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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,

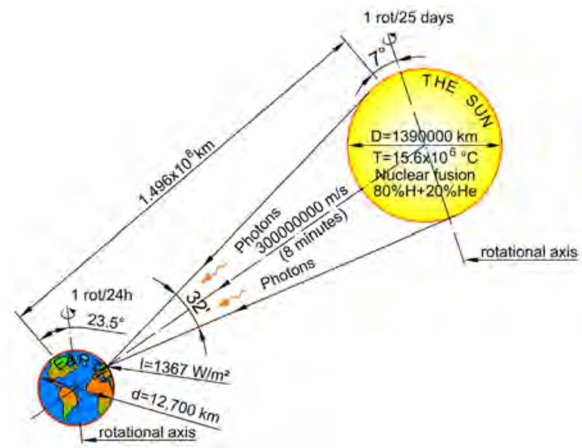

Fig. 1. Sun-Earth geometrical characteristics.

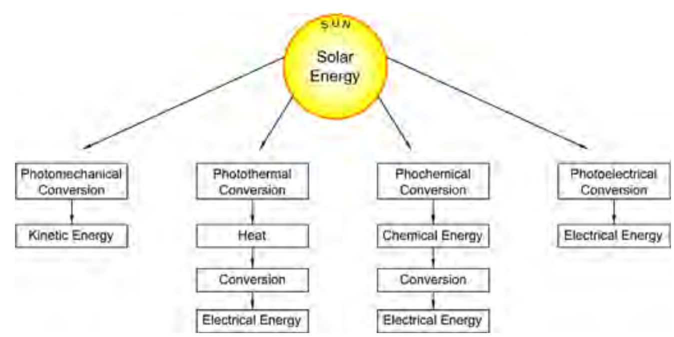

Fig. 2. Solar energy conversion into other forms of energy.

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 is known as the Shockley–Queisser limit [34,35].

The main applications are dominated by telecommunications, water pumping, public lighting, BIPV, agriculture, water heating, grain drying, water desalination, space vehicles and satellites [36] and of course energy.

3.2. PV in the global power sector

Based on the principle of sustainable development, photovoltaic solar energy should be taken more and more into consideration in the future, since air pollution has been continuously growing and the world's main source of energy (fossil fuels) is rapidly decreasing. RES have the potential to aid in meeting global sustainability, environmental, safety, social, and economic goals [37]. Fossil fuels have numerous disadvantages: they represent a finite supply, they cause the increase of CO_2 in the atmosphere and burning fossil fuels is a major factor in the global temperature increase, which is harmful for the wildlife. On the other hand, PV solar energy brings many advantages, such as lower CO_2 emissions, lower energy costs in the long term for consumers, and it can improve the air quality as the solar energy systems become more common. Also, they can be installed on land deemed inadequate for agriculture, covering unused space. Whereas it is necessary to remove the disadvantages from burning fossil fuels to generate energy, PV solar energy (together with other renewable energy sources) could replace conventional energy sources. Capturing solar energy through photovoltaic panels, in order to produce electricity is considered one of the most promising markets in the field of renewable energy. Due to its fast growth outlook and high levels of investment involved, the photovoltaic market is now being more disputed around the world, especially in Europe, China and in the United States [36]. Due to the fact that PV solar energy is a new energy solution, the worldwide PV cumulative capacity increases every year. Additionally, the European Union set a target for 2020, which encourages EU countries to provide 20% of their energy needs from renewable energy sources [38].

The global PV solar energy grew from 136.5 GW in 2013 to 260.6 GW in 2016, which represents, on average, a 25% annual growth. Going forward, global solar PV cumulative capacity is expected to rise from 176 GW in 2014 to near 430 GW in 2020 (+ 16% annually on average) [39]. The world's top PV market has been led every year by China since 2014 and is followed by Japan and U.S.A. Meanwhile in Europe, the leader in 2016 was U.K. with 1.97 GW in 2016, but other countries such as Germany, with its market at 1.5 GW, have continued to expand. Countries such as Germany and other European countries have been developing specific regulatory mechanisms to encourage its use either by government programs or by financial and/or tax incentives [40]. Some medium-sized European markets continued to progress, such as the Netherlands, or have stabilized, such as Switzerland and Austria, while others are experiencing growth again (Belgium, Portugal). New smaller markets, such as Poland and Sweden, have continued their growth, but their installation levels remain below the 100 MW mark. Some former GW markets have continued to experience a quasi-complete shutdown, with between nothing and a few dozens of MW installed: Czech Republic, Greece, Romania, and Bulgaria, for instance [41].

As can be observed in Fig. 4, in Europe PV began to grow slowly, starting in 2000, as a renewable and sustainable energy resource. While Romania had a modest start in 2011, the installed capacity leaped from 50 MW in 2012 to 1158 MW in 2013.

Romania's PV capacity in 2016 makes about 0.91% out of the world's PV capacity and in 2020 it is expected to have a 24% share of energy from renewable sources in gross final consumption of energy [38]. At that moment, Romania will meet and exceed the 20% EU standard for renewables.

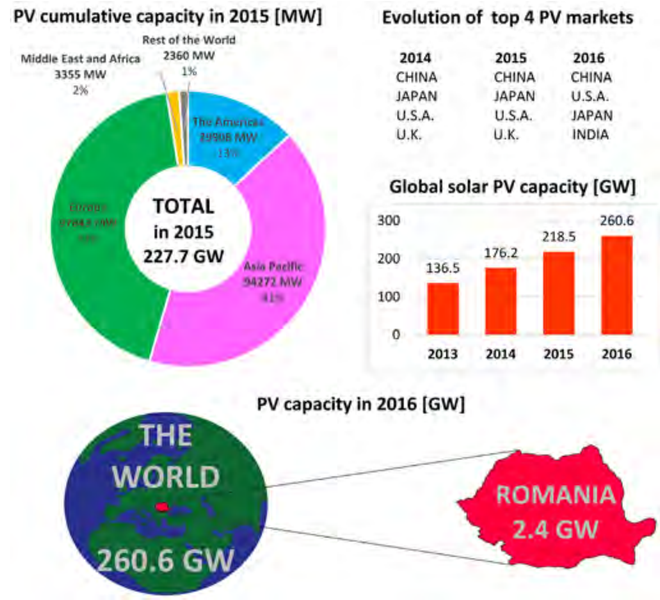

Fig. 3. Global solar PV cumulative capacity.

3.3. Local climatic conditions in the European landscape

Performance of PV modules is usually specified under standard test conditions (STC) (1000 W/m^2, 1.5 air mass and 25 °C module temperature) [42]. However, under real field conditions electricity generation with photovoltaic panels is influenced mainly by solar irradiance, surface air temperature, surface wind velocity and geographic location. In Romania, as in other regions of Europe with snowy winters, another factor influencing the PV efficiency is the snow layers on the surface of the panels. If the panels have a rough surface, in the winter time this can increase the snow retention on the modules, blocking the irradiance access.

Europe can be divided into four areas of sunlight, as shown in Fig. 3: the orange zone, with 1,600-1800 kWh/m^2/year; the yellow zone, with 1400 kWh/m^2/year; the green zone, with 1200 kWh/m^2/year, and the blue zone, with less than 1000 kWh/m^2/year. Although the Southern part of Europe benefits from over 1400 kWh/m^2/year, the PV leaders are Germany and U.K., both located in the Northern Europe Fig. 5.

Solar irradiation at ground level is influenced by a series of meteorological factors, the most important being: nebulosity, atmosphere transparency and the type and position of the clouds. While analyzing the use of solar energy, a few factors must be considered, such as the intensity of solar radiation, the average number of sunny days and the distribution of daily intensity.

As can be observed in Fig. 6, Romania is divided into three main areas of sunlight: the orange zone, higher than 1400 kWh/m^2/year, corresponding to Oltenia, Muntenia, southern Dobrogea and Moldova, yellow zone, 1,200-1400 kWh/m^2/year, which includes the Carpathian regions of Muntenia, all of Transylvania, the middle and northern Moldova, Banat, and the bluezone, over the mountains, with less than 1200 kWh/m^2/year. According to meteorological statistics, there are 210 sunny days per year in Romania and Câmpina (near Ploiești) is the city with the sunniest days, 160–180 days per year. Romania has high potential of solar energy usage in significant regions of the country, especially on the Black Sea coast and in the southern area.

Romania has favorable climatic conditions for renewable energies and in the last ten years it has become a very dynamic market in this respect.

The Black Sea is the region with the highest average annual sunlight in Romania, over 2300 h a year. The southern part of the country has average annual sunlight of over 2200 h a year. In the northern part of

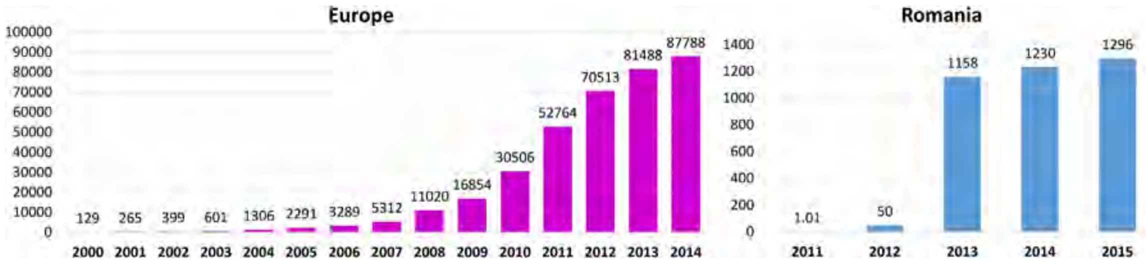

Fig. 4. Europe's and Romania's PV installed capacity trend over the years (values in MW).

the country the values are lower, dropping from 1900 h/year to 1600 on mountain peaks, as can be seen in Fig. 7. The intermontane depressions represent a special case, because due to the nebulosity, the long foggy periods and the obstacles that limit the horizon, the annual periods of sunlight are low.

According to the existing statistics for the main cities in Romania presented in Fig. 8, Constanta is the most favored city in terms of sunlight duration, having the highest values for 7 months a year. All year round, the sunlight duration for the whole country has had monthly average values of over 200 h over a 5-month period. For Constanta, there are three months during a year in which the sunlight period is of more than 300 h.

The average hourly sunshine record varies according to the geographical location and climatic conditions of each place, around 12 P.M. for the most important cities in Romania are shown in Fig. 9. Except for Cluj area, it is noted that the average sunshine period around 12 P.M. has values higher than 0.7 during the summer and early autumn.

The surface air temperature on the PV panels influences the conversion process, leading to a reduction in solar or electrical conversion efficiency as the PV cells get warmer.

Wind velocity influences the surface air temperature on the PV panels. Wind can reduce the surface air temperature, which is beneficial for the PV efficiency.

Snow can severely affect the energy production process, depending on the amount of snow accumulated, the period of time during which it has remained on the modules, the tilt angle, the period of time during which the temperatures are sub-zero and the roughness of the PV panels.

An important aspect of the efficiency of photovoltaic energy production is represented by the annual photovoltaic potential in the optimally tilted plane. As shown in Fig. 10, the potential for using photovoltaic energy in Romania is high.

3.4. Romanian regulations and financing on photovoltaic energy

"Green Energy" is a term that refers to renewable and non-polluting energy sources. The electricity generated from these sources can support the development of clean technologies that will reduce the environmental impact associated with generating conventional energy and increase energy independence.

Photovoltaic technology is a viable solution for areas that are currently not connected to the National Electricity Grid. In the future, through appropriate legislation, these systems can also become cost-effective for the consumers connected to the national grid by eliminating the need to use battery packs and delivering energy directly to the grid.

Romanian legislation promoting the electricity from renewable energy sources started with the Government Decision No:443/2003, which establishes the legal framework necessary to promote the program to increase the contribution of renewable energy sources to the production of electricity, taking into account the current utilization

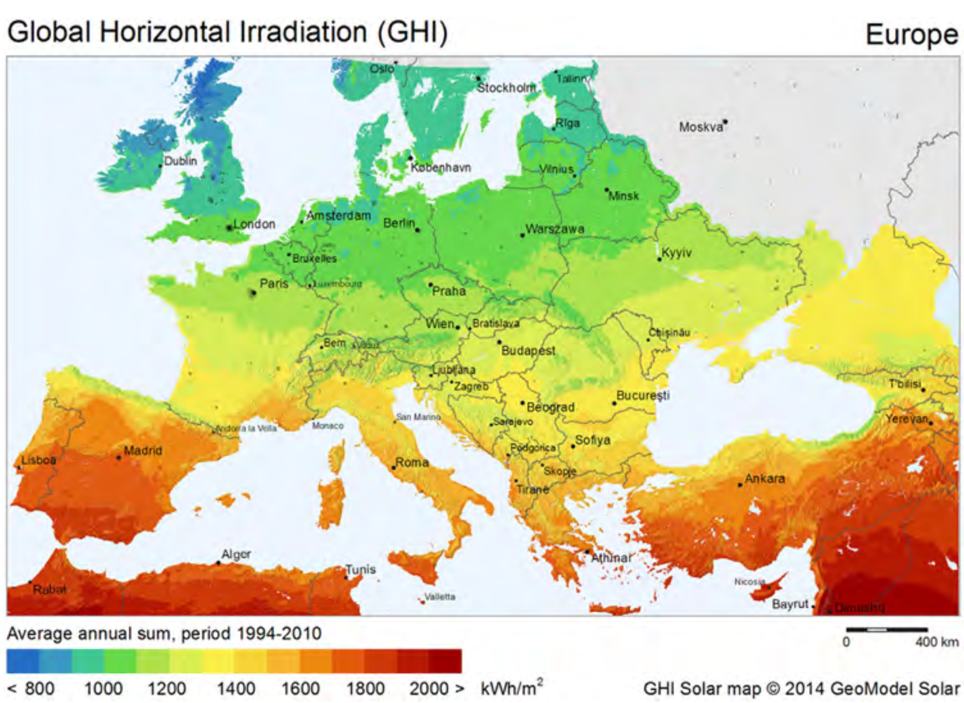

Fig. 5. Global horizontal irradiation over Europe [43].

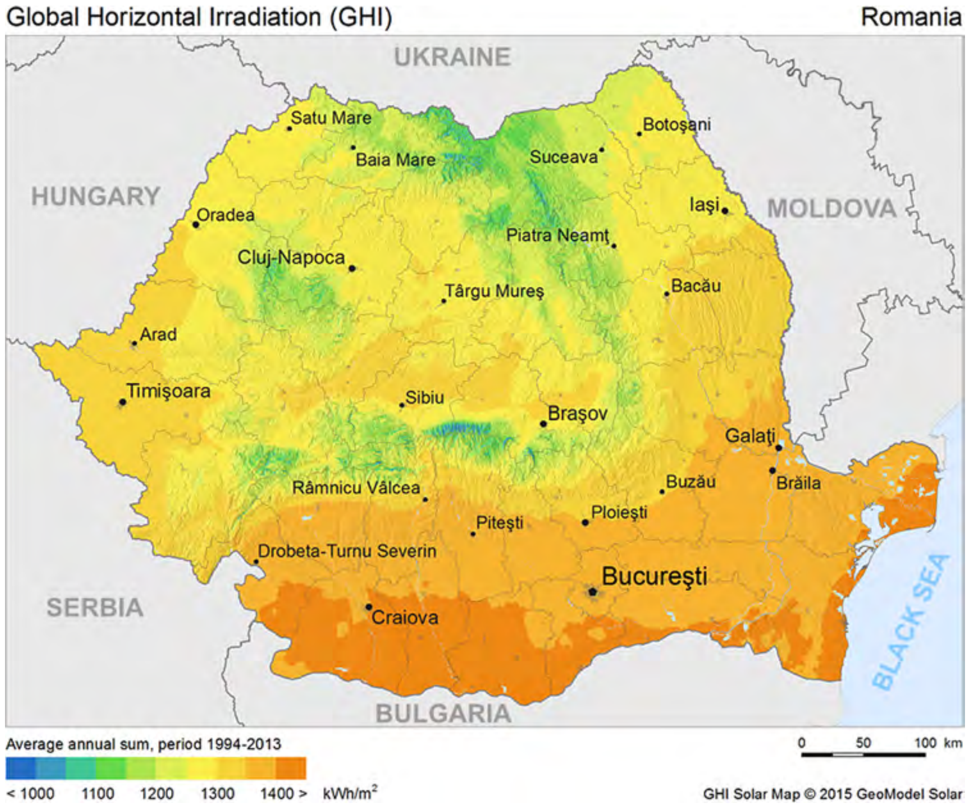

Fig. 6. Global horizontal Irradiation over Romania [44].

Fig. 7. The average annual sunshine duration, for Romania, in hours per year [45].

potential of these energy sources [50]. The first law regarding renewable energy sources was introduced in 2008 and had as main objectives, the integration of electricity from renewable energy sources needed to increase security in the energy supply and to reduce the imports of primary energy resources, the stimulation of sustainable development at local and regional level, and creating new jobs related to the processes of valorization of renewable energy sources. Other objectives of the law intended to reduce environmental pollution by reducing the emission of pollutants and greenhouse gases and ensuring the necessary co-financing in attracting external financial sources, meant to promote renewable energy sources in favor of the local public authorities [51].

Another important aspect related to Law No.220/2008 is that for the first time an incentive scheme was introduced which included "green certificates" to promote the system and established that this law

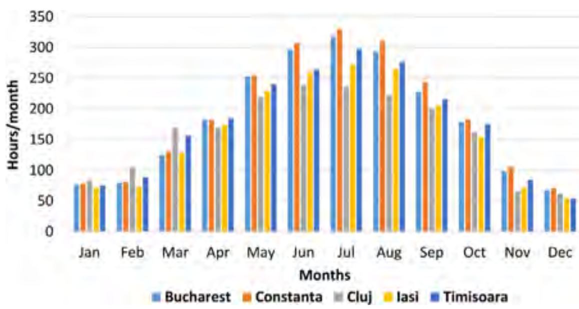

Fig. 8. Average sunshine duration for the most important cities in Romania [46].

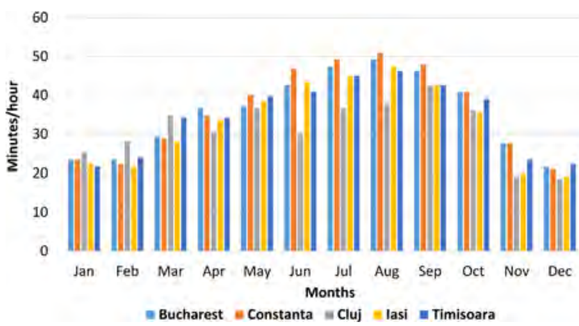

Fig. 9. Average sunshine duration at noon (11:30–12:30) for the most important cities of Romania [46].

applies to all electricity produced from renewable sources. A green certificate represents a title certifying the production of electricity from renewable sources. The certificate can be traded, distinct from the amount of electricity it represents, in an organized market, under the law. The green certificate isn't considered to be a financial instrument [51].

Over the years this law was modified by a series of Government Decisions and another law (139/2010). In its current form, it states that in the photovoltaic sector the producer will receive 3 green certificates for every MWh produced. In its first form from 2008 the law stated that PV energy produces received 6 green certificates for every MWh produced. This statement was modified by the Government Decision No. 994/2013 and reduced the number of green certificates awarded to renewable energy producers and reflected in a diminishing of the ascending trend of the installed power in the PV sector [52]. Also in 2013, the Government temporary limited the ability to trade green certificates until 2017 to the amount of 2 green certificates form the total of 3 received by the PV energy producers for every MWh of electricity [53]. In 2017 another modification to the law stated that the producers will be able to recover the postponed green certificates starting from 2018 in monthly equal rates until 2025 and also postponed the ability to trade newly awarded green certificates until 2024 [54].

Every year ANRE updates the limit values for trading the green certificates, as well as the equivalent of an unpaid green certificate based on art. 11, which stipulates that the trading values are indexed annually by ANRE according to the annual average inflation index for the previous year, calculated at the level of the Euro area of the European Union, officially communicated by Eurostat of EU statistics. The value in RON is calculated at the average exchange rate established by the National Bank of Romania (BNR) for December the previous year.

Thus, in 2017 the minimum amount for a certificate was of 29.4559 euro and the maximum one of 60.0054 euro. Over the years these values have not varied much because of the low rates of the inflation and the EUR-RON exchange rate. In reality the green certificates are traded on the market at a value slightly over 30 euro, which is near the lower trading limit.

The amount of electricity produced by photovoltaic panels is relatively negligible compared to other renewable energy sources, but their

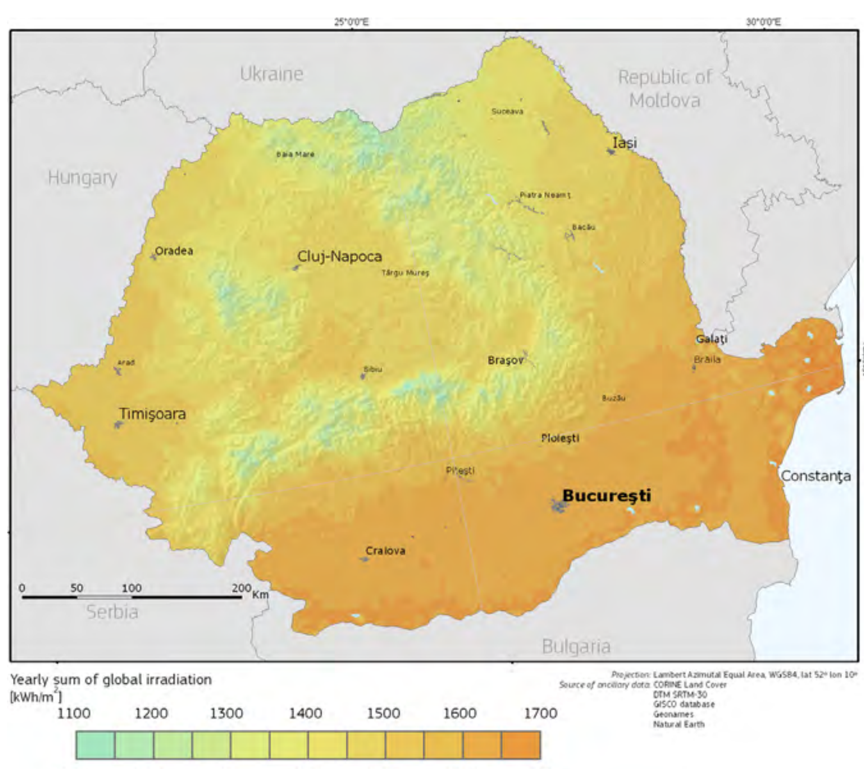

Fig. 10. Global irradiation and solar electricity potential for optimally inclined photovoltaic modules, in Romania. Yearly sum of solar electricity generated by 1kWp system, with performance ratio of 0.75 [kWh/kW$_{peak}$] [47–49].

capacity is growing. Real financial support is needed to keep this growing trend at European level and to achieve a reduction in the costs needed for large-scale development. Legislative measures take time to encourage and promote renewable technologies. We need to shorten this period of time and make sure the regulatory factor is not an obstacle for a sustainable future.

3.5. Photovoltaic contributions to Romania

Romania has, in recent years, started to favor the market integration of other renewables, including PV, because of the support policies adopted in accordance with EU legislation. Since PV can also be installed on a residential scale, the PV electricity production is much more complicated to measure and evaluate for an entire country. PV started to contribute to energy production in general and electricity in particular, in Romania, and can now compete with fossil-nuclear sources. Globally, until 2016, about 1.3% of the electricity demand was covered by PV, while in Romania this proportion is about 3.7%.

Romania has a Green Certificate scheme, with certificates selling for between €108 and €220 for each MW produced from solar sources for the next 6 years. A Green Certificate is a document which proves that 1 MWh of electricity was produced from renewable energy sources.

Recent investments in PV power plants, in Romania, show the future trend and what a significant role the sustainable and renewable power production is playing. In Romania, during the first six months of 2017, the energy production from fossil-nuclear sources contributed about 60%, while the rest was covered by renewable sources. Within the RES, the PV electricity production is less than 4%, and is the third source in the mix, after hydro (24.1%), wind (11.6%) and before biomass (0.6%).

Now, Romania's electricity market demonstrates an excellent growing context which reflects the possibility of using the enormous potential of its natural, renewable, recyclable and sustainable resources, combined with the refurbishment and replacement of existing non-renewable energy production facilities.

4. Discussion

4.1. Photovoltaic research-oriented projects in Romania

Europe is the world's largest contributor to knowledge as a global public good and EU is a research promoter. Research and Development (R&D) activities in Romania are carried out by research organizations, universities and PV industry. In Romania, most of the R&D activities, if not all, are financed from public funds as a result of accessible EU funds. That is why the public sector has had a leading role in promoting PV together with all other RES. The PV industry brings innovation to the market and they also have a key role in R&D. These factors have decreased the PV hardware costs over the years Fig. 11.

In Brasov (Brasov, Romania, 45.65°N, 25.65°E, 600 m above the sea level), at Transilvania University, we are currently running two large projects, one developed on the University Hill (Fig. 7A) and the other at the R&D PRO-DD Institute (Fig. 7B). In the first project, four panel types (mono-crystalline, poly-crystalline and amorphous Silicon and CIS type) have been installed on a real-time Sun tracking platform and all the information (as to the angle, position etc.) is compared with the reference panels installed at a fixed position/angle.

For the tested conditions during the analyzed month the following ranking of the four PV technologies was obtained; this ranking refers to the average gain of the tracked PV modules compared to fixed ones. The highest average gain results were obtained using the CIS modules, ~ 20%. The second-best technology was monocrystalline Silicon with ~ 18%, followed by the amorphous Silicon modules (~ 17%). The smallest gain was obtained for polycrystalline Silicon (~ 5%) due to their increased temperature sensibility [55]. The two rows of panels in the back of the Fig. 7A is a tracked PV string platform of 10 kWp, with one single axis tracking system, of pseudo-azimuthal type, installed to cover the energy needs of a NyZEB (nearly zero energy building) called the Solar House [56].

In the second example, five types of photovoltaic (PV) modules were comparatively analyzed considering the electrical output, efficiency and relative loss in efficiency, based on infield data collected in a temperate mountain climate, over 14 months. The result indicates that in a mountain temperate climate, with cold, snowy winters and with sunny summers the best performing modules are p-Si, m-Si and CIGS, while high relative efficiency losses are observed for the CIS and CdTe thin film modules. The transparent glass surface on the PV modules plays a significant role during winter; rough surfaces can increase the snow retention on the modules, blocking the irradiance access, as was found for the m-Si and p-Si modules [57].

A Building Integrated Photovoltaic Power System of 30 kWp was installed in 2006 at University Politehnica of Bucharest, Romania, on the roof of the main building of the Electrical Engineering Faculty. At that time, it was the first grid-connected and largest PV system in the country. Personnel with no previous experience with roof PV systems, putting an innovative mounting system and documentation to the test, performed array installation. The PV power system and its installation process are described in [58], special attention being accorded to the complex mounting system.

4.2. Photovoltaics as a renewable and sustainable energy source in Romania

Renewable energy sources provide clean, reliable, secure and affordable energy helping our country to meet its sustainable development goals, locally and in the EU. The economic benefit of using PV systems as a renewable source depends on the availability of the solar resource, the size and nature of the load and the cost of the alternative power sources available in the country. In our opinion, the key advantage of the photovoltaic system is that it uses the Sun as “fuel”, which is not exposed to price volatility and is available anywhere in the World.

The largest solar parks in Romania range from 50 to 82 MW and are listed in Table 1.

In Romania, the National Energetic System (SEN) is currently a decentralized system in which production, transport, distribution and supply are distinct activities, where the consumer interface is represented by the supplier. All participants in the electricity market are accredited by the National Regulatory Authority for Energy (ANRE).

The electricity market in Romania is fully liberalized, which means that all consumers, including the household ones, can freely choose their electricity supplier. This particularity is meant to lower the price of electricity and offer better services to consumers.

The transmission of electricity in Romania is performed through electric transport networks (110 kV), consisting of electrical stations, lines and other electro-energetic interconnected equipment. Currently, the electric transport network is managed by "Transelectrica" SA and consists of 81 electric stations, 8931.6 km overhead power lines (OPL) and 218 major transformation units totaling 37,794 MVA. Most of the lines and power stations that exist in Romania were built between 1960 and 1980, meeting the technical requirements of those times.

Romania's electrical transport network and installed photovoltaic power plants, as at June 30, 2017 are shown in Fig. 12.

Although PV power plants are spread all over the country and appear to have a uniform distribution, the total PV installed capacity in Romania is less than 2.5 GW. The PV power distribution over Romania, observed on July 10, 2017 can be observed in Fig. 13, for all 41 counties. The top position is held by Brasov county, with 286.967 MW installed, followed by Prahova on the second place, with 227.09 MW, and Giurgiu at third, with 197.534 MW.

It can be observed that the distribution in Fig. 13 is in accordance with the global irradiation and the solar electricity potential for optimally-inclined photovoltaic modules in Romania are shown in Fig. 10.

Over the last decade, the utilization of renewable energy in the

Fig. 11. Three examples of photovoltaic research-oriented projects in Romania. Panel A: R&D photovoltaic projects on Transilvania University Hill, Brasov, Romania; Panel B: R&D photovoltaic projects at Transilvania PRO-DD Institute; Panel C: Building Integrated Photovoltaic Power System of 30 kWp at Politehnica University of Bucharest, Romania.

Table 1
Top four solar parks in Romania.

Solar park name	Ucea de Sus	Sebiș	Livada	Izvoarele
County	Brașov	Arad	Satu Mare	Giurgiu
Installed capacity [MW]	82.00	65.00	56.00	49.98
Absorbed capacity [MW]	69.00	55.00	47.00	42.50
Annual output [GWh]	115	91	33.6	70
Operational PV units	332,000	317,000	230,000	215,000
Land surface covered [ha]	200	200	330	310
Building costs	€100 million	€100 million	€65 million	€77 million
Voltage [kV]	110			
Commission date	2013			
Solar field type	Flat-panel PV			

electricity sector, especially from solar and wind sources, is growing at a much faster pace than the rest of Europe and world-wide. The significant cost reduction of solar PV and wind power during this time and their zero-fuel cost volatility have increased their attractiveness. Between 2005 and 2015, the installed solar PV power in Europe has 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 effect on 4 November 2016 will be another accelerating factor for the use of electricity from renewable energy sources [59].

Although relatively little capacity was being operated in Romania at the end of 2016, interest in solar PV has been on the rise ever since. As in most countries, the PV market in Romania is driven largely by the government incentives and regulations.

As shown in Fig. 14, the average values of monthly energy provided by the photovoltaic system in Romania, between 2013 and 2016, have continuously increased from less than 50 MWh in 2013 up to more than four times higher in 2016, when the maximum recorded in July was of 223 MWh. As expected, the peak values of the energy provided by PV network are recorded between April and September, when the Sun travels a high path through the sky. Most of the solar power installed throughout the country is represented by MW-sized flat-PV plants built under the green certificate scheme, which was launched in 2011.

If we analyze, for the same time interval, the cumulated values of yearly energy provided by the RES systems in Romania (Fig. 15), we notice that the largest contributor is hydropower, followed by wind power and photovoltaics. In most cases, from year to year, we have had an increasing trend for all the renewable-energy sources. This corresponds to the fact that from one year to another, Romania has intensified the installation and use of renewables. By doing this, the negative effects of fossil fuels are reduced, which contributes to the general aim of minimizing the adverse effects on the environment. In the future, we expect large investments in off-grid systems, if the cost of the technology (PV panels and batteries) keeps decreasing.

4.3. GHG emissions reduction in Romania, by use of photovoltaics

The evolution of the power generation system over the last thirty years had led to important results, which have influenced its further development. The first major event was the economic recession of the 1990s, which led to a significant reduction in electricity consumption. Another important fact was represented by the start of the two units of the Cernavoda nuclear power plant, in 1996. The third significant detail in the development of power generating systems was the implementation of the aid scheme for renewable energy producers in 2010. Together, these moments have caused a significant decrease in GHG emissions from the power generation process by reducing electricity from fossil fuel combustion It is unanimously acknowledged that the production and use of electricity from renewable energy sources leads to a significant decrease in GHG emissions, thus stimulating the interest in wind, photovoltaic and biomass electricity. Recent studies have

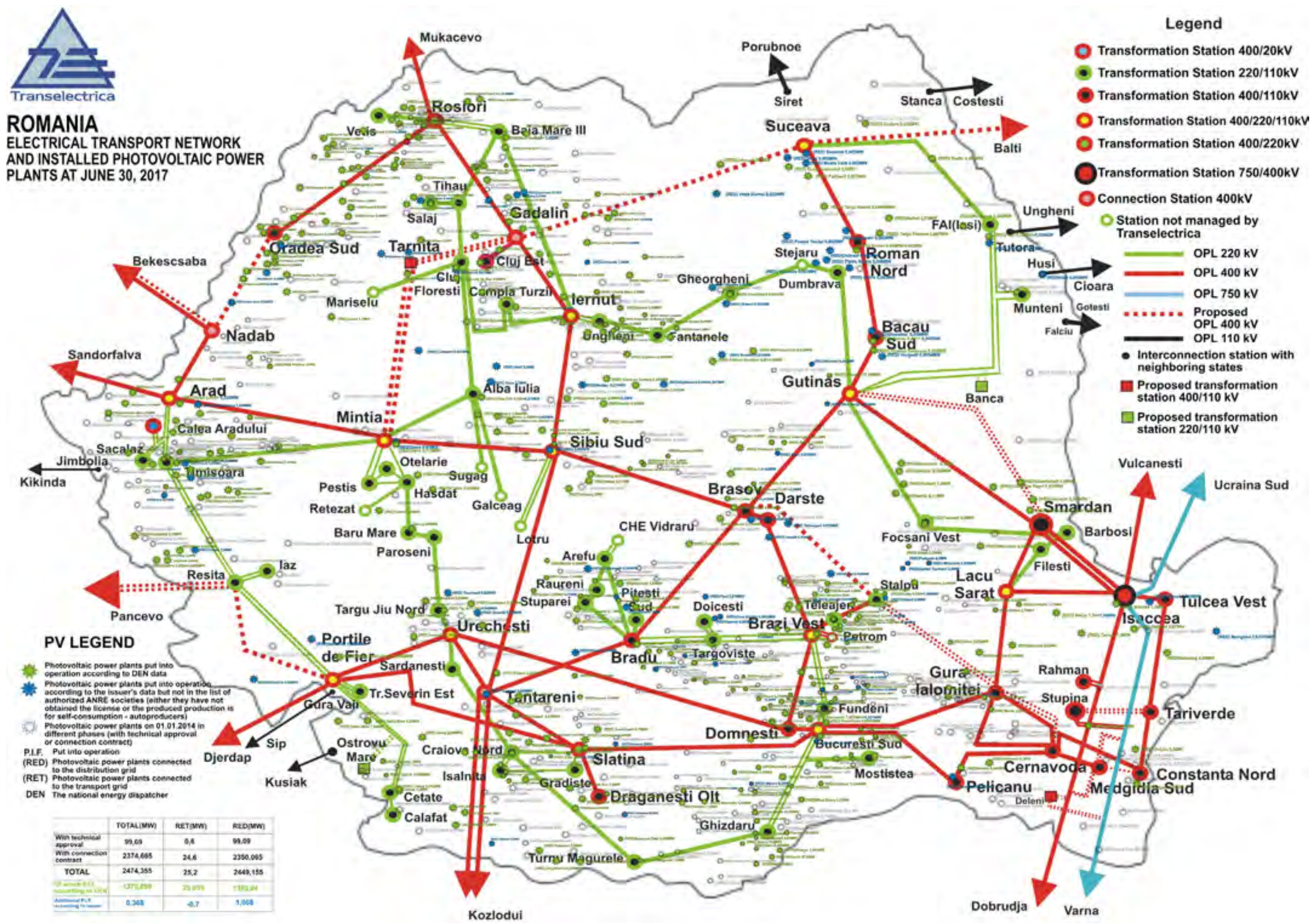

Fig. 12. Romania's electrical transport network and installed photovoltaic power plants, observed on June 30, 2017 (http://www.transelectrica.ro).

highlighted that the production of photovoltaic electricity would reduce CO_2 emissions by up to 16 times, compared to coal-fired electricity.

Greenhouse gas emissions are typically given as single greenhouse gas, CO_2 emissions based on the life-cycle perspective (LCA) and thus including up and downstream impacts throughout the electricity generation value chain [61]. The weighted average environmental indicators for life-cycle-based CO_2 emissions, for renewables and fossil fuels, are given in Table 2.

After 2010, along with the implementation of the aid scheme for electricity generators from renewable sources, the photovoltaic power sector has achieved a rapid development by having important investments in this sector. Promotion of electricity from renewable sources over 2010–2013, through the national subsidy policy has led to a significant drop in greenhouse-gas emissions from the production of electricity from 438 g/ kWh in 2011–326 g/kWh in 2015 [62]. The development of the photovoltaic parks has led to a decrease in electricity from burning fossil fuels and has also reduced the GHG emissions from the electricity sector. The evolution of the electricity generation sector in Romania, the CO_2 emissions and their reduction due to the use of photovoltaic energy are shown in Fig. 16.

Last year in Romania, photovoltaic power accounted for 1.1% of the total electricity produced. In 2016, 61.74 TWh of electricity was produced in Romania, 0.72 TWh of which was produced by photovoltaic systems. The photovoltaic electricity produced in Romania has led to a decrease in the electricity produced by the burning of fossil fuels and to a decrease of 12.49 million TCO_2 in 2016. This decrease reflects the switch in the electricity production process, from fossil fuels, particularly coal, to electricity generated from renewable sources, in particular, hydro [63], wind power and photovoltaics.

4.4. Environmental concerns in photovoltaic energy exploitation

As described through the paper, the Sun represents a significant resource for generating clean and sustainable energy. The energy produced by solar energy systems provides considerable benefits for both human activities and the environment, in contrast to conventional energy sources. As with any other energy source, the environmental impact can be assessed on two levels, the local or national, and the global one. Photovoltaics (PV) are generally considered a reliable and harmless system for the environment, since they do not generate waste (chemicals, reactive, corrosive etc.), are quiet (they do not involve moving parts) and, in most cases, have a positive impact from the aesthetic point of view.

The environmental aspects of photovoltaic power generation include: land use, visual impact, noise intrusion, depletion of natural resources, air pollution, accidental discharge of toxic substances and waste management.

4.4.1. Land use

In urban areas, photovoltaic panels are in many cases incorporated in the building envelope, where they can serve a double purpose: to produce electricity and to function as a shading device. The other case is when they are installed on roofs, covering the unused space.

When the photovoltaic panels are installed in natural ecosystems, the impact can be different, according to several factors, such as the

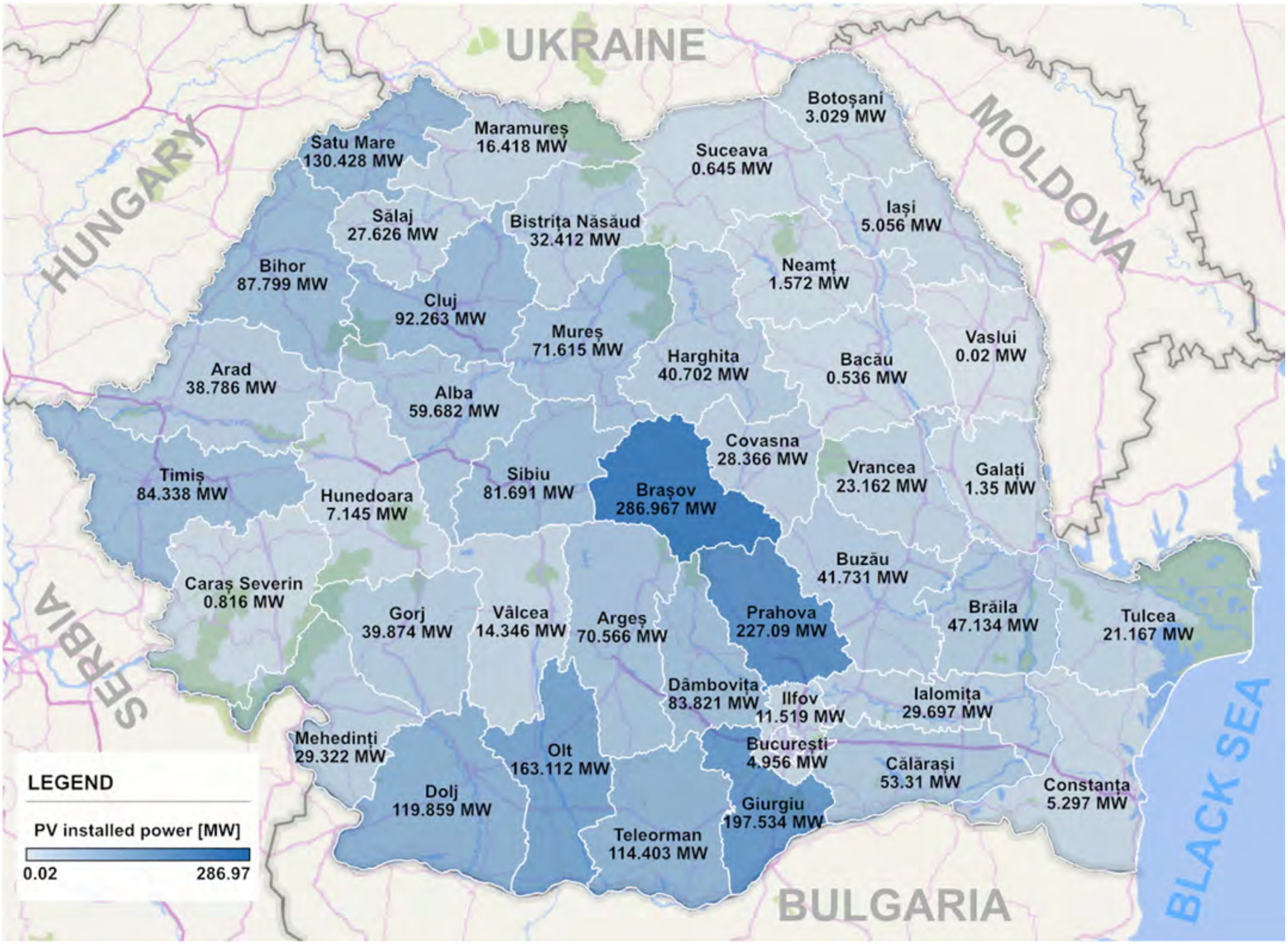

Fig. 13. PV installed power all over Romania, observed on July 10, 2017.

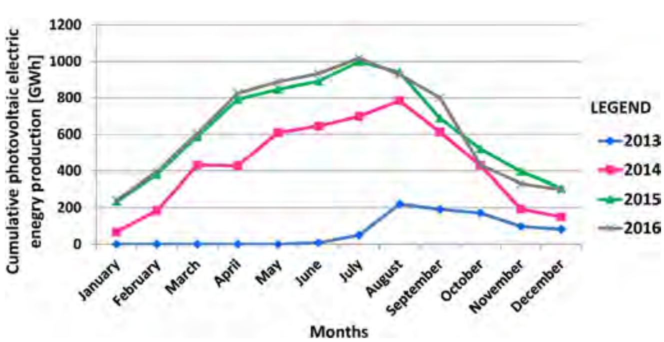

Fig. 14. Average values of monthly energy provided by the photovoltaic system in Romania, between 2013 and 2016 [60].

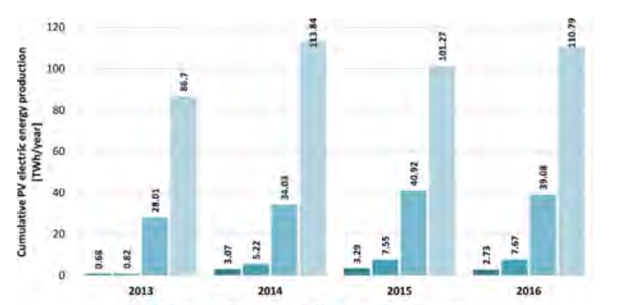

Fig. 15. Cumulated values of yearly energy provided by the RES systems in Romania, between 2013 and 2016 [60].

type of land, biodiversity, the initial character of the land, the landscape or distance from the sensitive area Fig. 17.

Usually land surfaces covered by photovoltaics are large and can be commissioned primarily for this purpose for long periods of time (tens of years). As can be observed in Fig. 16, in some cases the land can be commissioned for secondary purposes as well.

Installing photovoltaic panels does not necessarily mean lack of farm activities but it can still affect the landscape. Photovoltaic agriculture, the combination of photovoltaic power generation and agricultural activities, is a natural response to supply the green and sustainable electricity for agriculture [64].

4.4.2. Visual impact

PV installed on modern buildings, besides their practical purpose (energy generator, shading system or heat remover), might have a positive impact aesthetically from an architectural point of view, but they can be less appealing when installed on old buildings with or without a historical value.

The visual impact of the PV installed outside the city limits depends on the surface covered, the scheme used to cover the land and the surroundings. Usually large PV power plants are built in areas where the visual impact is not considerable and the inhabitants can see them only occasionally.

Table 2
The weighted average environmental indicators for life cycle based CO_2 emissions, for renewables and fossil fuels [61].

Energy source/technology		LCA CO_2 (kg/kWh)
Renewable	Solar	0.0624
	Wind	0.0182
	Hydro & Marine	0.0053
	Geothermal	0.0549
	Biomass & Biogas	0.1181
	Unspecified (renewable)	0.0299
Fossil	Hard Coal	1.0382
	Lignite (or brown coal)	1.1986
	Natural Gas	0.5258
	Oil	0.8869
	Unspecified (fossil)	0.806

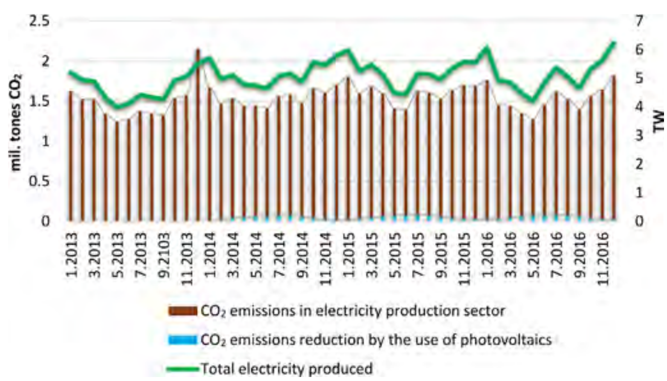

Fig. 16. CO_2 emissions from the power generating system and their reduction by use of photovoltaic systems [60].

4.4.3. Noise intrusion

By default, PVs do not generate noise, but while building a PV power plant noise, typical of construction environments, can be produced. Of course, the noise is temporary present and will completely disappear once the power plant is finished.

4.4.4. Depletion of natural resources

The photovoltaic effect requires materials sensitive to sunlight, such as silicon (Si), copper indium selenide (CIS), copper indium gallium (di) selenide (CIGS), cadmium telluride (CdTe) and gallium arsenide (GaAs).

Silicon is the most common material used for manufacturing solar cells and is the most abundant element in the Earth's crust.

4.4.5. Air pollution

PV power plants do not pollute the atmospheric air while in operation, but they do when all the components are manufactured. The environmental performance of the manufacturing process can also vary, depending on the factory's energy efficiency.

4.4.6. Accidental discharge of toxic substances

As mentioned before, the raw materials used to manufacture different PV panels include silicon, copper, indium, gallium, selenium, cadmium, tellurium, arsenic etc.

While in operation, PV panels do not release liquid, solid, gaseous or radioactive pollutants into the atmosphere, but in case of an atypical operation or for service purposes small quantities of toxic substances, as arsenic or cadmium, can be released locally.

4.4.7. Waste management

Photovoltaic panels are recyclable. Waste management in case of PV power plants is related to the chemical substances included in the batteries (heavy metals), which can be improved by using recycling schemes.

4.5. Research outcomes, useful guidelines and future works

4.5.1. Research outcomes

The main focus of this study is to present and promote PV power sector existing in Romania from small to large-scale. We show photovoltaics, as renewable and sustainable energy technology, can have a beneficial impact on the economy, society, and environment.

Through this research we evaluate the National Energetic System by collecting and integrating a wide range of information from existing publications on PV, to provide a quality review to some level of detail that can be used to improve national energetic, economic and environmental strategies and help researchers and others to easily identify the existing PV market in Romania. Our study reveal that current use of PV technology has just begun and will evolve extensively through continuous growth and we see it a way to engage the community.

4.5.2. Useful guidelines

In general, electric energy obtained through solar panels is more expensive than other sources of electricity, but it has a number of advantages: it has no mechanical moving parts, lasts for decades, easy to be installed, can be located at users site, is modular and requires minimal maintenance. In this paper we evaluate and organize raw data, about photovoltaics in Romania, in a manner that provides useful information and guidelines, so that anyone interested (researchers, investors, project managers, performance auditors, equipment manufacturers and servicing firms) is able to focus on a specific aspect, avoiding irrelevant data collection.

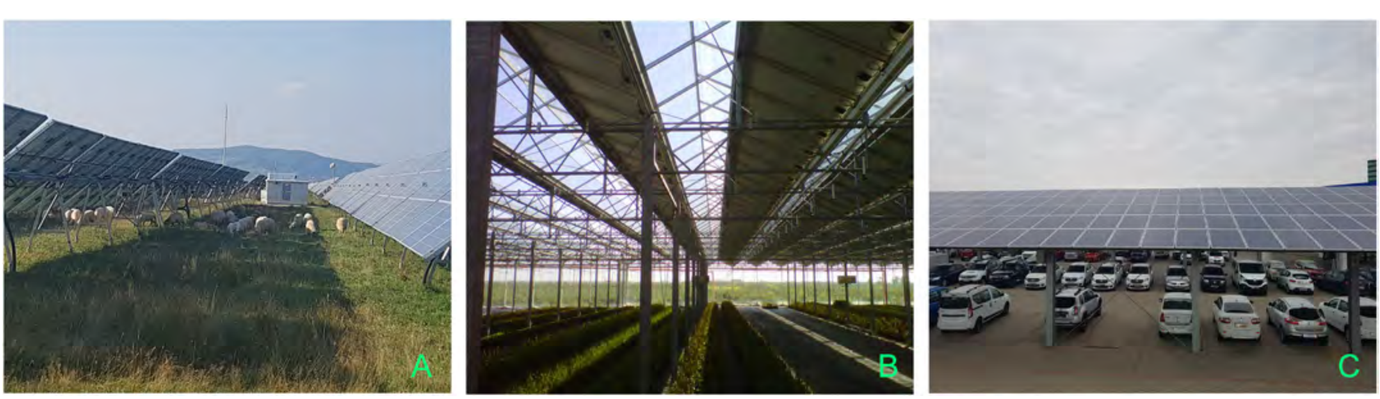

Fig. 17. Examples of types of land used to install PV power plants on, where the land has practical outcomes (Panel A – grassland for animals (Ucea de Sus, Romania), Panel B – greenhouse for various plants, Panel C –PV solar parking lot (Bucharest, Romania)).

4.5.3. Future work

Solar PV is a worldwide promoted and installed technology that is now no longer an expensive lifestyle product used only in research or for space applications but a commercial, affordable and attractive option. Even so, third-generation of solar cells are being made from a variety of new materials besides silicon, including conductive plastics, conventional printing press technologies, solar dyes an ink. These new technologies are technically attractive because can be manufactured at considerable lower costs, can have a higher efficiency and can be made in flexible formats.

Future work can be done by extending this study also to concentrated solar power (CSP), sometimes called solar thermal. Another future work can provide an overview of how PVs work and are incorporated in the existing and newly designed buildings. Also, another field of knowledge is related to integration of PVs in different commercial applications such as indoor and outdoor artificial lighting, space conditioning, refrigeration, etc.

5. Conclusions

In Romania, the total energy production in the first six months of 2017 was 7376 MWh, while the average consumption was 6898 MWh. The energy mix in Romania consists of 60% produced using fossil fuels and 40% produced using RES (hydro, wind, photovoltaic and biomass). Within the RES, the PV electricity production is less than 4%, and is the third source in the mix, after hydro (24.1%) and wind (11.6%), and before biomass (0.6%). Romania at present has a total of 1122 PV investments, ranging from a few Watts, the smallest, to 82 MW, the largest. The projects are spread all over the country.

Our study has addressed several aspects related to present and future development of photovoltaic power in Romania, as a member of the European Union.

Romania started to slightly develop its photovoltaic industry in 2011 and it had a drastic growth ever since. Today, Romania's largest solar park (with a surface of 200 ha) was inaugurated in 2013 and it is placed in Ucea de Sus, Brasov County. It has an installed capacity of 82 MW and uses 320,000 PV units.

In Romania, the domains of renewables, the environment, and sustainable energy have great potential and offer substantial business opportunities. Photovoltaic energy can contribute toward a sustainable development, economically, environmentally and socially. Photovoltaic cell development is playing a key role in the future of this system's usage and implementation. In the past few years, the trade intensity of PV cells has varied from region to region, but the trend has been growing globally as a result of increase in energy demand. Global warming or climate change, together with air pollution, has to be reduced and ultimately stopped, if possible. To achieve this, renewable and sustainable solutions have to be researched, promoted, produced and implemented. At the moment, photovoltaic systems are a good alternative to fossil fuels, because they have the advantage of using an "unlimited" resource, the Sun.

By capturing energy from the sun and by using photoelectrical conversion systems, the solar energy can be converted into electric energy. The sunlight can be converted directly into electric energy, through photoelectric effect, by using solar cells or photovoltaic cells. Now, the typical power of solar PV modules is less than 500 W and as future purpose for the upcoming research is to increase the efficiency, the power output and to reduce the temperature sensitivity.

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