10}$$

The vessel has more than 2 h operating time at maximum load. In this autonomy estimations, the test time and movement time are reported by a GPS tracking system.

It was found that, for the first test trips, the energy consumption was small, but when thick reeds were intensively harvested, the measured consumption was 10.71 kWh/h, this value being very close to the maximum designed figure of 11 kWh. Under these conditions, the battery could maintain the harvest for 2.46 hours.

CONCLUSIONS

Following the testing of the experimental model of the *Aquatic biomass harvesting equipment*, symbolized as ERBA, the following conclusions were drawn:

1) The equipment fulfils the functional role for which it was designed, being autonomous equipment, electrically operated, and remote controlled. The presented equipment can be scaled in different sizes, both in length, installed power and predicted autonomy. Such of harvester provides an important link in aquatic biomass management, especially in old floating reed control, by contributing to the maintenance and clearance of navigation canals affected by the development of aquatic biomass in excess. The harvester can be used in fish lakes, canals, ponds, and the Danube Delta.

2) The working capacity of the equipment at the speed v = 1.51 and 3.05 km/h (minimum and maximum working speed) was 0.15 - 0.305 ha/h, the furrow width l_f was 1.03 m.

3) The ERBA harvester achieves autonomy of over 2.46 hours of working time in the maximum load scenario.

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REFERENCES

[1] Calotă, R., Savaniu, M., Girip, A., Năstase, I., Georgescu, M. R., Tonciu, O. (2022). Study on Energy Efficiency of an Off-Grid Vending Machine with Compact Heat Exchangers and Low GWP Refrigerant Powered by Solar Energy. *Energies,* 15(12), 4433. https://doi.org/10.3390/en15124433

[2] Cao Zhen, Jin Xin, Liao Qingxi (2011) Experimental research on physical and mechanical parameters of matured bottom stalk of the reed for harvester design. *International Journal of Agricultural and Biological Engineering,* vol. 4 no 2. pp. 36-42

[3] Clayton, J. S, (1996). Aquatic weed and their control in New Zeeland lakes. *Lake and Reserv. Management.* Vol 12(4):477-486.

[4] Culcea, M., Darie, E., Gheorghe, S., Pecsi, R., Savaniu, M.I., (2023). The influence of a DC-AC inverter used in a stand-alone vending machine equipped with photovoltaic panels, *IOP Conference Series: Earth and Environmental Science,* 1185 (1), 012003, DOI:10.1088/1755-1315/1185/1/012003.

[5] Hofstra, D.E., Clayton, J.S. (2001). Evaluation of Selected Herbicides for the Control of Exotic Submerged Weeds in New Zealand: I. The Use of Endothall, Triclopyr and Dichlobenil. *Journal of Aquatic Plant Management,* 39: 20-24.

[6] Hu, Z., Yuan, J. (2018). China's NEV market development and its capability of enabling premium NEV: Referencing from the NEV market performance of BMW and Mercedes in China. *Transportation Research Part A: Policy and Practice*, 118, 545–555. https://doi.org/10.1016/j.tra.2018.10.010

[7] Huang, J. C., Zhang, B., Tian, K. P., Liu, H. L., Shen, C. (2022). Design and optimization of the parameters of the key components for reed harvester. *Int J Agric & Biol Eng*., 15(6): 96–103.

[8] Ivan, Gh., Mircea, C., Brăcăcescu, C., Găgeanu, I. (2016) Considerations regarding reed harvesting technologies, *ISB INMATEH 2016 International Symposium*, pp.383-390.

[9] Lavergne, S., Molofsky, J., (2006). Control Strategies for the Invasive Reed Canarygrass (Phalaris arundinacea L.) in North American Wetlands: the Need for an Integrated Management Plan, *Natural Areas Journal* 26(2), 208-214, https://doi.org/10.3375/0885-8608(2006)26 .

[10] Obreja, C.D., Buruiana, D.L., Mereuta, E., Muresan, A., Ceoromila, A.M., Ghisman, V., Axente, R.E. Detection of reed using CNN method and analysis of the dry reed (phragmites australis) for a sustainable lake area. *Plant Methods 19,* 61 (2023). https://doi.org/10.1186/s13007-023-01042-w.

[11] Piccitto, A., Scordia, D., Corinzia, S.A., Cosentino, S.L., Testa, G. (2022). Advanced Biomethane Production from Biologically Pretreated Giant Reed under Different Harvest Times. *Agronomy*, 12, 712, https://doi.org/10.3390/agronomy12030712.

[12] Popovici, I.A., Savaniu, M., Tonciu, O., Culcea, M., Teodorescu, A., (2022). Various operation mode of construction machinery using energy obtained from renewable sources. *Proceedings of 2022 International Conference on Hydraulics and Pneumatics – HERVEX*, 86-98.

[13] Sciuto. L., Licciardello. F., Barbera. A.C., Cirelli. G. (2023). Giant reed from wetlands as a potential resource for biomethane production, *Ecological Engineering*, 190, 106947, ISSN 0925-8574, https://doi.org/10.1016/j.ecoleng.2023.106947.

[14] Shahrukh, N.A., Bhaskar, S., Abhishek G. (2021). Aquatic weed as a biorefinery resource for biofuels and value-added products: Challenges and recent advancements, *Cleaner Engineering and Technology*, 4, 100235, https://doi.org/10.1016/j.clet.2021.100235.

[15] Siemering, G., Jennifer, H. (2005). Aquatic Herbicides: Overview of Usage, Fate and Transport, Potential Environmental Risk, and Future Recommendations for the Sacramento-San Joaquin Delta and Central Valley. *White Paper for the Interagency Ecological Program.* SFEI Contribution 414. San Francisco Estuary Institute, Oakland, CA.

[16] Suvac, A., Cucu, L., Stoica, M., Savaniu, M. (2019). Development and optimization of a three-wheeled electric vehicle frame using structural materials. *In Journal of Physics: Conference Series*, 1297(1), 012021. IOP Publishing. DOI: 10.1088/1742-6596/1297/1/012021.

[17] Ștefan, V., Constantin, A.M., Popa, L., Tudor, E., Miron, C. (2022). Equipment used to harvest biomass from lake areas*, ISB INMATEH International Symposium* 2022, 544-553.

[18] Torawane, S., Mokat, D. (2019). Aquatic weed management and development through innovative ways. *ASM Group of Institutes*, 491-502

[19] Tudor, E., Matache, M.G., Vasile, I., Sburlan, I.C., Stefan, V., (2022). Automation and Remote Control of an Aquatic Harvester Electric Vehicle. *Sustainability 14*, (10), 6360, https://doi.org/10.3390/su14106360

[20] Tudor, E., Matache, M.G., Vasile, I., Sburlan, I.C., Stefan, V., (2023). Electric drive system powered by LI-ION batteries for aquatic biomass harvester, *INMATEH Agricultural Engineering*, 69 (1), 609-616, https://doi.org/10.35633/inmateh-69-58

[21] Wenbo, L., Ruyin, L., Hong, C. (2016). Consumers' evaluation of national new energy vehicle policy in China: An analysis based on a four-paradigm model. *Energy Policy 2016*, 99, 33–41.