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Assessment of the solar and wind energy potential related to Romanian southern lakes

EUGEN RUSU, FLORIN ONEA, ALEXANDRA DIACONITA, LILIANA RUSU*

[1]Faculty of Engineering, 'Dunarea de Jos' University of Galați
47 Domneasca St., Galati, Romania

Abstract. The aim of this article is to assess the renewable energy potential (solar and wind) of some representative water bodies for the southern part of Romania, more precisely the lakes Izbiceni, Razim, and Frasinet. As a first step, based on 20 years of ERA5 data (January 2003-December 2022), the monthly average distribution of some important parameters, such as the wind speed, solar irradiance and evaporation, was represented. In the case of the wind speed, the local resources were evaluated for a reference height of 100 m, since this is the level where most of the commercial onshore and offshore wind turbines operate. In this case, the Razim Lake presents a higher wind potential, which can go up to 7 m/s during the wintertime, comparing to 5.5 m/s expected from the Frasinet dam corresponding to the same time interval. This aspect is also reflected by the performances of the Siemens SWT 3.6-120 wind turbine that can provide a maximum power of 0.95 MWh/year in the case of the Razim Lake. In terms of the solar irradiance, there are slight differences between the considered sites, being noticed values in the range 52-277 W/m^2. For these lakes, the water body was gradually covered with floating solar panels, the proposed scenarios involving case studies that go from 10 to 30%. Besides the electricity production, it was found that a solar project can significantly reduce the water evaporation, being associated to a maximum water volume of 15 x 10^6 m^3 (Razim Lake, 30% scenario). Finally, we can mention that a solar/wind project can be successfully implemented in most of the Romanian lakes, especially on the ones associated with the agricultural areas where the water scarcity may intensify in the near future due to climate change.

Keywords: Romania, lakes, solar, wind, renewable energy, evaporation.

* Correspondence address: Liliana.Rusu@ugal.ro

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1. Introduction

Exploration of alternate renewable energy sources has attracted substantial interest in the goal of a sustainable future. The use of lakes for energy generation has emerged as a promising alternative among the new techniques for capturing clean and sustainable power [1]. We can tap into the enormous natural resources available and harness the unique qualities of these water bodies by placing floating solar panels and wind turbines on lakes. The advantages of floating solar panels, also known as floating photovoltaic (FPV) systems, over typical land-based solar installations, are considerable [2]. Lakes, such as reservoirs, man-made lakes, and retention ponds, provide enormous expanses of open water surfaces that are frequently underutilized. We can optimize land use and alleviate strain on limited terrestrial regions by placing floating solar panels on these bodies of water. Also, the presence of water cools the solar panels, which increases their total efficiency. Numerous studies have demonstrated that the cooling effect of water increases the electrical output of solar panels by reducing thermal losses and maintaining lower operating temperatures. Considering all the advantages they have; solar panel farms have started to be increasingly widespread. Fig 1 shows a series of projects with floating solar panels from various parts of Europe.

Fig. 1. Overview of some floating solar projects, developed in: (a) Alqueva, Portugal [3]; (b) Lac de Toules, Switzerland [4]; (c) Port of Constanta, Romania [5]; (e) Oostvoornse Meer, Netherlands [6].

The advantages of floating solar panels are demonstrated by several research that have been conducted. According to a study by Oliveira-Pinto et al [7], the amount of energy produced by a small solar project with solar panels increases by 0.31 to 0.46% compared to those on land, and for a large-scale project, the increase in production is in the range of 1.81 to 2.59%, depending mainly on the location and the solar panel technology used. A similar study [8] shows that energy production for a small project increases by approximately 1.3%, and for a large one by 2.4%.

In Majid's study [9], which was conducted for a brief period of time, it was shown that the production increased even by 15.5% in relation to the projects on land.

Furthermore, floating solar panels on lakes help to reduce water evaporation, which is especially important in water-stressed areas [10]. The shading effect of the panels lowers direct sunlight exposure of the water surface, lowering evaporation rates and conserving valuable water resources. According to the study from Fereshtehpour et al [11], by installing solar panels on an area that represents just 10% of Iran's important water reservoirs it is possible to conserve 70.7 thousand cubic meters/year, or the water required for one million residents. According to the study by Kakoulaki et al [12], which investigated the energy potential of 337 hydrodynamic reservoirs in Europe, water losses due to evaporation are approximately 9380 MCM, and installing solar panels on roughly 2.3% of the surface area could save up to 557 thousand cubic meters per year. Other literature sources that investigated the evaporation of water include Vidović et al [13], Durković et al [14] and Kulat et al [15] respectively.

Wind turbines provide another option for capturing renewable energy from lakes. We can tap into the continuous wind resources available in these places, particularly in areas with good wind conditions, by putting wind turbines on the surface of lakes. Lakes are generally closer to shorelines than offshore wind farms in the open sea, minimizing transmission losses and allowing for simpler integration into existing electricity networks. This proximity helps the conveyance of wind turbine-generated electricity, reducing the need for substantial transmission infrastructure. Furthermore, because of the local topography and the lack of impediments that can impair wind flow, lakes create consistent and predictable wind patterns. These favorable conditions contribute to increased capacity factors, which compare actual power output to maximum potential and result in more reliable and efficient energy generation.

Wind farms are being gradually on the inland waters, a special attention being given to the lake areas [16]. The largest wind turbine farm located in inland waters is on the Lake Ijsselmeer (Fig 2) and which is made up of 89 turbines with a power of 4.3 MW and can produce an amount of energy equivalent to 1.2% of the consumption of the Netherlands [17]. Another project that is planned for installation is the one on Lake Erie (Fig 2), which will initially only have 6 turbines built. If the feasibility of the project is proven, further turbines will be added. In this regard, Afsharian S. et. all [18] investigate the impact of placing wind turbines on Lake Erie. In the absence of wind turbines on this lake at a height of 10 m, the average wind speed reaches a maximum value of 10 m/s and an average value of around 4 m/s, and by placing 432 wind turbines with a power of 9.5 MW in the center of the area, the speed can be reduced by up to 60%, and the average being approximately 16-17%. Six wind turbines will be placed on this lake to study their behavior.

Fig. 2. Wind projects developed on inland waters, where: (a) Lake Ijssel, Netherlands [19]; (b) Lake Erie, North America [20].

The agricultural industry in Romania makes extensive use of its lakes. In order to support agricultural crops, reservoir lakes are used for irrigation, storing water during rainy seasons and releasing it during dry spells. A few small reservoirs or natural lakes are used to directly irrigate agricultural land. Additionally, some lakes have wet meadows where livestock can graze, which helps with animal growth. To preserve the environment and ensure sustainable water resource management, lakes must be used responsibly for agriculture. In this context, three lakes from Romania (Razim, Frasinet, and Izbiceni) were chosen for which the energy potential, solar radiation, and water evaporation were investigated.

2. Methods and materials

2.1. Target area

The area of interest for the study is the southeastern part of Romania, a particularly important region for agriculture and water resources. Within this region, we have selected three notable lakes, which are used extensively for the irrigation of agricultural land. Their location is depicted on the map in Fig 3 and general information, including size and locations, is presented in Table 1 Lake Izbiceni is located in Olt County. This lake has a generous area of 10.95 km^2 and plays an essential role in supporting the irrigation of the nearby agricultural lands. Through its hydrographic network and water availability, Lake Izbiceni is a key factor in the development of the agricultural sector in the respective region. Another significant lake is Lake Razim, located in Tulcea County, it is one of the most famous lakes in the area, with a variable surface depending on the water level, but generally with a surface of 415 km^2. Due to its size and connection to the Black Sea through canals and bays, Lake Razim provides an important source of water for the irrigation of nearby agricultural land. The third notable lake that we included in our study is Frasinet Lake in Calarași County, which is part of the complex of lakes known as "Calarasi Lakes". This reservoir with an area of 14.6 km^2, formed by the construction of a dam on the course of the Vedea River, provides the necessary water for the irrigation of agricultural crops in the region. Studying this region and the previously mentioned lakes will help us comprehend their significance in terms of agricultural growth and the preservation of water resources.

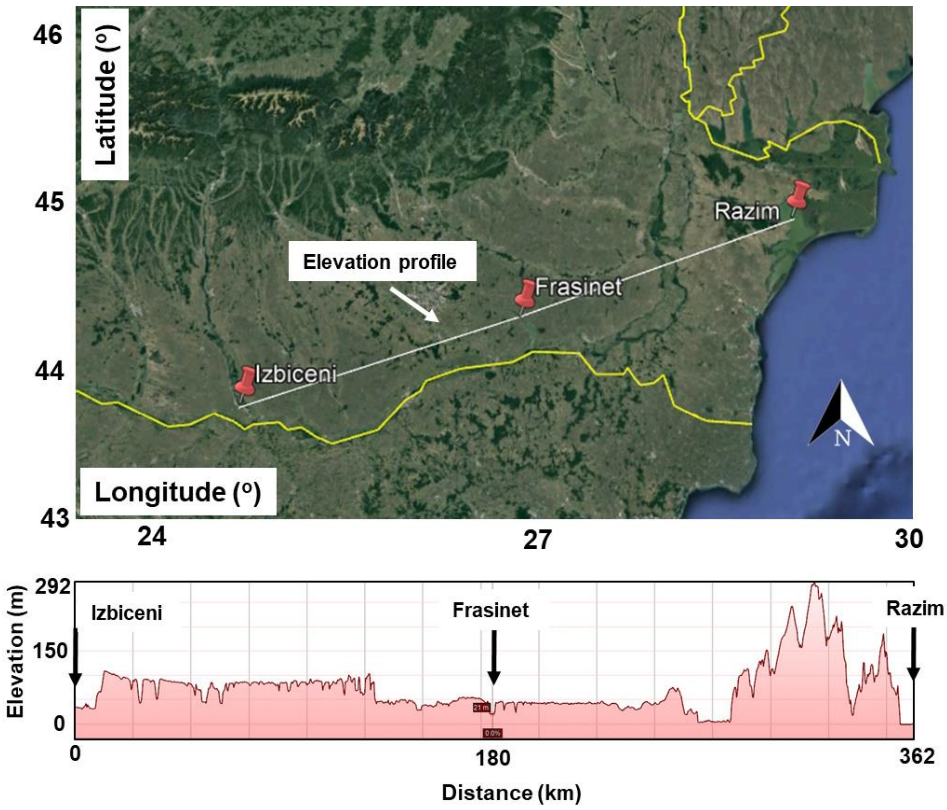

Fig. 3. Main features of the Izbiceni, Frasinet and Razim lakes, where: upper panel – geographical location; lower panel – elevation profile. Info processed from Google Earth, 2023.

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Table 1. Main features of the water bodies (Izbiceni, Razim and Frasinet) considered for evaluation.

Name	Type	County	Area (km^2)	Coordinates	
				Lat (°)	Long (°)
Izbiceni	Dam	Olt	10.95	43.81	24.68
Razim	Lake	Tulcea	415	44.88	28.95
Frasinet	Dam	Calarasi	14.6	44.32	26.80

2.2. Wind and solar data

ERA5 is an innovative meteorological reanalysis database developed by the European Centre for Medium-Range Weather Forecasts (ECMWF). This extensive database provides a comprehensive picture of historical weather conditions globally with an impressive spatial resolution of approximately 31 km. It offers meticulous and precise details, capturing the evolution of atmospheric conditions on an hourly basis from 1979 to the present. Various meteorological parameters such as temperature, wind, humidity, atmospheric pressure, and precipitation are available in this vast collection of data. High-quality information is ensured through advanced data assimilation techniques and sophisticated numerical models. ERA5 represents an invaluable resource for researchers, climatologists, and meteorologists, offering profound insights into the evolution of climate and weather phenomena over the past decades, as well as aiding in the development of future weather and climate forecasting models.

For this study, parameters such as wind speed at 100 m, surface solar radiation, and evaporation were extracted. These parameters are generally used for the assessment of wind and solar renewable resources, and the last parameter is mainly used for hydrological studies, water resource management, and assessing the availability of water for irrigation and other purposes.

2.3. Wind and solar systems

Two Siemens Gamesa wind turbines with the same power output of 3.6 MW were chosen to study wind performance. One turbine is designed for onshore operation and the other for offshore operation. Fig 4 shows the power curves for both turbines, these curves are graphic representations of the energy-generating performances at various speeds. The two key metrics of the two turbines, namely cut-in and rated wind speed, reveal the differences between them. The cut-in speed represents the speed at which the turbine starts generating power, and for the onshore turbine the value is 3 m/s, while for the offshore one, the value is 3.5 m/s. For the rated wind speed the value for the onshore turbine is higher with a value of 12.5 m/s while for the offshore one, the value is 12 m/s, this parameter represents the minimum speed at which the turbine generates the maximum rated output power.

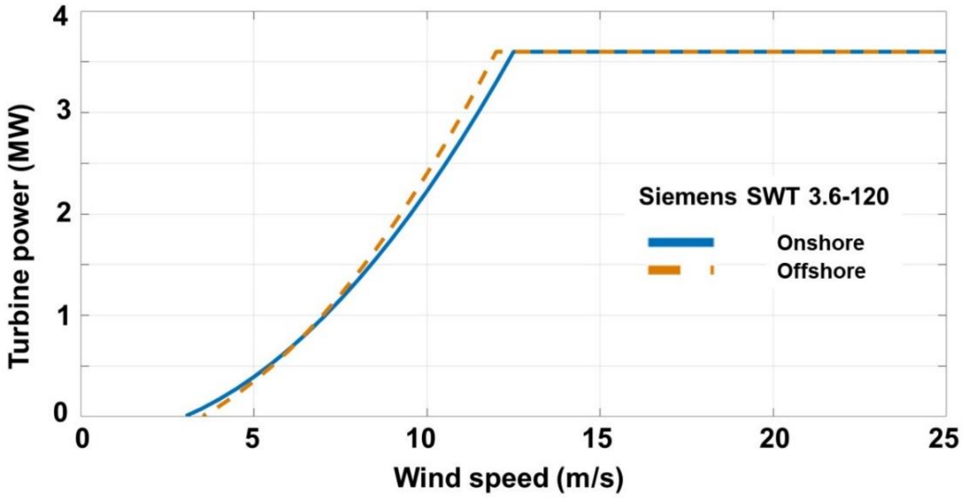

Fig. 4. Power curve of the Siemens SWT 3.6-120 generator, including the onshore and offshore version, respectively. Representation based on the info provided in [21,22].

The data obtained from the ERA5 database are at a height of 100 m, however as the two turbines operate at a height of the tower of 90 m, the wind speed will be interpolated at this height.

The Annual Electricity Production (AEP_{wind}-MWh) may be generally computed using the mean wind speed [23,24]. Developers and operators can calculate the expected energy output of a particular wind turbine using this parameter:

$$AEP_{\ wind} = T \times \int_{cut\text{-}in}^{cut\text{-}out} f(u)P(u)dU \tag{1}$$

where T = 8760 hours per year is the turbine's yearly operating time, cut-in speed is the wind speed at which the turbine first starts to rotate and generate power, cut-out speed represents the safety speed where there is no risk of damaging to the rotor (the two parameters are in m/s) [25], P(u)- W/m^2 is the power curve of a specific wind turbine, f(u) is the Weibull distribution function and has the formula [26]:

$$f(U) = \left(\frac{k}{c}\right)\left(\frac{u}{c}\right)^{k\text{-}1} \exp\left[-\left(\frac{u}{c}\right)^{k}\right] \tag{2}$$

where *k* represents the shape parameter (known also as the Weibull slope), *c* is the scale parameter, *u* is the wind speed.

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The regions surrounding Lake Razim, Lake Izbiceni, and Lake Frasinet in Romania offer ample solar resources, making them favorable candidates for the development of renewable energy projects.

One of the main objectives of this study is to evaluate the performance and benefits of a floating solar farm using the JRH 540 panel. With a power output of 540 W, the JRH 540 system boasts a remarkable maximum efficiency of 21.35%, coupled with a surface area of 2.58 m^2.

The calculation of the annual solar energy production (AEP_{solar}-MWh) involves various factors that influence the amount of energy generated by solar panels. Eq. (3) is used to determine the AEP, considering several parameters [27]. These include the incident solar radiation's density (SPD-W/m^2) on the solar panel's surface, the total area covered by the solar panels (A_s-m^2), the number of hours of available radiation (T_{TSH}), and the efficiency of the solar panel itself (η). While some research includes additional parameters to estimate energy production, such as accounting for efficiency losses caused by dust deposition, terrain slope, changes in the zenith angle of incident shortwave radiation, and variations in air temperature, these specific factors are not considered in our study. The exclusion of additional parameters simplifies the modeling process, allowing us to derive meaningful and practical insights into the solar farm's potential energy output under given conditions.

$$AEP_{solar}=SPD\cdot A_s\cdot T_{TSH}\cdot\eta \quad (3)$$

After determining the amount of energy generated, the volume of water saved by the presence of solar panels will be determined using the following formula [28]:

$$\Delta V=k\times E\times A_{CA} \quad (4)$$

where k is a reduction factor that is associated with the type of photovoltaic panel platform (in this study the value is 0.6), E represents the amount of evaporation obtained from ERA5 and is measured in m/day, A_{CA} the lake area covered with photovoltaic panels (in m^2).

3. Results and discussion

When comparing the maximum wind speeds recorded for all three lakes, we find that Razim has the highest peak wind speed of 7.09 m/s, followed by Frasinet with a peak wind speed of 5.45 m/s, and then Izbiceni with a peak wind speed of 5.24 m/s. This comparison indicates that Razim experiences the strongest winds among the three lakes, while Izbiceni and Frasinet have slightly lower maximum wind speeds. On the other hand, when considering the minimum wind speeds, we find that Izbiceni lake has the lowest recorded value of 3.87 m/s, followed by Frasinet lake with a minimum wind speed of 3.94 m/s, and then Razim lake with a minimum wind speed of 4.9 m/s. This reveals that Frasinet lake experiences the least windy conditions at a height of 100 m, while Izbiceni and Razim have slightly higher minimum wind speeds. The connection between the three lakes lies in their relative wind patterns throughout the year. All three lakes follow a similar trend of having higher wind speeds during the winter months and lower wind speeds during the summer months. This indicates a seasonal pattern where the wind intensity tends to be stronger in the colder months and weaker in the warmer months for all three locations.

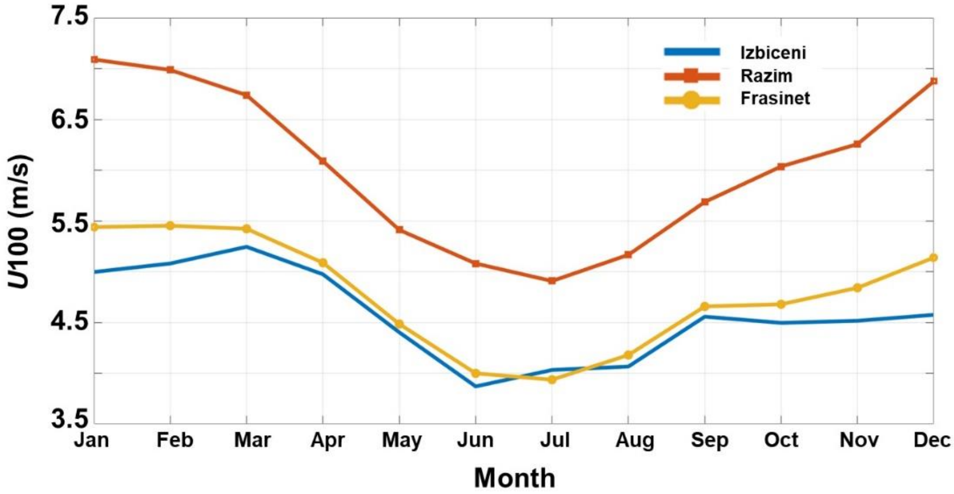

Fig. 5. U100 monthly distribution reflected by the ERA5 data for the sites Izbiceni, Razim and Frasinet, respectively. A total of 20-years of data (January 2003-December 2022) was taken into account.

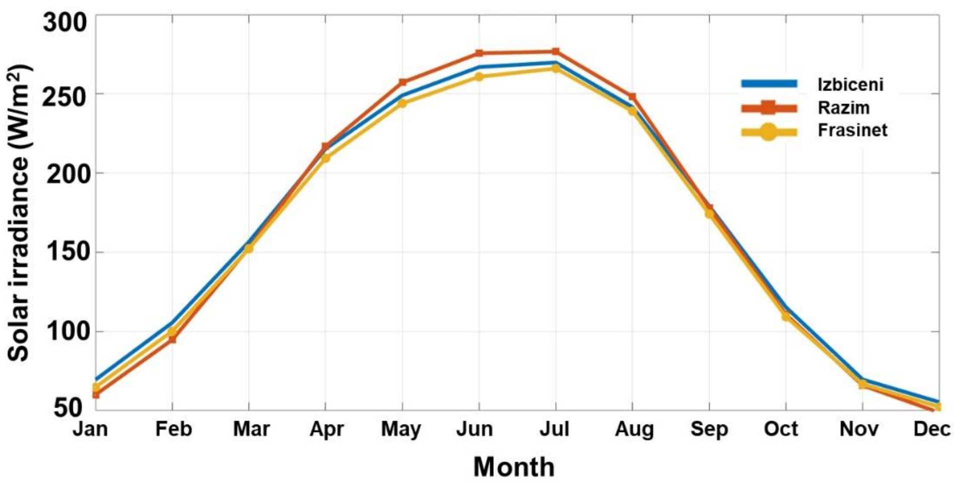

Fig. 6. Solar irradiance distribution reflected by the ERA5 data for the sites Izbiceni, Razim, and Frasinet, respectively. A total of 20 years of data (January 2003-December 2022) was taken into account.

The addition of solar radiation data in Fig 6 provides valuable information about the amount of solar energy received at each lake throughout the year. From this Fig, we can see that all three lakes experience their maximum solar radiation values in July. Razim has a maximum of 276.7 W/m^2, Frasinet has a maximum of 266 W/m^2, and Izbiceni has a maximum of 269.8 W/m^2. July corresponds to the summer months in the Northern Hemisphere when the days are longest, and the sun is at its highest position in the sky. This results in more direct and intense solar radiation reaching the Earth's surface, leading to higher solar energy values recorded at the three lakes. Conversely, the minimum solar radiation values for all three lakes occur in December. Razim has a minimum of 48.8 W/m^2, Frasinet has a minimum of 52.4 W/m^2, and Izbiceni has a minimum of 55.4 W/m^2. Comparing Fig 5 and Fig 6, we can observe an inverse relationship between solar radiation and wind speed for these lakes. The months with higher solar radiation (summer months, especially July) coincide with the months of lower wind speed (July) and vice versa.

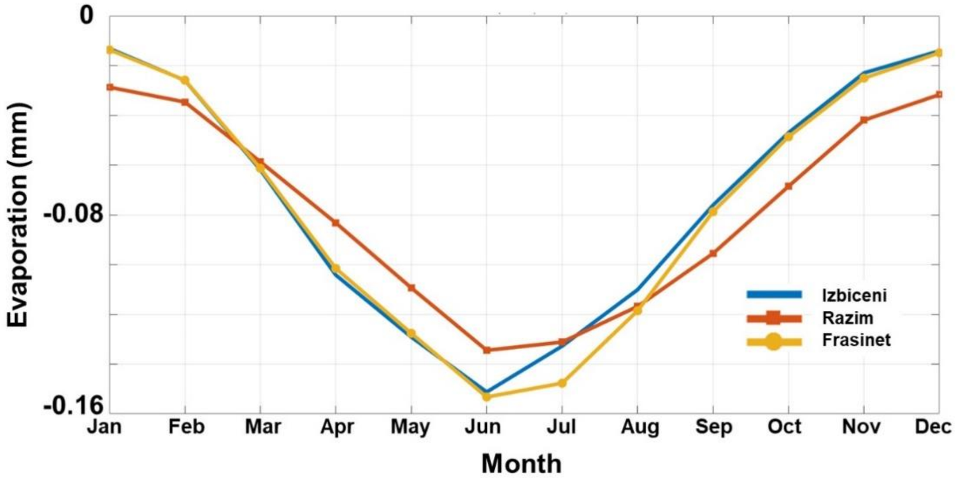

Fig. 7. Evaporation reflected by the ERA5 data for the sites Izbiceni, Razim and Frasinet, respectively. A total of 20-years of data (2003-2022) was taken into account.

Fig. 7 presents a comprehensive analysis of monthly water evaporation data for the three lakes, namely Frasinet, Izbiceni, and Razim. The dataset provides valuable insights into the seasonal variations of evaporation rates and their temporal distribution across different months for each lake. The maximum evaporation rates for all three lakes are consistently observed during the month of June. Frasinet and Izbiceni lakes exhibit peak evaporation values of -0.15 mm, indicating a significant water loss during this period. In contrast, Razim lake records a slightly lower maximum evaporation value, approaching -0.13 mm. On the other hand, the minimum evaporation values are noticeable during the winter months, especially in January and December. In these months, the evaporation values for all three lakes are close to 0, implying that there is little to no water loss due to evaporation during the colder winter period.

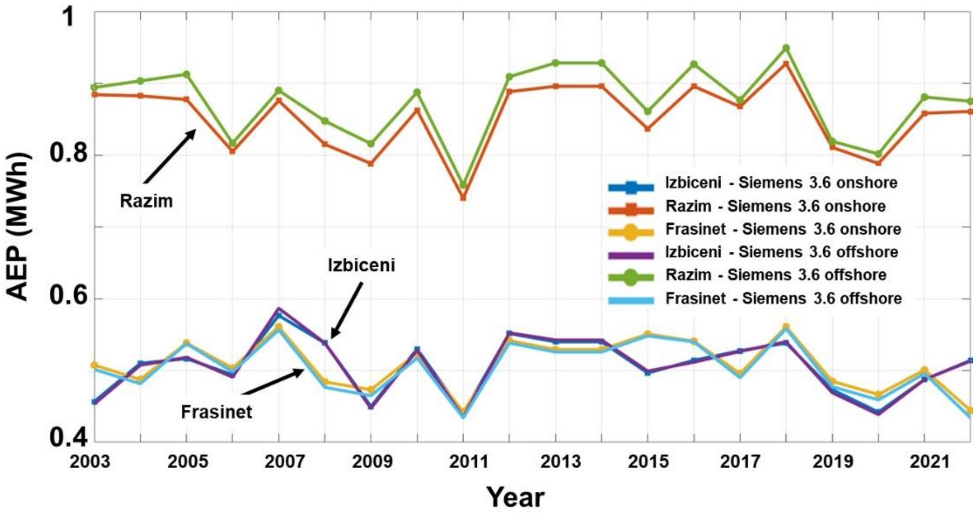

Fig. 8. AEP production of the Siemens 3.6 wind generator expected from the sites Izbiceni, Razim and Frasinet, respectively. Results based on the ERA5 data (2003-2022).

Fig 8 presents the energy production data from two Siemens 3.6 MW wind turbines, one onshore type, and one offshore type. The dataset covers the period from 2003 to 2022 and individual production curves are depicted for three lakes: Razim, Izbiceni, and Frasinet. The results reveal substantial variations in energy production, with Razim far surpassing those recorded for the other two lakes, highlighting its exceptional wind energy potential in this location. The data unveils a recurring trend wherein the offshore wind turbine consistently outperforms its onshore counterpart, particularly evident in the context of the Razim. Notably, the year 2018 stands as a noteworthy example, during which the offshore turbine achieved its highest recorded energy production with a value of 0.95 MWh for Razim, highlighting its exceptional efficacy in harnessing wind energy in this specific offshore environment.

On the other hand, the onshore wind turbine constantly shows greater energy output for the Frasinet and Izbiceni lakes. In particular, the onshore turbine is primarily responsible for the greatest energy production value of 0.56 MWh recorded in 2018 for the Frasinet. The maximum value of energy production for Izbiceni is recorded for the year 2007 using the offshore turbine this time, and its value is 0.59 MWh.

Table 2 provides a comprehensive overview of different scenarios regarding the occupation of the surface area of the three lakes, with proportions of 10%, 20%, and 30% being considered. As anticipated, the third scenario with a 30% occupation results in the largest installed capacity and subsequently, the highest energy production. Notably, Fig 9 presents the specific outcomes obtained for the

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Izbiceni lake, considering that the Frasinesti lake would yield similar results. However, the data for Lake Razim are not included here since they are significantly greater than those of the other two lakes in terms of sun radiation.

Table 2. Performances of the JRH 540 W solar system indicated for the Izbiceni, Razim and Frasinet water areas, under different scenarios.

Name	Covered surface	Number of panels	Installed capacity (MW)	AEP (GWh)
Izbiceni	10%	423,762	229	341
	20%	847,523	458	682
	30%	1,271,285	686	1,023
Razim	10%	16,060,372	8,673	12,877
	20%	32,120,743	17,345	25,755
	30%	48,181,115	26,018	38,632
Frasinet	10%	565,015	305	442
	20%	1,130,031	610	885
	30%	1,695,046	915	1,327

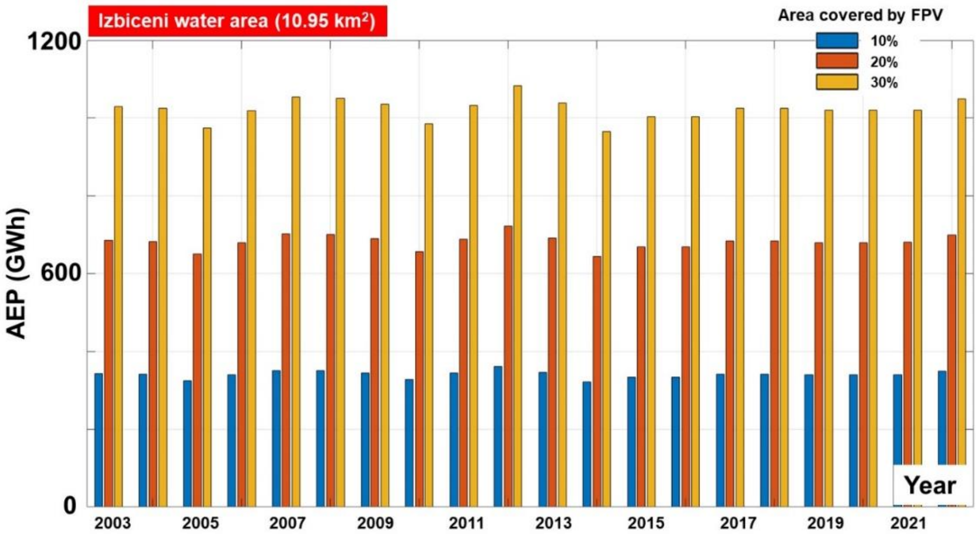

Fig. 9. AEP output of a floating PV module operating on the Izbiceni Lake. The results are based on ERA5 data (2003-2022), where the covered water surface is gradually increased from 10% to 30%, respectively.

Analyzing the results presented in Fig 9, we observe that the peak energy production value of approximately 1082 GWh was recorded in the year 2013. This significant energy production highlights the substantial potential of the Izbiceni lake for harnessing wind energy resources effectively.

Furthermore, when considering the 30% occupation scenario, the annual energy production registrations exhibit minimal variations. The difference between the recorded values remains within a maximum range of 10%, indicating a relatively /stable and consistent energy production trend for this scenario.

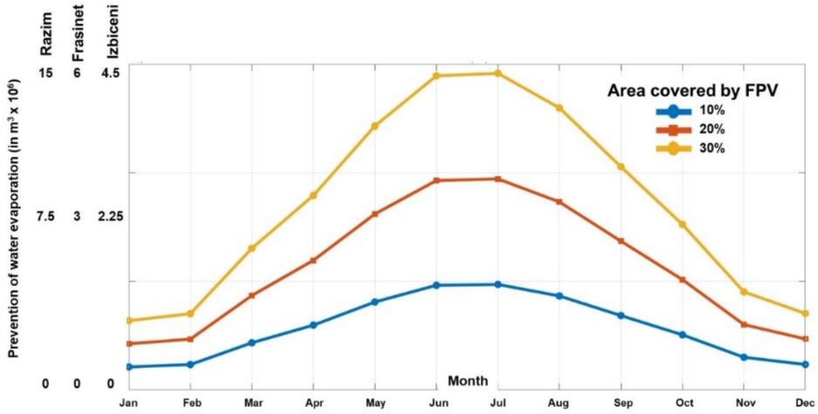

Fig. 10. Monthly water prevention from the presence of a FPV project, by considering different scenarios involving the Razim/Frasinet/Izbiceni Lake (10, 20 and 30%).

The water saved for each month of the year is shown in Fig. 10, which gives important details about how water conservation is accomplished in various circumstances. It is noteworthy that scenario 3, which has a significant number of installed solar panels, regularly records the highest quantity of water saved for all lakes. In this scenario, Lake Razim stands out with the highest value recorded in June, amounting to 14.6 m^3. This substantial volume is a result of the lake's larger surface area than the other two lakes. For Frasinet and Izbiceni lakes in scenario 3, the maximum water savings are 5.8 m^3 and 4.3 m^3, respectively. These values demonstrate the positive impact of solar panels in conserving water resources in these locations.

In Rusu T.M. et al. [29] we noticed that in Romania, for the production of one ton of wheat, an amount of approximately 1827 m^3 of water is consumed, for one ton of vegetables, an average of 326 m^3 of water is consumed, and for the production of one ton of sheep meat, 8801 m^3 of water is consumed. So that if we consider the most favorable scenario and take into account only the months in which irrigation is done for wheat, with the amount of water saved from Razim we will get a quantity of 11553 tons, with that from Frasinet we will get 4840 tons and for Izbiceni we will get 3705 tons. If we refer to the vegetable plantation for which irrigation is done on average from March to August, we will have for Razim a production of 213607 tons, for Frasinet we will get 84168 tons, and for Izbiceni 61266. To produce sheep meat, we can get 11621 tons with the water saved from Razim, 3946 tons for Frasinet and 2915 tons for Izbiceni.

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4. Conclusions

The use of lakes for renewable energy generation via floating solar panels and wind turbines gives an appealing prospect for long-term power generation. The benefits of employing lakes as platforms for these technologies, such as greater efficiency, optimized land use, water conservation, and closeness to populated regions, show their potential as viable solutions in the renewable energy landscape. As research into the refinement of floating solar panels and wind turbines progresses.

The present study provides a comprehensive and technical analysis of the renewable energy potential of three lakes: Razim, Izbiceni, and Frasinet, situated in the region of interest. The evaluation is based on data extracted from the ERA5 reanalysis database, encompassing parameters such as wind speed at 100 m, solar radiation, and evaporation, spanning approximately 20 years from 2003 to 2022. A number of renewable energy technologies, including the two 3.6 MW Siemens wind turbines and the 540-kW solar panel, were also considered in addition to this data. The study also includes three scenarios to investigate the development of solar energy and water evaporation. The surface occupancy percentages in these situations range from 10% to 30%.

In conclusion, the comprehensive study highlights the promising renewable energy potential of the region, particularly in wind and solar resources. The analysis demonstrates Razim Lake's exceptional wind speed and energy production capabilities, positioning it as a prime candidate for wind energy projects. Frasinet and Izbiceni also display promising renewable energy potential, offering favorable conditions for wind and solar energy utilization, contributing to a greener energy landscape. Moreover, the integration of solar energy technologies and water conservation strategies underscores the region's capacity for a comprehensive and sustainable approach to energy generation. By harnessing these abundant and clean energy sources, the region can pave the way towards a greener and more environmentally conscious future, contributing to global efforts in combating climate change and advancing towards a clean energy revolution.

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