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ASSESSMENT OF THE SOLAR ENERGY POTENTIAL IN THE ROMANIAN NEARSHORE

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Abstract: In December 2019, the first official European Green Deal document was released, which aims to reduce greenhouse gas emissions gradually by 2050, when the carbon neutrality target should be reached. The aim of the paper is to analyse the possibility of implementing solar farms in Romania with particular interest for the nearshore area of the Black Sea. Moreover, it is analysed the current status of electricity generation sources in Romania, the profile of consumers connected to the National Energy System (NES), and the electricity injected into the grid through solar farms. On the other hand, the possibility of intermittent injection of energy into the grid and the effects on the stability of the national energy system are analysed.

Key words: Black Sea, carbon neutrality, DNI, GHI, Global Horizontal Irradiance, photovoltaic panel, national energy system, solar farms.

1. INTRODUCTION

In the current economic and political context, the issues of raw material supply for the energy sector are a much-debated topic in most European countries. At the same time, visible changes in the dynamics of the environmental matrix due to technological and human activity/evolution are accelerating climate changes. To combat these phenomena, EU member countries have devised a strategy to aggressively reduce greenhouse emissions. The main target is a transition to a carbon neutral position [1]. This favours investment in renewable energy resources, in particular wind, solar and marine energy. In addition to accelerating price increases, the low availability of raw materials for electricity generation in conventional thermal power plants creates energy security problems and requires rapidly implemented solutions.

In the European Union, investments in green energy are encouraged now. The main renewable sources of electricity generation use: wind energy, solar energy, hydropower, ocean energy, geothermal energy and biofuels and biomass. According to the latest European economic strategies, natural gas and nuclear energy have been added to the list of 'green' sources [2].

The stability of the national energy system is represented by the balance between electricity produced and consumed. This means that sources of electricity generation are always needed. A list of green energy sources shows that hydroelectric and geothermal energy are the most suitable sources for producing electricity in a CO_2-neutral way. In addition, nuclear energy can provide significant amounts of electricity and provide grid stability. However, it is recommended to use more green energy sources to provide the electricity needed in critical situations.

On the other hand, electricity produced by other renewable sources (wind, solar, ocean energy) has a variable profile that can be predicted using mathematical algorithms. But it cannot be permanently correlated with the consumer profile.

Even though natural gas (NG) is on the list of green energy sources, the reduced availability of NG in Europe due to eastern political conflicts makes it currently unsuitable for long-term power generation. This calls for a detailed study of the possibility of energy exploitation according to available energy resources and consumer needs.

In addition, a detailed analysis of the energy consumer profile is needed, as there must always be a balance between what is produced and what is consumed. While for industrial consumers it is possible to predict the maximum electricity consumption and its profile, for domestic consumers it is found that most of the energy consumed is during the day, while at night consumption drops to a minimum.

In these conditions, the European Union is focusing on wind energy extraction with an ambitious target of 300GW. This represents the installed capacity, and is 25 times higher than in 2021 (12GW) [2]. It also aims to increase Marine Renewable Energy (MRE) extraction capacity. The proposed target for 2050 is to install 40GW of offshore energy extraction capacity (floating

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solar farm and wave), compared to the current capacity of 13MW [3] [4].

2. ROMANIAN ELECTRICITY SECTOR

Romania's energy sector is supported by power plants using various raw materials, most of them using green, clean sources. Figure 1 shows the percentage share of energy sources for electricity supply in the last 12 months in Romania (July 2021 - June 2022) [5].

The largest share in electricity production is hydropower (25%), followed by electricity produced from nuclear energy (20%), fossil fuels especially coal (20%), hydrocarbons (heavy fuel and natural gas) 19%. Wind energy contributed 13% to total energy production. Photovoltaic electricity production contributed 2% while biomass contributed only 1%.

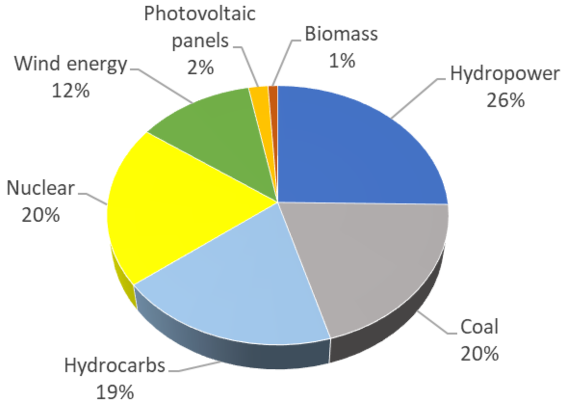

Figure 1 Power generation sources [5]

According to the decisions at European level, among all these sources, green energy is considered if renewable energy sources (wind energy, solar energy, hydropower, ocean energy, geothermal energy, biomass, and biofuels), natural gas and nuclear energy are used. However, it can be seen that of the total energy produced, more than 60% is from green energy sources. If we also consider a few percent of the total electricity produced from hydrocarbons as 'green' electricity produced from natural gas, the total percentage of green energy increases.

If the energy source is free, producing electricity from that green source comes with another cost: availability. The only free green sources that have permanent availability are hydro and geothermal. Electricity production using solar and wind power is intermittent. Figure 2 shows below the hourly electricity consumption in Romania in the cold season (January 2021) [5].

Figure 2 Electricity consumption in January [5]

Analysing the instantaneous consumption shows that there are always differences in consumption between day and night of up to 2-3 GW. Electricity consumption starts to increase around 6AM and starts to decrease after 7PM. Further, Figure 3 shows the hourly electricity consumption for one month in the warm season (June 2022). This time, the differences between day and night are between 1 and 2 GW. Electricity consumption starts to increase around 6AM and starts to decrease around 10PM.

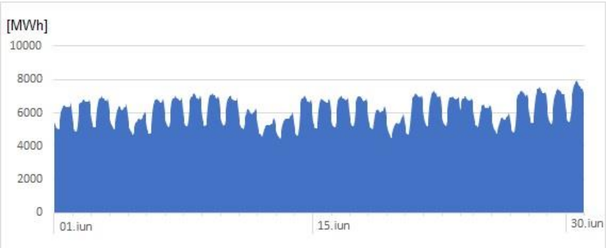

Figure 3 Electricity consumption in June [5]

Given the profile of electricity consumers, it is clear that we need an intermittent/variable source of electricity in addition to the established sources of electricity. This should be able to produce about 1-2 GW in summer and 2-3 GW in winter. Variable summer consumption can be provided by photovoltaic panels, producing electricity exactly when needed.

3. RESOURCE AVAILABILITY

In view of the above, the possibility of implementing solar farms in Romania is analysed. Electricity produced by photovoltaic panels represents only 4% of the total green energy. Figure 4 shows the level of solar irradiation measured in $kWh/m^2/year$ in Romania.

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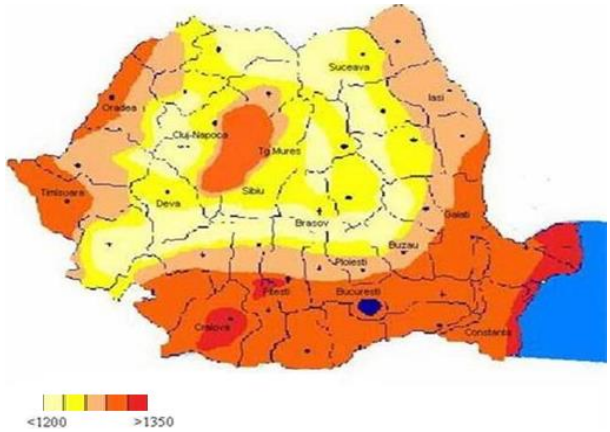

Figure 4 Solar irradiation in Romania [6]

Solar irradiation reaches its highest values in the Oltenia and coastal areas. Considering that the Oltenia area is suitable for agriculture, the possibility of building solar farms in the Romanian nearshore, preferably floating solar farms near the Black Sea coast, remains to be explored. At the same time, the cost of buying or renting a long-term agricultural land is higher compared to the nearshore area.

The energy received from the sun in the form of electromagnetic radiation is called solar irradiation. This is measured in watts/m^2.

For any project related to harnessing solar energy, a proper assessment of the available resources is necessary. The following parameters are used to assess solar irradiance:

- Direct Normal Irradiance (DNI) [W/m^2];
- Direct (Beam) Horizontal Irradiance (EBH) [W/m^2];
- Diffuse Horizontal Irradiance (DHI) [W/m^2];
- Global Horizontal Irradiance (GHI) [W/m^2];

Direct Normal Irradiance (DNI) is the solar irradiation arriving directly from the sun on a perpendicular surface. Direct (Beam) Horizontal Irradiance (EBH) is the horizontal component of Direct Normal Irradiance (DNI). Diffuse Horizontal Irradiance (DHI) is the component of solar irradiance received on a surface by a path (diffusion, reflection) other than direct. Finally, we have Global Horizontal Irradiance (GHI) which represents the total solar radiation received by a surface. It includes normal irradiance and diffuse irradiance [7] [8]. GHI is calculated with relation 1 and is the most important parameter that is considered when making analyses for the implementation of photovoltaic farms.

$$GHI = DNI * \cos(\theta) + DHI \quad (1)$$

The figure below illustrates the components of global horizontal irradiation.

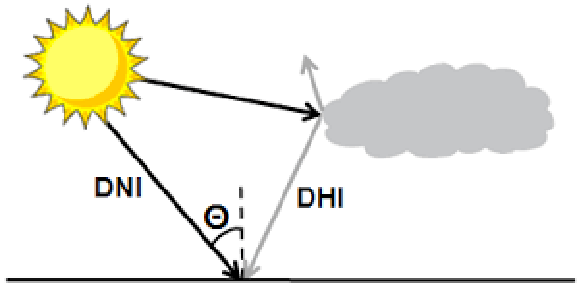

Figure 5 Global Horizontal irradiation [9]

Generally solar panels are installed with a tilt of 20 to 60 degrees. The optimal angle for maximum electricity production depends on the season and geographical location. Under these conditions a new parameter is defined: Global Tilted Irradiance (GTI). Unlike GHI, GTI also considers the reflection of surrounding objects, especially the reflection of the ground. The numerical differences between GTI and GHI are small because the reflectance of the earth's irradiance has low values. For this reason, this parameter is not used. On the other hand, if we look at floating farms, we see that the water reflectance is much higher than for solar farms on ground.

The air temperature in the nearshore area is lower than the air temperature in the neighbouring areas with land that allows photovoltaic farms. In addition, the higher wind speed in the nearshore area cools the solar panels much better [10] [11].

According to simulations by Golroodbari and Wilfried [12] annual electricity production is 12.96% higher for floating photovoltaic (PV) panels than for ground-mounted panels. At the same time, the solar irradiance on PV panels is 8.54% higher for the floating solution. As expected, waves help reflect solar radiation, and humidity, wind, and lower air temperatures (compared to ground-mounted solar farms) provide better cooling, which leads to higher efficiency of PV panels. Hudișteanu [13] also observed that additional cooling of PV panels can increase the electricity produced by up to 9%. Additional cooling of the panels is necessary because the temperature of the photovoltaic cells is 20-30°C higher than the air temperature [14]. The temperature of the cells depends on the manufacturing technology and the cooling system of the panel [15].

4. DATA PROCESSING

Figure 6 shows the maximum Global Horizontal Irradiance (GHI) as a function of the months of the year. The statistics are made with the Solcast [16] database, representing the maximum values of the last 10 years in the Romanian coastal area.

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Figure 6 GHI irradiation Romania, Constanta [16]

The maximum values were chosen to be able to analyse an ideal case with clear skies. In this area, 6 months a year the solar radiation exceeds the threshold of 750 W/m^2, reaching for 3 months values of over 900W/m^2. In the cold season, solar radiation barely reaches maximum values of 400 W/m^2 in ideal conditions with clear skies. The data presented in Figure 6 are valid for solar farms on land. In the case of floating photovoltaic farms, solar irradiance could exceed 1000 W/m2. At the same time, natural cooling favoured by the ambient environment could maximise the output of the panels.

In terms of microclimate, there are studies showing that photovoltaic panels mounted horizontally on the water surface (suitable for lakes) cause the water surface to warm up by 1 degree. At the same time, it reduces the amount of evaporated water and stops aggressive algae growth [17].

In addition to the advantages presented above, the main disadvantages of floating solar farms compared to land-based solar farms can also be predicted: higher initial implementation cost, more difficult maintenance, special electronic equipment and wiring connections, long distance to the grid. In addition, there is a risk that seabirds may nest or foul the surface of the PV panels and equipment.

Next, an analysis of the public data provided by the national energy system (Figure 70 [5] shows that in June, when solar irradiation reaches its highest values of the year, the instantaneous electricity production in Romania produced by photovoltaic panels is slightly above 700 MW. Given the consumer profile, photovoltaic panels would be a solution for the difference in consumption between night and day. Electricity production starts after 6AM, and ends after 7PM, providing almost half of this time an instantaneous production of over 600MW.

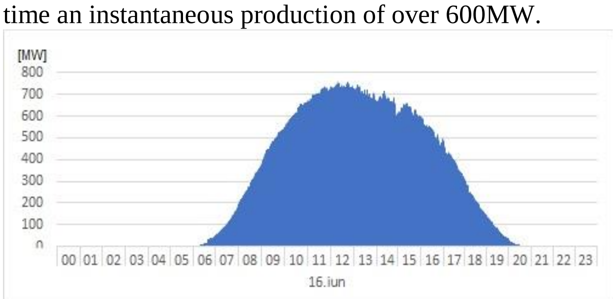

Figure 7 Electricity produced from solar power [5]

In the context of climate change and reduced river flows, solar panels can provide electricity during the day, allowing water to be stored in the dam area. This allows hydropower plants to supplement their needs when solar panel production starts to decline.

In the cold season, solar irradiation decreases in intensity and exposure time. Figure 8 shows the electricity produced during a clear winter day. The panels start producing electricity after 8AM, producing just over 400MW in the 11AM - 1PM time frame. After 4PM the production tends towards 0 MW [5].

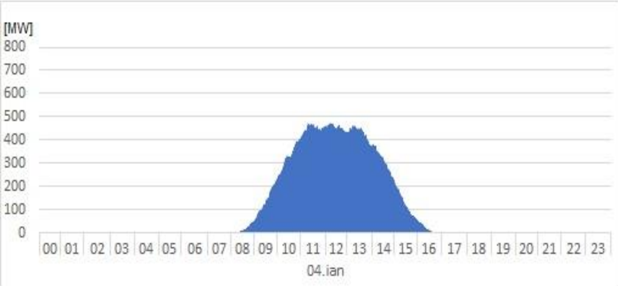

Figure 8 Electricity produced from solar power [5]

It is clearly that the cold season is not a very productive one for photovoltaic panels due to the reduced 'raw material'. At this time of the year, wind turbines are much more profitable. However, these systems should coexist in order to have 'free' energy every season [18] [19].

5. CONCLUSIONS

According to the solar irradiation level maps, it is suitable to install photovoltaic panels in the Oltenia area and in the Black Sea coastal area. Since agriculture plays an important role in the Oltenia area, it is recommended to use floating panels only in the dam areas of the Olt hydropower plants. The exploitation of solar energy in the Romanian coastal area can be carried out in the marine environment as the land area is an important tourist destination.

Studies show that floating photovoltaic panels can produce 12.96% more energy than ground-mounted ones.

Following the analysis of the profile of energy consumption in Romania, a difference in electricity consumption between day and night with variations of up to 3 GW during the cold season was found. In the warm season the difference between night and day is 1-2 GW.

At the moment, the electricity produced by solar panels on sunny days barely reaches 0.7 GW. It is obvious that it is necessary to double the current production, even triple it just to compensate for the daily consumption variations. Now, we are either importing quantities of energy during the day or increasing the load

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on the generators of hydropower and thermal power plants (hydrocarbon and coal). Increasing the capacity of solar farms would help reduce electricity imports and help balance the national energy system, at least in summer. During the hot season, the profile of electricity production with photovoltaic panels is close to the variations in electricity consumption.

The analysis of the evolution of the global horizontal solar radiation in the coastal area shows that half of the year the solar radiation is above the threshold of 750 W/m^2 in case of a clear sky, and three months a year the solar radiation exceeds the value of 900 W/m^2. In addition, temperatures in this area are lower and water vapour can further cool photovoltaic panels, improving their efficiency.

It is recommended to carry out complex studies on possible technical solutions for the implementation of floating farms with photovoltaic panels, wind farms, wave synergy and the possibility of connection to the national energy system.

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