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Photovoltaic development in Romania. Reviewing what has been done

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ABSTRACT

The Sun is the primary energy source for all life on Earth. Solar energy is clean and is available all over the world. The total energy produced, in 2016, was 7236 MWh, while the total consumed was 6660 MWh. The average photovoltaic energy generated was 255 MWh, which accounts for 3.5% of the total production and 8.2% of the RES (3096 MWh). Investments in renewable energy in Romania began in late 2008, when Green Certificates were granted by Law no. 220. In this paper, we review the photovoltaic system development in Romania, from 2011, when the market began to develop, to the present day.

The climate change and air pollution have to be slowed down and reduced by implementing renewable and sustainable solutions in order to generate electricity. The photovoltaic industry has an important role in Romania's development, both economically and environmentally and by having the "unlimited resource" advantage, it is a good alternative to fossil fuels.

Now, the largest solar park in Romania, with 332,000 operational PV units, located in Ucea de Sus, Brasov County and commissioned in 2013, has an installed capacity of 82 MW, and covers a land surface of 200 ha.

178 years ago, French physicist Edmond Becquerel discovered the photoelectric effect, in 1839. At the moment, the typical power of solar PV modules is less than 500 W, depending on efficiency and temperature sensitivity. Currently, long-term research on photovoltaic cells focus on increasing the power output, increasing the efficiency and reducing the temperature sensitivity.

1. Introduction

PV system technologies development in recent years has encouraged investments and facilitated access to competitive prices [1–6]. The growing global demand for energy from fossil fuels plays a key role in the upward trend in greenhouse gas (GHG) emissions and air pollutants [7] and for this reason the European Union changed its Energy Policy to promote smart, sustainable and inclusive growth [8,9]. Between 2005 and 2015, the installed solar PV power in Europe as increased 50-fold to reach 95 GW and wind power has increased three and a half times to 142 GW at the end of 2015. The fact that the Paris Agreement went into force on 4 November 2016 will be another accelerating factor for the use of electricity from renewable energy sources [10]. The use of renewable energy sources can considerably reduce fossil fuel dependency as well as providing environmental friendly solutions [11–15]. The transition to renewable and sustainable energies is intensifying global competition for knowledge exchange, policy development and joint action. This way we pave the road for a world with less or without fossil fuels.

An advanced search on Web of Science Core Collection, using the keywords "renewable" and "Romania" returns 59 papers (53 articles and 6 reviews) made by Romanian authors and if we refine the search adding the word "photovoltaic" the result show only two results, a case study [16] and a study not directly related to photovoltaics [17]. Another database search using "photovoltaics" and "Romania" as topic, identifies 7 results (4 proceeding papers and 3 articles). Therefore, literature-search indicate the subject of photovoltaics in Romania needs to be investigated and presented in greater detail.

The main objective of our work through this paper is to review the Romania's profile and developments in the PV power sector over the last ten years and compare these achievements with the EU context and the global background.

The secondary objectives of the study are:

- to identify and to analyze the existing trends in renewable energy and to disclose associations not yet detected and presented on

Abbreviations: PV, photovoltaic; AU, Astronomic unit; NREL, National Renewable Energy Laboratory; BIPV, Building Integrated Photovoltaics; EU, European Union; STC, Standard Test Condition; RES, Renewable Energy Sources; GC, Green Certificates; ANRE, National Regulatory Authority for Energy; BNR, National Bank of Romania; GHG, Greenhouse-gas emissions; SEN, National Energetic System

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photovoltaics topic, in Romania;
- to describe Romania's photovoltaic network, Romanian legislation on renewables and the role of PV in the local power industry;
- to establish the climatic factors influencing Romania's photovoltaic network and to fit these conditions into the European landscape;
- to present the main challenges faced by PV industry in Romania and discuss the current practices;
- to determine the ratio of photovoltaics and the rest of the renewable energies existing in Romania

2. Methods and procedures

This study traces the evolution of Photovoltaic energy in Romania from its beginnings (2006) to its current state by presenting the climatic factors influencing Romania's photovoltaic network, Romanian legislation on renewables and the role of PV in the local power industry. We started with an overview of the world's PV energy, by 2016, then we analyzed the PV sector in Europe, and finished by narrowing it down to the local context, Romania. Once we have identified our country's position in the European Union, we analyzed PV energy in Romania, with the aim of emphasizing its advantages as a sustainable and renewable energy resource. Romania is significantly decreasing its dependence on traditional fossil fuels. Our study is not a review of the published literature, but of the issue of photovoltaics in Romania, as a renewable and sustainable resource of energy, on the one hand, and as a regional focused coverage of renewable energy, on the other.

3. Photovoltaic energy in Romania

3.1. Fundamental considerations in photoelectric conversion

World's energy demand is growing fast because of population explosion and technological advancements. It is therefore important to utilize reliable, cost effective and everlasting renewable energy sources to satisfy future energy demands. Solar energy, among other renewable sources of energy, is a promising and freely available energy source for managing long term issues in energy crisis [18]. Renewable energy (RE) based electricity generation is becoming increasingly favored because it is environment-friendly and sustainable. Gradual technical advancement and rapidly decreasing costs have led to widespread deployment of solar photovoltaic (PV) systems [19]. Solar energy is being widely considered as an important energy source for the future due to the environmental issues associated with the use of fossil fuels as well as their limited reserves [20]. Harnessing the Sun's energy to produce electricity has proven to be one of the most promising solutions to the world's energy crisis [21]. The Sun is a star with an average diameter of about 1.39 million km, at an average distance (1 astronomical unit – 1 AU) of 149.6 million km from Earth, as presented in Fig. 1. The Sun is emitting a constant amount of energy into space, in the form of electromagnetic energy, at a rate of 3.8×10^{23} kW/s. The Earth intercepts only 1.8×10^{14} kW/s. About 60% (1.08×10^{14} kW/s) of this reaches the surface of Earth, the rest being absorbed by the atmosphere or reflected back into space.

The solar constant is measured by satellites and is the amount of the incoming solar electromagnetic radiation per unit area incident on a perpendicular plane to the rays, at the average distance from the Sun to the Earth. This value is obtained by averaging over time.

The solar radiation resource, in particular the global horizontal daily solar radiation (H) for a specific location, is a decisive parameter for site selection, plant design, and for the feasibility study of a solar power plant project [22].

Capturing maximum energy from the sun by using photovoltaic systems is challenging [23]. The solar energy can be converted directly into electric energy, by using photoelectrical conversion systems (photoelectric effect). The solar energy can also be transformed into electric energy using other types of conversion, as presented in Fig. 2,

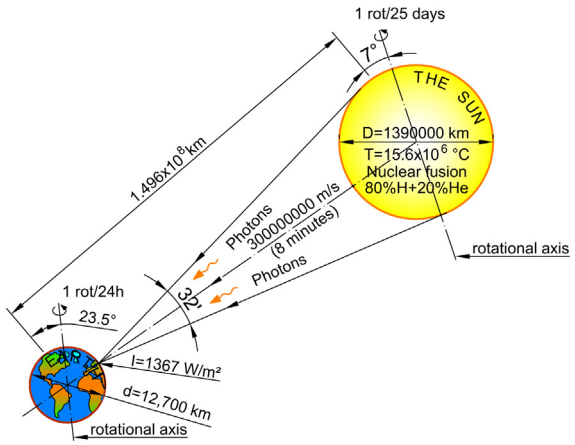

Fig. 1. Sun-Earth geometrical characteristics.

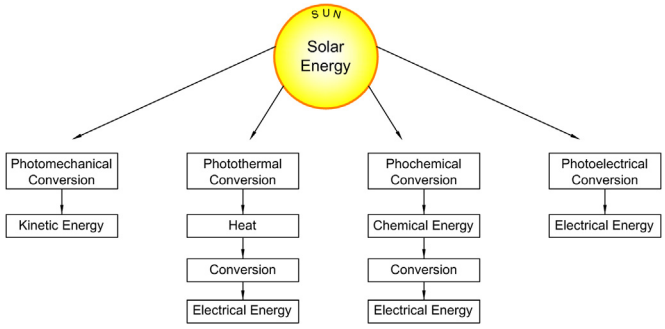

Fig. 2. Solar energy conversion into other forms of energy.

but the process requires multiple conversions.

The theory of solar PV energy conversion can be classified broadly on the basis of dual nature of solar radiation, i.e. particle and wave nature. Assuming solar radiation behaves as particles, the photons of energy greater than and equal to the energy band gap of the solar PV cell are responsible for the electric energy generation, and the energy difference between the band gap and higher energy photons are contributing to the heat energy through the thermalization process [24,25].

Solar energy has great potential as a clean, cheap, renewable and sustainable energy source, but it must be captured and transformed into useful forms of energy as plants do [26].

When a photoemissive material absorbs sunlight (electromagnetic radiation) and frees electrons from it, the phenomenon is defined as the photoelectric effect. All electromagnetic radiation consists of photons. A photon is an elementary particle of light. As Einstein explained in 1905 [27], all the characteristics of the photoelectric effect are due to the interaction between individual photons and individual electrons. Einstein won the Nobel prize for explaining the photoelectric effect. The electrical devices that convert the sunlight directly into energy, through photoelectric effect, are called solar cells or photovoltaic cells.

Since the photoelectric effect was both observed in increasingly precise experiments by Hertz [28], Hallwachs [29], Lenard [30] and Millikan [31,32] and explanted via Einstein [27], the photoelectric effect has attracted much attention because of the rich physics involved as well as their potential use in physics, chemical and materials applications [33].

The photovoltaic panels use multiple solar cells to generate electricity. Conventional solar cells are made of silicon wafers with conversion efficiency of about 6% when they were first manufactured. According to the National Renewable Energy Laboratory (NREL), modern silicon solar cell can reach up to 25% efficiency. The theoretical maximum efficiency of a single junction solar cell is about 31%, which