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ARE THERE OPPORTUNITIES OF USING SOLAR ENERGY IN IRRIGATION SYSTEMS?

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Abstract

The paper aims to have a look over the energy production over the time, and its specific nowadays, with the desire to find alternative solutions, but taking into account the specifics of the way in which irrigation systems and schemes in Romania are structured and used, and watering methods are distributed according to the plants, over the territory. Analysing the Romanian Energy System for 2 different periods (winter and summer) and the distribution the energy sources, there are comparisons between the evolution of energy production and energy needed for irrigation. In that manner it is possible to conclude if and when solar energy has efficient utilization.

Key words*: energy, solar, irrigation, consumption-demand balance, storage.*

INTRODUCTION

Social and economic development implies an increase in the energy need. Industrial evolution was based, in its first phase, on fossil energy resources (that have the advantage of a high energy density): coal was the main source of energy, quickly followed by oil (Figure 1).

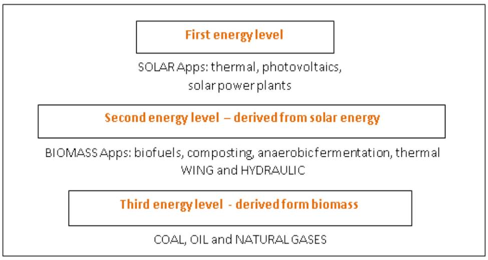

Figure 1. Energy levels depending on generation mode and historical time

The primary energy received from the sun is converted in a short time into wind, hydraulic and biomass energy. The third level of energy was due to natural biomass transformation processes.
The energy density increases from the first level to the last one, high efficiency applications being made throughout the period of industrial development. Hydraulic energy has developed throughout the entire mankind development period due to the multiple advantages related to efficiency and the possibility of storage.
The technology transfer and the society development have led to the continuous increase of the energy requirement with an unfavourable effect on the environment.
The main ways of environmental impairment caused by energy production are:
- natural resources overexploitation, deforestation, change of land use, water resources extensive and intensive use;
- mining, oil extraction and processing;
- tailings - associated land and water pollution;
- carbon emissions, powders, other combustion gases, atmospheric pollution.

In recent period, climatic changes were highlighted, the measured values show temperature increases and precipitation regime changes, these effects being closely related to the greenhouse effect produced by carbon and powders high concentrations in atmosphere.
In this context, a plan was proposed to modify the energy field and re-technologically the entire society, whereby the energy sources from level 3 (Figure 1) are gradually abandoned and the necessary provision is made through the resources mentioned at level 2 and 1, as seen in the energy production evolution between 2010 and 2020 graph by source type (Figure 2).

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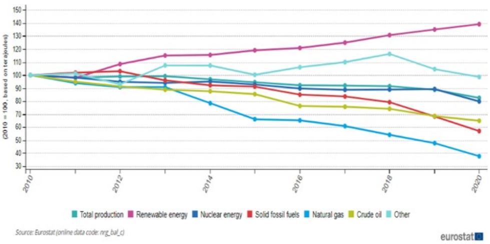

Figure 2. Production of energy by source type, EU, 2010-2020 (Source: Eurostat, 2021)

The directions of action are:
- increasing energy efficiency in all activity fields;
- giving up coal and oil (level 3);
- energy provision from renewable sources (level 1 and 2);
- consumption and transport based on electricity and hydrogen;
- balancing the demand-supply stages based on natural gas and electricity storage systems (through hydropower methods, hydrogen production, integrated production-storage-consumption systems) and intelligent consumption systems.

The energy system transformation involves a considerable volume of investments in which both producers and consumers will have to be engaged, through following methods:
- changing the type of used energy, investments in electricity production, storage and transport units;
- car fleet replacement, entire transport system restructuring;
- processes optimization and automation.

THE CURRENT SITUATION OF ENERGY IN ROMANIA

Nowadays, in Romania the main activities that involve energy consumption are (INSS, 2018; 2019; 2020; 2021; 2022):
- transport consumption: derived from oil (diesel, petrol and LPG): 300 l/year.consumer ≈ 2,400 kWh/year.consumer = 6.6 kWh/ day.consumer (average values, considering the reduced fuel consumption during the Covid pandemic period);
- total electrical energy consumption: 5,000-8,000 MWh/hour ≈ 150 GWh/day = 8 kWh/ day consumer;
- consumption for heating in the cold period: 50-150 W/m^2 ≈ 50 kWh/day consumer;
- consumption for domestic hot water preparation: 50 l/day = 1.5 kWh/ day consumer.

Romanian data show that the largest share of consumption is found in the heating sector, the consumption of electricity and for transport being at a low level.

In order to reduce energy consumption in Romania, in accordance with the European plan for reducing carbon dioxide emissions, the following projects are underway:
- buildings insulation and thermal rehabilitation;
- conversion to electric transport;
- electricity production from renewable sources;
- increasing the processes energy efficiency;
- biomass and biofuels projects development;
- capture and recovery of thermal energy using heat pumps.

Overall, the energy system modification and the predominant of electricity use implies the increase of this system by approx. 200-300 % in all sections: production, transport, distribution.

To characterize the national electricity system current situation, an analysis of production and consumption was carried out for two periods: June 18-25, 2022 (the longest day of the year) and December 18-25, 2022 (the shortest day of the year), resulting:
- production-consumption- balance and the share of each category of energy in production (Table 1);
- hourly evolution of solar and wind energy production.

Table 1. Production-consumption balance for the analysed periods

Period		18-25 jun. 2022		18-25 dec. 2022	
		GWh	%*	GWh	%*
Consumption	GWh	1175.09	100.00	1250.65	100.00
Production	GWh	1141.07	97.11	1333.40	106.62
Coal	GWh	250.70	21.33	217.05	17.35
Hydrocarbs	GWh	208.42	17.74	284.04	22.71
Hydro	GWh	361.16	30.73	412.40	32.97
Nuclear	GWh	131.55	11.20	268.51	21.47
Wind	GWh	130.20	11.08	129.74	10.37
Photovoltaic	GWh	48.45	4.12	10.71	0.86
Biomass	GWh	10.61	0.90	10.97	0.88
Sold	GWh	34.04	2.90	-82.74	-6.62

*percentage-weight of the total consumption

For the analysed periods, it turns out that the share of renewable energy produced in the national energy system is about 16% in the hot season and 10% in the cold season. The differences are due to climatic factors that especially affect solar energy, 4% weight in the warm period and only 0.9% in the cold period (Figure 3).

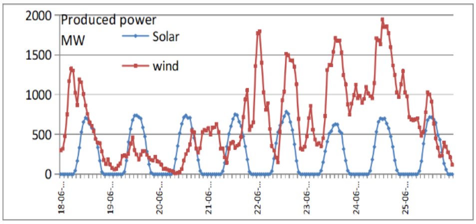

Figure 3. Evolution of solar and wind sources energy production - period (18-25).06.2022 (processed data, Transelectrica, 2023)

It can be seen that on the 19th and 20th of June the production of photovoltaic energy was higher compared to wind energy. For the period analysed it is found productions close for solar energy, making predictable this category of energy, depending on the weather forecast and the evolution.

There are periods with low consumption and high production originating from the wind component. For these reasons, wind energy sources require energy storage systems, while predictable photovoltaic energy can be used in the national distribution and consumption system without the need for storage in compensation, especially with hydraulic energy.

Figure 4 shows significant variations in the two energy categories and the possibility of correlation: large day-to-day differences in solar energy can change wind energy production due to changes in weather conditions, differential heating and local or regional generation of air mass movements in atmosphere.

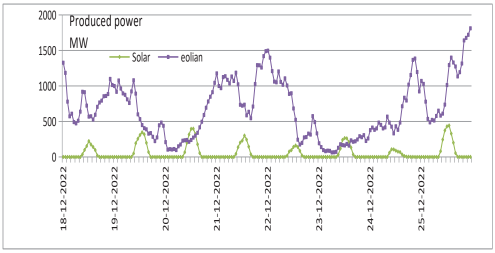

Figure 4. Evolution of solar and wind sources energy production - period (18-25).12.2022 (processed data, Transelectrica, 2023)

Figure 5 shows the significant production variations within the winter period and reduced values compared to the summer period; the values produced in winter days can be of the order of percentages compared to warm season production.

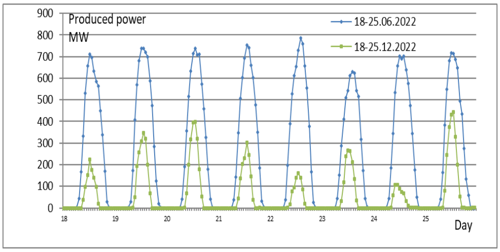

Figure 5. Comparative evolution of summer-winter photovoltaic energy production (processed data, Transelectrica, 2023)

The production evolution shown in Figure 6 indicates significant variations and the need for compensation in the national system or the creation of storage systems.

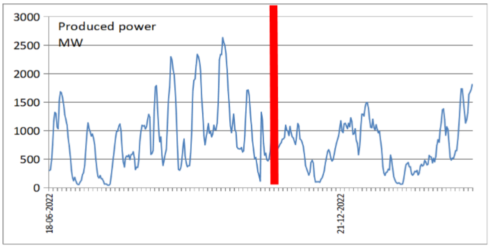

Figure 6. Evolution of solar and wind sources energy production - periods (18-25).06.2022 and (18-25).12.2022 (processed data, Transelectrica, 2023)

Figure 7 shows the relatively constant daily production but also the significant hourly variations: about 4 hours/day the production is at a level of over 90% of the maximum value and about 7 hours/day at a production of over 70% of the maximum value. The obtained graph shape coincides with the one described by Victor, 2011.

The production uniformity during this period makes predictable this type of energy production, depending on the weather conditions.

The overlapping of the production during the period of high consumer demand means that this type of energy does not require storage units if the introduction into the national energy system is ensured.

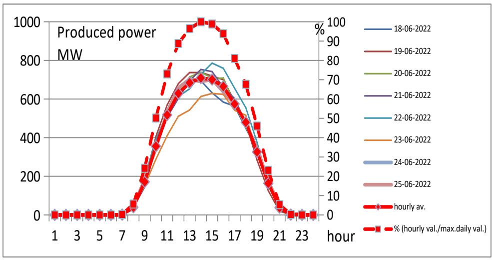

Figure 7. Hourly evolution of photovoltaic energy production- period (18-25).06.2022 (processed data, Transelectrica, 2023)

Figure 8 shows the significant hourly and daily variations of the photovoltaic energy production during the analysed winter period.

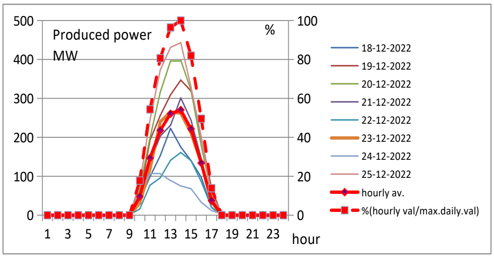

Figure 8. Hourly evolution of photovoltaic energy production- period (18-25).12.2022 (processed data, Transelectrica, 2023)

The average value of the maximum daily production at a value of 270 MWh is about 2.5 times lower than that obtained in the summer period analysed in Figure 5, where the average production at the maximum of the day was 700 MWh.

SOLAR-PHOTOVOLTAIC ENERGY USE FOR IRRIGATION

The irrigation systems are large energy consumers; for example, the U.S. agricultural irrigation consumed 60.6 TWh in 2018 and there is an acute interest to diminish the energy footprint of this activity (Sow & Dicataldo, 2022).

Climate changes affect the energy consumption of irrigation systems, major adaptation needed cause the fact that increasing water use efficiency means intensifying energy use through increasing pumping head (Daudin & Weber, 2020).

The irrigation systems in Romania were created to ensure the water requirements for large areas, in the context of the state ownership of the respective areas. The plan for the irrigation systems development envisaged investments for 3 million ha, an area that represents approximately 20% of the country's agricultural area.

The irrigation technology for these extensive systems involves watering with high rates at a time interval calculated or resulting from the water balance for each irrigated plot.

Practically, the volume of active soil is considered as the storage volume between the minimum and maximum humidity (field capacity), the technology involves soil irrigation.

The energy requirement for pumping water for large surfaces is high and optimization measures are adopted in operation:

- pumps high efficiency operation;
- reduction of water losses form transport channels and pipelines networks;
- watering installations function at minimum pressures

The transition to a new society organization led to labour force reduction, which migrated to the industry, more economically efficient, so the irrigation systems were equipped with hydraulic displacement equipment that requires higher pressures at the pumping station (about 6-7 bar).

In these conditions, considering an irrigated surface of 1 million ha with an average rate of 1500 m^3/ha/month, the energy requirement only for the pressurized stations is 570 MWh/h, which represents approx. 10% of the current capacity of the national energy system (Burchiu et al, 2004):

$$P(kW) = \frac{\gamma Q H}{\eta.p X \eta.me} = \frac{9.81 X \frac{1500}{30 X 20 X 3600} X 60}{0.8 X 0.9} = 0.57 kW$$

where:

P - power of the pumping unit, Kw;

Q - pumped flux rate, m^3/s;

H - pumping head, mCA;

η.p - pump efficiency;

η.me- electric motor efficiency.

The estimated value in this case is optimistic, the energy consumption being higher due to:

- energy losses during the transport and transformation of electricity (approx. 10%);
- infiltration and evaporation water losses in transport systems;
- energy consumed by pumping and

repumping stations (different, specific value for each irrigation system and plot);
- ensuring the necessary irrigation norms in dry periods (reaching values of 3000 m^3/ha/month).

The previous analysis shows that for extensive irrigation systems it is impossible to provide energy from solar energy sources, the main incompatibilities being:
- high energy requirement for irrigation throughout the day including during the night (when watering is recommended to ensure higher efficiencies);
- high energy requirement for irrigation and low solar energy density, the use of the variant involving investments in photovoltaic parks on large areas;
- large hourly variations in the photovoltaic energy production and the impossibility of ensuring the necessary power on a constant basis;
- the lack of overlapping of the energy production period with the efficient irrigation application period;
- the need to over-equip irrigation systems or the use of other complementary energy sources;
- the high production price of photovoltaic energy.

For agricultural production systems on small areas, specific to horticultural farms, efficient irrigation systems "at the plant", through drip or similar systems, the option of using photovoltaic energy can be adapted. On the same calculation assumptions, the result for 1 ha is a photovoltaic system of 0.57 kW x 20 hours = 12 kWh/day with an area of 15- m^2.

The watering norms application can be ensured by oversizing the irrigation installation or by storing energy in the form of electricity or hydraulic, the last option requiring the oversizing of the photovoltaic system depending on the additional pressures required.

CONCLUSIONS

Photovoltaic energy production is variable both seasonally and hourly, which makes it impossible to ensure the necessary for domestic and industrial consumers. To compensate for hourly production, storage systems for high production capacity are not justified; the overlapping of production over demand implies the injection of this photovoltaic energy directly into the energy transport systems. Low-capacity storage systems for the isolated individual consumer can be considered cost-effective.

The advantage of solar energy is that it is predictable in terms of production depending on weather conditions and can be easily compensated in the national energy system. In the cold season, the production is variable in a wide range, the share within the national energy system being reduced.

Variable wind energy production requires storage systems or extreme compensation measures within the national energy system.

Photovoltaic energy can provide the necessary for small surfaces irrigation systems with plant watering, oversizing the watering system or storing the energy in hydraulic form. For extensive irrigation systems, photovoltaic solar energy is not suitable due to the hourly non-uniformity energy production and the reduced production time.

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