Boat-to-Grid Electrical Energy Storage Potentials around the Largest Lake in Central Europe

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Abstract: With the dynamic growth in both the global hunger for electrical energy and the share of variable renewable energy sources in the energy mix, distribution networks are facing new challenges where conventional solutions may not be the best ones. The increase in load in distribution grids is routinely countered by network development and expansion, in a great part to supply for on-peak load demand, which could also be done by utilizing supplementary technologies to lessen the need for or defer such expansion. Vehicle-to-grid technology could efficiently contribute to handling this issue, as electric vehicles can potentially function as storage capacities to mitigate the fluctuations of power generation. The battery energy storage systems of hybrid or completely electric watercraft, which are becoming increasingly popular, are no exception, either. These vehicles represent a considerable potential to create more complex vehicle-to-grid solutions for countries with significant inland or seaport networks, for example, Hungary, with the largest lake of Central Europe. Since there is only deficient information on the topic, the main goal of this study was to explore the energy storage capacities of small electric boats in the context of Lake Balaton, Hungary. By this example, the paper presents the potential utilization of Europe’s significant network of sea and inland recreational ports for the purpose of energy storage. Similarly to other European countries, Hungary’s energy strategy for 2030 also includes the promotion of virtual production integration, local energy communities and micro-grid solutions. At the beginning of 2021, the small electric boats in the sailing marinas of Lake Balaton represented a cumulative energy storage capacity of 4.8 MWh, which may reach even 15.6 MWh by 2030, by the promotion of micro-grid solutions. The innovative novelty of this study is that it regards small fully electric boats not just as vehicles, but also explores their energy storage potentials. The novel goal of these examinations is to explore the volume of the energy storage potentials of the small fully electric boats around Lake Balaton, the knowledge of which may facilitate the creation of new types of flexibility services related to energy storage.

Keywords: solar energy; grid integration; energy storage; vehicle-to-grid; Hungary

1. Introduction

1.1. The Potentials of Using Vehicle-to-Grid Technology

Today, it is a widespread belief and hope that electric vehicles (EVs) will play a key role in reducing greenhouse gas emissions by tapping into renewable energy sources. In addition, the ever-growing demand for fossil fuels is becoming critical, concerning the costs and the general availability of these resources. In the quest to solve global environmental issues, the vehicle-to-grid (V2G) technology is one of the most recent trends, which is based on the ability of EVs to feed power into the grid when it is needed [1,2]. While using individual EVs for this purpose is not as useful as other battery-based storage solutions, or even generators, with the advances of EV infrastructure seen today and expected in the future, EVs may be a viable alternative to contribute to maintaining power grid stability [3,4].
During their conventional operation, EVs only receive electricity from the grid, whereas the V2G mode of operation is bidirectional, involving receiving power as well as feeding it into the grid [5]. The batteries in V2G operation are charged and discharged depending on technical and economic conditions [6]. Thus, they work in a way resembling the operation of other battery energy storage systems; however, most of those are stationary, while EVs are mobile by definition [7].

The benefits for utility grids offered by the V2G technology are manifold, since it is capable of supplying a part of the load demand, importantly, also during peak times. The EV energy thusly injected into the grid means peak load cutting for the system [8]. The intermittency of power production [9] can also be lessened by V2G [5], for example in the case of wind turbines [10] or solar power generation [11]. The ideal dispatch provided by V2G can enhance the dependability of the entire network [12].

More complex and sufficient operation can be achieved by the coordinated power management of EV charging load coupled with other technologies, for example various energy storage systems, photovoltaic (PV) systems and demand response programs. Users of models such as that may participate in the frequency containment reserve and day-ahead markets in order to make a profit [13]. It must be noted here, however, that it is not an easy task to accurately assess the combined technical effects of EV charging stations and PV power generation on the power grids because of the fluctuations in loads and electric energy generation, which calls for precise analytical techniques [14].

The V2G technology may be useful in micro energy systems, such as homes and other buildings [15], as it has the capacity to store energy at times when prices are low and discharge it when they go up, resulting in saving costs for end users [16]. Homes with renewable energy and V2G also enjoy the benefit of the ability to supply the demand and having a back-up in case of electricity outages [17]. This makes the vehicle-to-home concept an efficient approach to managing energy in the home [18]. Evidence shows that V2G is a suitable solution for the operators of microgrids [19], where the demand response can also be modelled by V2G operation [20]. All in all, it can be concluded that V2G makes a favorable impact on microgrid energy management [21].

As the use and benefits of V2G are versatile, as stated above, it can also be used for several purposes in active power markets, such as frequency regulation, peak load shaving, providing base load and spinning reserve capacity. Concerning power quality services, it can be successfully applied for motor starting, voltage improvement, reactive compensation and active filtering of harmonics. The charging stations of EVs can also serve as a kind of reactive power compensator [22].

By managing PV energy and EVs together, smart charging and V2G operation can decrease power ramps, shave the on-peak load demand and enhance system operation altogether. On the other hand, EV charging without control could not make use of PV energy in an efficient way, leading to a need for power from non-photovoltaic sources [23]. The suitable coordination of charging and discharging EVs involves collective decision-making. The effective central coordination of V2G can prevent pulling demand and excessive charging, which affect battery life [1].

In spite of its numerous benefits, V2G also has its drawbacks, the greatest of which is battery life time [24]. As EV batteries only have a finite number of charging cycles, using EVs for storing energy will decrease the lifetime of their batteries. Therefore, those involved in the operation of V2G systems have to be incentivized to take participate in such programs, since with no compensation for lost battery lifetime VE owners would not be motivated enough [25].

1.2. The Importance of Energy Management Systems

An energy management system involves the planning of both energy demand and supply, as well as smart energy management, which connects the two sides. For the efficient implementation of energy management systems in ports and marinas, it is of paramount
importance to measure and estimate their energy consumption accurately. Besides these, an established management strategy is also necessary [26].

While, on the one hand, the measurement of energy consumption requires the use of some device or instrument, its estimation, on the other hand, is done on the basis of perceptions and calculations. It is quite obvious that the lack of detailed energy consumption data makes the use of methods aimed at energy efficiency more difficult, and thus, it creates problems in focusing attention on the right area, operation or equipment. Consequently, the assessment of the effects of energy efficiency methods, for example their economic (the possibility of making use of lower energy prices during certain periods) or environmental (GHG emission data, carbon footprint calculation) impacts is compromised too [26].

Monitoring the energy consumption in real time, however, can increase the flexibility of energy management [27]. Unfortunately, since the installation of special equipment is needed for real-time measuring, it is also relatively expensive most of the time. Systems for monitoring energy consumption in real time, which are linked to real-time operations monitoring [28], can be comprised of a smart meter and smart energy management systems [29–31].

The various operations at ports and marinas are based on energy from different sources, including fossil fuels and/or clean energy sources, including renewable ones. The electric energy consumed is either supplied through the grid or it is produced on the premises [26].

The concept of integrating energy suppliers (also those of renewable energy) and consumers as well as tools of controlling, monitoring, analyzing and optimizing power by enhancing communication between all components of the system is generally referred to as a smart grid [32,33]. Smart energy management systems, whose purpose is to achieve the balance of energy supply and demand in an intelligent manner by using advanced technologies, consist of four main pillars. The first element is that of the management of energy supply (power generation, also including on-site renewable energy generation, combined heat and power [CHP] systems, grids, etc.). The second and the third components are energy storage systems (e.g., battery storage systems) and energy demand management (featuring real-time consumption measurement, among other things). The final pillar is that of optimal management and communication between all active resources (by means of various methods of optimization, peak shaving, load diagram control and utilization management in the grid) [29,34]. In general, smart grids and microgrids can have a variety of applications in buildings, warehouses and urban areas [32,35]. More specifically related to port (or marina) operations, smart grids can provide integrated port–grid platforms consisting of electricity grid technologies [29], advanced smart meters, sensor technologies, [36–38], systems for real-time monitoring [39], battery technologies, control tools [40] and technologies for communication. Smart grids and microgrids are forecasted to supplant conventional grids in ports in the not too distant future [40]. Following the general, upward trend, ports are also producing more and more renewable energy, which can be put to use either directly on the premises or it can be fed into the grid. However, as relatively few ports have already installed their smart grids, there is still room for improvement in this respect. Some sources also claim that the ports of the future will also have their own combined heat and power plants, and they will even be used as facilities for carbon capture and storage [26].

1.3. The Growing Importance of Energy Storage Markets

According to a forecast by the U.S. Department of Energy [41], it is expected that by 2030, the energy storage markets including stationary and transportation will increase to 2.5–4 TWh from 2020’s 800 GWh. A major driving force behind this growth is the rising penetration of electrified powertrains, because of which today, mobility accounts for the greatest demand for energy storage, about five to ten times more than stationary energy storage by energy capacity. The compound effects of fast decreasing battery storage prices, the development of electrified transportation and the growing share of variable renewable
energy sources of energy in electric energy generation have resulted in an unprecedented growth in the use of energy storage all around the world. Stationary energy storage is widely regarded now as an effective solution for demand management and enhancing the resilience and reliability of the grid in the context of grid-tied renewable electricity. Parallel to this, the surge in the numbers of EVs, also thanks to various government incentives and the manufacturers’ relentless efforts to boost production, is predicted to be a lasting global trend too [41].

1.4. The Benefits of V2G Solutions

Due to the challenges facing the energy and transport sectors at present and in the predictable future, there is no alternative to decarbonization and decreasing pollution, which is not viable without utilizing novel solutions and cutting-edge technologies. This is also the only way to comply with increasingly rigorous international regulation. Today, EVs are widely seen as the solution for attaining sustainable transport, and the efficient management of their charging may also offer additional benefits for the energy sector too. The activity of EV charging, as such, connects both symbolically and practically the above two fast-developing sectors, because of which EVs can double as grid-connected batteries when not moving and connected to the grid. This, in turn, can ensure two things: on the one hand, the necessary range those vehicles can drive as well as charging rates acceptable to the operators of the vehicles, and on the other hand, the sufficient flexibility of the electric grid, provided the infrastructures of charging are suitable and the processes are managed well. Consequently, the dynamic spread of EVs has to be coupled with the concept and practice of optimized charging or “smart charging”. The deployment of bi-directional chargers can offer further benefits by adopting V2G solutions and foster the integration of the power and transport systems [42].

As EV batteries can be a source of support for the power grid [43], so can those of various modern watercraft [44]. This is due to the fact that the trend of electrification with a view to mitigating CO$_2$ emissions and enhancing energy efficiency has also reached military as well as commercial shipping [45–47]. Vessels with energy storage systems could be of help in terms of peak load shaving, spinning reserve capacity and frequency regulation too [2,44].

1.5. Hungarian Ambitions Related to the Energy Storage Sector

Similarly to the international energy sector, that of Hungary has also been going through significant changes recently. As the strategy for decarbonization has come to the fore, the revision of Hungarian incentives has been started in order to renew the regulatory environment and to transform the production and purchase portfolios. It has become necessary to reformulate the National Energy Strategy of Hungary, which includes the sustainable and operational framework and the objectives, which also take the interests of state asset management policies into account and complies with EU law [48,49].

The changes in global temperatures resulting from the recent explosive growth in development and the consumption trends are predicted to radically change energy deployment, the capacities of energy generation and, as a consequence, those of energy storage. Increasing energy consumption has been an inevitable result of the development of the Hungarian society too. For the achievement of the medium- and long-term climate policy goals, the use of batteries seems indispensable in the field of electromobility as well as in the supply of electric energy, due to their short-term energy storage function. For dependable and continuous energy security, countries need energy storage technologies that are less dependent on depleted energy sources and whose manufacturing is as least harmful to the environment as possible. The increasing deployment of variable renewable energy (VRE) has led to the need for energy systems which are suitable for integrating the new technologies into the network. In energy systems utilizing VRE, certain periods are characterized by oversupply, exceeding consumer demand, while others by the lack of sufficient supply. Such situation can be dealt with by the interim storage of electrical energy.
The National Battery Industry Strategy 2030 [49] of the Hungarian Ministry of Innovation and Technology puts forward goals and measures related to flexible energy generation and storage which will pave the way for the creation and spread of vehicle-to-grid concepts in Hungary [50].

The number of battery energy storage systems of hybrid or completely electric watercraft is increasing worldwide. By their improved energy efficiency and saved fuel, these vessels have the potential to contribute to the effort of the protection of the local and global environment and the mitigation of air pollution, including CO\textsubscript{2} emissions. These vehicles represent a growing opportunity for certain countries, including Hungary, for the elaboration of even more complex vehicle-to-grid concepts, although the relevant information available is insufficient at present. This study explores the energy storage capacities of small electric boats in the context of Hungary’s Lake Balaton, the largest lake of Central Europe, since, concerning this field, there is no available scientific information or analyses that consider small electric boats as potential energy storage capacities. Hungary’s energy strategy for 2030 stipulates the promotion of virtual generation integration, local energy communities and micro-grid solutions. A great advantage of increasing EV (road as well as waterborne) penetration is that they could expand the range of new flexibility services in innovative ways. To this end, however, first of all, the energy storage capacity represented by these vehicles, including the small electric boats at Lake Balaton, needs to be determined as accurately as possible. This study is aimed at fulfilling this essential task.

2. Materials and Methods

2.1. The Area of the Study and Its Significance in Hungary

Lake Balaton, in the west of Hungary, is often referred to as the largest freshwater lake of Central Europe (Figure 1) [51]. Although the large catchment (5.705 km\textsuperscript{2}) feeds a lake of a huge surface area of 595 km\textsuperscript{2}, the lake is rather shallow with a depth 3.25 m on average [52]. The greatest length of the lake is about 77 km, but its water volume is only approximately 2 km\textsuperscript{3} [53]. While the shallowness of the water, which warms up quickly, is favorable for tourism, it makes the lake more sensitive in an ecological sense and susceptible to pollution [54]. This is one of the major reasons why the use of combustion engines is not allowed on the lake, except within 200 m of the ports, which creates a huge opportunity for electric boats, whose batteries could be utilized for energy storage also.

Since 1846, shipping has played a paramount role in the life of Lake Balaton. Currently, passenger ships, ferries, service boats, barges, small motorboats, waterborne machinery, yachts and hundreds of sailboats travel on the approximately 600 km\textsuperscript{2} water surface of the lake daily. To give an impression of the significance of shipping, Figures 2–4 show the sailing marinas, passenger ports and anglers’ ports in the towns and villages around the lake. Figures 2 and 4 demonstrate the number of sailing marinas and anglers’ ports, while Figure 3 only shows passenger ports serving scheduled services (there is only one passenger port per town/village) [56]. This study only focuses on the sailing marinas of Lake Balaton. The number of marina operators is relatively high; typically, the owners of the given lakeside properties are the marina operators too. The majority of the ports suitable for accommodating larger ships, waterborne machines and barges belong to the Balaton Shipping Company Ltd. For environmental reasons, sports or recreational motor boats are not allowed to travel on the lake [56].
Figure 1. Location of the study area, based on [55].

Figure 2. The number of sailing marinas per town/village at Lake Balaton, based on [55].

Figure 3. The passenger ports of Lake Balaton, based on [55].
2.2. The Direction of the Development of the Sailing Marinas at Lake Balaton and Its Connections to Energy Storage Developments

Figure 2 illustrates well that sailing marinas have a great significance in the shipping activities of Lake Balaton. A part of this study was also the determination of the number of permanent berths and visitors’ berths at the sailing marinas of the towns/villages of Lake Balaton, since in possession of this data, the numbers of small electric boats at present and in the future could also be established. The initial data and information for this were provided by the Government Agency of the City of Budapest [57] and the atlas of the ports and marinas of Lake Balaton [58]. Moreover, how large the present and the predicted energy storage capacities of the small electric boats moored in the sailing marinas are has also become a timely question by now. The input information necessary for answering this was supplied by the Government Agency of the City of Budapest [57], AQWIA Ltd. (Balatonfüzö, Hungary) [59] and Stickl Yachts Ltd. (Gárdony, Hungary) [60]. Stickl Yachts Ltd. [60] and AQWIA Ltd. [59] together have a share of 60% of the market of the registered electric boats in Hungary. This study considered the number of berths in the marinas to remain constant in the future, since the construction of further facilities around the lake is unlikely [61] because of environmental reasons, among others [62]. The economic environment that supports the spread of small electric boats is extremely important, since it will contribute not only to the development of the green infrastructure at the lake, but also to the process of these vehicles becoming an organic part of virtual generation integration, local energy communities and micro-grid solutions, in accordance with Hungary’s energy strategy for 2030, as these boats can provide a possibility for creating new flexibility services.

The development of the present sailing marinas at Lake Balaton is of utmost importance. Based on the characteristics of the region and considering the potentials for future development as well, the main areas for development have been identified: mitigating the imbalances caused by seasonality, ensuring sustainable operation, increasing tourism-related revenue and aligning with the directions of tourism development. These development areas can also facilitate electric marina development constructions. In the sailing marinas of Lake Balaton, a prominent region of tourism development in Hungary, the construction of charging systems for electric watercraft that can serve both sailboats with electric motors and electric boats is underway. Recently, support has been granted to projects aiming at the creation of tourism services of high added value whose main goal is the building of a network that will make it possible for small electric boats to travel all around the whole lake. The charging points integrated into a network are able to ensure optimal capacity utilization by communicating with one another via various applications. A positive outcome of the charging network investments around Lake Balaton is the improvement of the quality of ground services in the marinas. Furthermore, the use of further services during the charging time is likely to increase the revenue of the marinas and other providers of services. Thanks to the developments, collaborations in partnerships and
agreements with tourist attractions may generate further growth in revenue and visitor numbers [63,64].

In the longer run a remarkable increase is expected in the spread of PV systems in Hungary. By 2030, the Hungarian Transmission System Operator (MAVIR ZRt, TSO) predicts the integration of 2.5–6.7 GW of PV power into the system according to three scenarios (Table 1). Scenario “A” foresees a balanced development, while “B” foresees a more pessimistic and “C” a more optimistic development. The Hungarian regulatory system needs to respond to such substantial growth, which poses great challenges for the whole Hungarian electric energy system. Based on current TSO data, it seems likely that the nominal power of energy storage will equal 5% of the nominal power of the PV power plants, which suggests the integration of 50 MW energy storage power and 200 MWh of energy storage capacity per 1000 MWp PV system into the grid in the following period [65]. Consequently, the selection of the suitable technology related to energy storage and that of the ideal products in the market has become indispensable.

Table 1. Changes in the net installed capacities of PV power plants and energy storage systems in Hungary based on [65].

| Year | 2019 | 2025 | 2030 |
|------|------|------|------|
| Scenarios | A | B | C | A | B | C |
| PV power plants [GW] | 1.3 | 4 | 3.7 | 6.7 | 2.5 | 6.4 |
| Batteries, power capacity [GW] | 0 | 0.20 | 0.08 | 0.19 | 0.34 | 0.13 | 0.32 |
| Batteries, storage capacity [GWh] | 0 | 0.80 | 0.33 | 0.76 | 1.34 | 0.51 | 1.29 |

Concerning the sailing marinas of Lake Balaton, in Hungary there are several available energy management technologies [66–68], which could contribute to the establishment of flexible energy generation connected to small electric boats. Among these, the PASS system, a Hungarian product, can be used as a complex energy system or to integrate and supervise already existing energy systems. The energy management module of the PASS system allows the individual control, analysis and reporting of consumption. In addition, the PASS solution can also be used in several fields of industrial and building automation, and it also makes it possible to create customized solutions. The solution is also used in low-signal-number measurement data collecting systems, the supervision of production lines as well as dispatch centers controlling whole plants. Within the building automation segment, it is also suitable for the energy efficiency supervision and automation of facilities ranging from private houses to complete office buildings [66].

Part of the research project presented herein was the determination of the power and energy storage capacity of the small electric boats in the sailing marinas at Lake Balaton, since with the help of these data it is possible to assess the flexibility potential represented by the small electric boats in terms of the energy storage systems required by the VRE power plants (typically PV in the context of Hungary). The exploration of this information is significant because, concerning this field, there are no available scientific knowledge or analyses, either at the Hungarian or the international level, that consider small electric boats as potential energy storage capacities.

3. Results

3.1. The Number of Sailing Marinas and Berths around Lake Balaton

The numbers of the permanent and visitors’ berths in the sailing marinas of each town or village at Lake Balaton were established. All around the lake, the number of permanent berths was 6542, while that of those for visitors was 349, i.e., altogether 6891 berths in total. Figure 5 presents the numbers of permanent and visitors’ berths in each sailing marina in detail. The information concerning the 10 most important towns and villages in terms of berths is further highlighted in Table 2 and Figure 6. In these 10 major resorts (Balatonfüred, Alsóörs, Balatonkenese, Balatonfüzfő, Balatonlelle, Siófok, Keszthely, Fonyód, Balatonfenyves, Balatonszemes, Balatonalmádi) there are 4714 berths altogether,
which is a significant proportion of all the berths at Lake Balaton at 68%. The geographical locations of these places around the lake are shown in Figure 6. As seen in the case of the 10 dominant resorts in Figure 6, there is a significant number of berths available all around the lake; however, it has to be noted here that at present, in 2021, all the marinas at Lake Balaton are operating with an occupancy of 100%, and there is a waiting list for those wanting berths. At lake Balaton, boat owners rent their berths, and the contracts are for one year, from 1 April till 31 March of the following year, everywhere. If the berth fee is received by 31 March, the client may keep their berth in the marina. The termination of the contract by the marina is subject to one year’s notice. Long-term rents are not possible [62]. In terms of developments, it is a favorable situation that marinas suitable for accommodating small electric boats are available everywhere at the lake. Thus, regarding charging the boats or connecting them to the grid, it cannot be a problem if the boats use the marinas of different resorts according to the actual needs.

Figure 5. The numbers of permanent and visitors’ berths in the sailing marinas of the resorts at Lake Balaton, own results.

Table 2. The 10 most significant resorts of Lake Balaton in terms of berths for sailboats, own results.

| Resort                  | Total Number of Berths [pcs] | Share of the Total Number of Berths [%] |
|-------------------------|------------------------------|----------------------------------------|
| Balatonfüred            | 785                          | 11                                     |
| Alsóörs                 | 678                          | 10                                     |
| Balatonkenese           | 520                          | 8                                      |
| Balatonfüzfő           | 425                          | 6                                      |
| Balatonlelle            | 406                          | 6                                      |
| Siólok                  | 376                          | 5                                      |
| Keszthely               | 360                          | 5                                      |
| Fonyód                  | 306                          | 4                                      |
| Balatonfenyves         | 300                          | 4                                      |
| Balatonalmádi          | 293                          | 4                                      |
| Balatonalmádi          | 265                          | 4                                      |
Figure 6. The 10 most significant resorts of Lake Balaton in terms of berths for sailboats, based on [55].

3.2. The Number of Small Electric Boats and Their Energy Storage Capacity at Lake Balaton—Present and Future

The power and the storage capacity of the batteries of the small electric boats in the sailboat marinas of Lake Balaton in 2021 were established based on the data made available by the Government Agency of the City of Budapest [57], AQWIA Ltd. [59] and Stickl Yachts Ltd. [60]. The power of the electric boats varies, as shown below:

- <6 kW, 4 kW on average;
- 6–10 kW, 8 kW on average;
- 11–20 kW, 16 kW on average;
- 21–40 kW, 31 kW on average;
- >40 kW, 46 kW on average.

There are altogether 213 small electric boats in the sailing marinas of Lake Balaton. Figure 7 shows their distribution by the power of their electric motors. It can be seen that boats with powers of 6–20 kW account for 68.5%, followed by the category of boats with 21–40 kW at 24.4%. Boats with powers above 40 kW or below 6 kW are not significant yet; they represent a mere 7% of the current fleet of small electric boats.

Figure 7. The distribution of the small electric boats in the sailing marinas of Lake Balaton by the power of their electric motors, own results.
Currently, the small electric boats in the sailing marinas occupy 3.1% of the total of 6,891 berths. Nevertheless, it is important to point out that, based on today’s data [57], the ratio of electric berths is expected to reach 10% of the total number of berths, which development is projected to be linear until 2030. The available data and the results were applied in a linearly proportional way for the year 2030 [57,59,60].

On the basis of the data provided by the Government Agency of the City of Budapest [57], Stickl Yachts Ltd. [60] and AQWIA Ltd. [59], the average and total energy storage capacities belonging to each electric boat motor power were also established. The averages of the energy storage characteristics of the electric boats vary, as shown below:

- <6 kW, 12 kWh on average;
- 6–10 kW, 15 kWh on average;
- 11–20 kW, 18 kWh on average;
- 21–40 kW, 36 kWh on average;
- >40 kW, 50 kWh on average.

Figure 8 shows the distribution of the energy storage capacities of the electric boats by the power of their electric motors. It is obvious that the lion’s share of the energy storage capacity of the electric boats belongs to the small electric boats with powers ranging 21–40 kW with approximately 1.9 MWh, followed by vessels with powers of 11–20 kW accounting for 1.5 MWh and then the third category of 6–10 kW representing almost 1 MWh. The rest of the of the boats with motors <6 kW and >40 kW feature a total energy storage capacity of more than 0.5 MWh.

![Figure 8. The distribution of the total energy storage capacity of the small electric boats in the sailing marinas of Lake Balaton in 2021 by the power of their electric motors, own results.](image-url)

From these data, it follows that the 213 small electric boats in the sailing marinas of Lake Balaton represent an energy storage capacity of 4.8 MWh altogether. This is merely 21% less than that of one of Hungary’s largest battery energy storage facilities (6.1 MWh), the one belonging to ELMŰ-ÉMÁSZ Energy Service Zrt. in the south of Buda (Budapest). In 2021, the investment costs of a Lithium-ion-based energy storage system of a storage capacity of 1 kWh typically amounts to about USD 300 [69], which means that the aggregate energy storage capacity of these small electric boats represents a value of approximately USD 1,440,000. The existence of the aggregate storage capacity of the small electric boats is also good news because, if suitably regulated, this capacity can contribute to the more optimized operation of grid-connected solar power plants and household-sized PV systems (called HMKE in the Hungarian regulation, connected to the national grid by definition) around Lake Balaton, e.g., during the periods of peak load demand. It is also worth noting...
that the greatest penetration of HMKEs in Hungary at the end of 2019 was in the north of the
Great Plain region, along the north-western border of the country, in Budapest, around
Lake Balaton and in the major cities (Figure 9) [70].

![Map of Hungary with energy storage capacity distribution](image)

**Figure 9.** The total power (a) and number (b) of HMKEs (grid-connected household-size small PV power plants) in the settlements of Hungary on 31 December 2019 [70].

According to the data in Table 1, an energy storage capacity of 4.8 MWh could even allow the regulation of a PV system of 24.1 MWp.

Provided the number of electric berths reached 10% of the total number of berths in the sailing marinas, thanks to the developments in the region of Lake Balaton, that increased capacity would be suitable for enhancing the security of supply and control over the system. If 10% of all the berths of the sailing marinas at Lake Balaton were occupied by small electric boats by 2030, that would mean 689 small electric boats, based on the linearity of the changes over time. In the case of this quantity, the energy storage capacity of the small electric boats would change as it is displayed in Figure 10. It can be seen that, according to the predicted spread of electric boats for 2030, most of the energy storage...
capacity would be provided by small boats with powers of 21–40 kW, with approximately 6 MWh. In the case of the smaller boats of 11–20 kW, this figure would exceed 4.7 MWh, while the category of 6–10 kW would contribute 3.1 MWh to the overall energy storage capacity. The figure of the remaining small electric boats of <6 kW and >40 kW could reach more than 1.6 MWh. Based on the data, it can be said that if 10% of all the berths of the sailing marinas of Lake Balaton accommodated electric boats by 2030, the aggregate energy storage capacity represented by all those watercrafts would amount to 15.6 MWh, which could be used to regulate a PV system of up to 78.1 MWp, according to the data in Table 1. This energy storage size would exceed that of the largest battery energy storage system of Hungary of 2021 significantly, at 2.6 times. An energy storage capacity of 15.6 MWh would have several benefits at Lake Balaton:

- It could facilitate the appearance of new types of flexibility services in the market.
- It could contribute to the promotion of renewable energy generation around the lake on a larger scale.
- It could assist with making the integration of PV projects into the grid more cost-effective.
- It could support supply security and system control in a sustainable way.
- It could assist the electric energy network around Lake Balaton with the integration of decentralized PV capacities in a cost-effective manner.

![Figure 10. The distribution of the total energy storage capacity of the small electric boats in the sailing marinas of Lake Balaton predicted for 2030 by the power of their electric motors, own results.](image-url)

It must be emphasized, of course, that the batteries of all the small electric boats at Lake Balaton could not be connected as one virtual storage system. This paper only wishes to present the storage potentials, i.e., to point out that it is worth dealing with the issue, and the electric boats could represent a considerable energy storage capacity at Lake Balaton.

4. Discussion

With the increasing number of EVs, which may act both as consumers and suppliers of electric energy simultaneously, V2G networks are becoming integral parts of electrical systems. The electricity usage information generated during the operation of V2G networks is a useful resource that can be the basis of a number of related services, including the forecasting of loads and prices, creating schedules for optimized energy consumption and the modelling of performances related to EV ancillary services. As the growing number of EVs is coupled with an increasing share of electric energy from renewable sources in electricity markets, adding demand and decentralized energy generation to the equation,
system operators are obliged to think about the expensive enhancement and extension of the infrastructure and use expensive solutions for redispatching. The rapid development of the V2G technology is a global phenomenon with great potential advantages in economic, environmental and even social terms, while also providing distribution system operators with great opportunities, for instance, by the possibility of controlled charging. While all the above make the V2G concept and technology a timely and popular subject for discussion and research, all-encompassing and time-tested solutions do not exist.

Among vehicles with potentials for use in V2G system, electric boats present an increasing opportunity in certain countries, e.g., Hungary, for the development of further V2G concepts and thereby introducing a new notion, that of “boat-to-grid” or “B2G” for short. Instead of road vehicles, the B2G concept concerns the energy storage capacities of waterborne vessels, which could become an integral part of the V2G concept in the future. The sailing marinas of the largest lake of Central Europe accommodate 213 small electric boats, which represent an aggregate energy storage capacity of 4.8 MWh in 2021. By 2030, this figure may exceed even 15 MWh. These values can be deemed considerable, and they could contribute to the more optimized operation of PV systems around Lake Balaton, however the problem of the integration of V2G concepts has not been solved as yet. It is worth noting that, currently, the electric companies that supply the Hungarian settlements with electric power do not make energy consumption data in greater than annual detail available, referring to trade secrets. With these data missing, it is impossible to prepare analyses taking seasonal aspects also into consideration. This situation highlights the importance of the application of energy management technologies that are suitable, for example, for the integration of energy systems, controlling consumption, overseeing energy use processes related to individual economic parameters, the enhancement of energy efficiency, the exploration of potentials for energy conservation, the realization of cost reduction or even the definition of economic and comfort functions. Related to the vehicle-to-grid concept, such energy management systems have not been created in Hungary around Lake Balaton yet. It is also important to note that the opening times of the sailing marinas at Lake Balaton are not uniform; certain marinas operate all year round (e.g., Balatonfüred or Balatonkenese), while others only during the ice-free periods (e.g., Balatonberény) or have individual opening times (e.g., Keszthely). This is an extremely important parameter, because in the case of using small electric boats for V2G, their annual availability must be known precisely, otherwise the applicability of the grid integration roles of these vehicles becomes problematic. These circumstances also justify the use of energy management systems, as thusly the necessary energy-related data would be available for each marina specifically. This is the reason why it is of utmost importance that the marinas of Lake Balaton, the electric energy suppliers/traders and the boat owners should cooperate together efficiently, according to concepts based on mutual benefits with a view of introducing new types of flexibility services in the market.

5. Conclusions

There is more and more proof that the bidirectional smart connection between vehicles and electric energy networks in V2G systems can create a win-win situation for utilities and suppliers and the owners of the vehicles, in which the former can manage their energy resources in a better way, while the latter can generate some extra income by selling the power they feed back into the network. The vehicles themselves double as means of transport when needed and energy storage facilities when connected to the grid. The rapidly spreading and large-scale deployment of electric energy produced with gradually decreasing carbon emissions plays an extremely important part in achieving Hungary’s climate policy targets. As a result, sustainable batteries and V2G solutions will have an increasingly decisive role in satisfying the thusly growing demand for electric energy.

As seen above, thanks to the existence of Lake Balaton, the boat-to-grid concept, as part of the V2G technology, represents a considerable potential for storing energy in Hungary. The results of this study suggest that the small electric boats kept in the sailing
marinas around the lake have a significant aggregate energy storage capacity, which is worth utilizing for the more optimized operation of the grid-connected solar power plants and household-sized PV systems located at Lake Balaton. It is expected that by 2030 this storage size will exceed that of today’s (2021) largest battery energy storage system in Hungary substantially, even 2.6 times. Such a storage capacity would be suitable for the regulation of a PV system of even up to 78.1 MWp. Hungary’s current economic environment, favorable to the spread of small electric boats, will contribute more and more effectively to the development of the green infrastructure of the lake, and if suitable incentives are in place, these small electric vessels will become an integral part of virtual generation integration, local energy communities and microgrid solutions, since they provide an effective and—rather importantly—cost-effective potential for creating novel types of flexibility services.

**Author Contributions:** H.Z. conceived, designed and performed the experiments. All authors contributed equally in the analysis of the data and the writing and revision of the manuscript. All authors have read and agreed to the published version of the manuscript.

**Funding:** We acknowledge the financial support of Széchenyi 2020 under the EFOP-3.6.1-16-2016-00015.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available within the article.

**Acknowledgments:** We acknowledge the financial support of Széchenyi 2020 under the EFOP-3.6.1-16-2016-00015.

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

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