

Analysis of Using of Solar Energies in Georgia

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Abstract: *The main sources of green energy (GE) as the cleanest form of energy or types of renewable energy sources (RES) are: wind, water, sun and earth. And solar energy (SE), which originates from the Sun, is one of the cleanest and most efficient renewable energy sources (RES). While the world, especially in the most developed countries of the world, has advanced far in the application of various forms of green energy (GE), in Georgia this field is in its infancy and it is not possible to predict when the first major positive developments in this field will be made. The paper presents a trend analysis and examples of the use of solar energy (SE) in Georgia currently and with a forecast until 2030. According to the data on the plans of the state authorities (Ministry of Economy and Ministry of Energy of Georgia), the development and use of solar energy (SE) with a plan of 250 MW for 2025 will increase according to the forecast for 2030 to 810 MW, with a CAGR value of 26,51 [%] and to 1330 [MW] in 2040, with a CAGR index of 11,79 [%] for that period. (or app. 5.32 times today's value). The paper also presents several examples of the use of solar energy (SE) in Georgia in various areas of application.*

KEYWORDS: ENERGY, GREEN ENERGY (GE), RENEWABLE ENERGY (RE), RENEWABLE ENERGY SOURCES (RES), SOLAR ENERGY (SE), TREND ANALYSIS, CONTINUOUS ANNUAL GROWTH RATE (CAGR).

1. Introduction

One of the most commonly used forms of energy is electricity, which is a basic part of nature. The main source of energy on planet Earth, currently, are non-renewable energy sources (NRES), which include: fossil fuels (coal, oil, natural gas, oil shale) and nuclear fuels. Fossil fuels or mineral fuels are fuels that are formed from the remains of plants and animals that are millions of years old, and include: coal, oil and natural gas. When used, this type of fuel emits harmful gases, which contain high percentages of carbon and carbon dioxide, which has a harmful effect on the environment.

The current global tendency is that electricity production is increasingly being shifted, for environmental reasons, to another form of energy generated from renewable energy sources (RES) [2,4,12,21,37,44,45,61]. Renewable energy (RE) is that form of energy that is renewable (naturally replenished) and is produced from sources that are constantly renewed, which means that this form of energy is created from natural sources (sun, wind, water, rain, waves, waves, geothermal heat, biomass and biogas, etc.). In addition to renewable energy (RE), the following terms are often used in the literature: green energy (GE) [1,6,11,15,22,24,29,31,33,41,43,49,56,59,62,64], sustainable energy (SE) [4,44,45] and clean energy (CE) [4,44,45]. The question arises whether there is a difference between: GE, SE, CE and RE energy and what is the difference.

The consumption of energy in the world, from year to year, is growing (which is in direct correlation with the daily increase of the human population), and therefore the need for its production is also increasing. The vast majority of that energy is from non-renewable sources (currently more than 80%), which is already causing undesirable consequences for the environment. One of the solutions, in accordance with the principles of sustainable

development, lies in reducing the share of fossil fuels in the total production and consumption of energy. So, the share of renewable energy sources (RES) should be significantly increased in the future, because there are fewer and fewer non-renewable energy sources and their reserves are running out, and also their harmful influence has become more pronounced in the last few years.

Currently, of the annual energy consumption, at the world level, appr. 50% spend on industry, appr. 25% is used for transport, and the remaining 25% is consumed by households and the commercial sector.

China and India have the highest growth in consumption of all types of energy, at the world level, and of the developed countries, the highest growth in energy consumption is recorded in the USA, while the EU records a decrease in energy consumption from appr. 2%.

All these facts show that the best solution from this situation is in the increasing use of renewable energy sources (RES) and green energy (GE), especially solar energy (SE), which is one of the cleanest and most efficient renewable energy sources (RES). The state and perspectives of the development and application of different types of green energy (GE) in different countries of the world are presented in papers [4,9,22,27,31,33,37,47,49,54,62].

Currently, the world, especially in the most developed countries of the world, has advanced far in the application of various forms of solar energy (SE), while in Georgia this field is in its infancy and it cannot be predicted when the first major positive developments in this field will be made. So that the state authorities in Georgia predicted in the following period until 2030 a greater application of this form of energy, with a CAGR value of 26,51 [%] compared to 2025. So, the trend analysis and examples of the use of solar energy (SE) in Georgia currently and with a forecast until 2030 is the goal of this paper.

2. Solar Energy

Solar energy (SE) is a form of energy that comes from the Sun and is one of the cleanest and most efficient renewable energy sources (RES). It can be converted into the following two forms of energy, namely:

- Thermal energy, with the help of solar collectors that heat water or air. It is used for heating households, swimming pools or in industry and
- Electrical energy, with the help of solar panels (photovoltaic cells) that convert sunlight directly into electricity.

Many experts and scientists claim that the energy emitted by the Sun in just one hour is enough to cover the entire electricity consumption of the entire planet for the entire year.

This data, as well as the current development of technologies and systems for solar energy, pose one basic question to man: why is so little of this green and free energy used in all countries of the world, but also at the global level, and why is there still no clear shift towards solar energy? Also, it should be noted that in addition to this data, there are many other advantages, but also several disadvantages.

The most significant and obvious advantages of using solar energy (SE) are:

- inexhaustible and renewable source of energy;
- various applications and installation locations, i.e. can be used almost anywhere there is sunlight;
- ecologically acceptable and clean source of energy, i.e. does not pollute the environment;
- reduces the cost of using electricity for a longer period of time;
- long life and exploitation life of the product and low maintenance costs;
- the system can be easily upgraded and increased;
- panels and systems for solar energy are silent;
- panels, systems and technologies for solar energy currently under development;
- ensures the energy independence of individuals, institutions and the state, etc.

Although at first glance it seems that solar energy and systems do not have any disadvantages because they are environmentally friendly, there are actually several facts that are not brought to the fore, and may be the reason for insufficient investment in solar systems. The disadvantages of using solar energy (SE) are:

- initial investments in equipment are high;
- a lot of space is needed for larger systems;
- it depends on the weather conditions (it gives less energy at night and in cloudy weather), etc.

Within the new technological trends in the development of solar energy (SE), they defined several new forms of this type of energy, which relate to the long-term availability and use of solar energy, such as: green solar energy (GSE), low-cost solar energy (LCSE), sustainable solar energy (SSE) [13,16], etc.

Solar energy (SE) as a form of energy has become very interesting in the field of scientific research and

publishing. For the phrases "solar energy" ∨ "solar panel" in the Scopus citation database, 197.588 documents were published (as of 20-08-2025). The first publications from this field within Scopus date back to the end of the 1800s, while significant growth was recorded in the early 2000s, and especially in the last five years. So, 12.290 publications were published in 2021, 2022=15.404, 2023=17.731, 2024=18.002 and 2025=10.635.

By country, the largest number of publications (NoP) from this field within Scopus are: China with 42.346 publications, U.S. (United States) with 29.474 publications, India with 23.913 publications, UK (United Kingdom) with 7.797 publications, Germany with 7.636 publications and etc. (Fig. 1). Authors from Georgia have published 77 publications in Scopus.

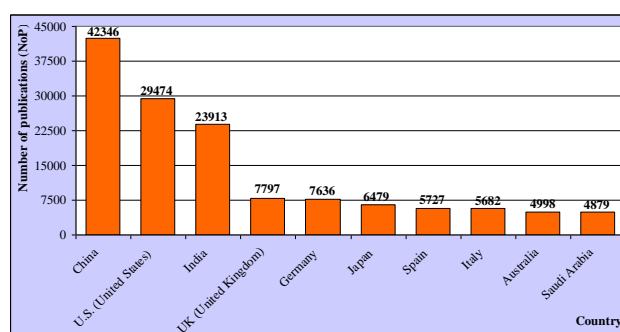


Fig. 1. Number of publications (NoP) by country for the top 10 countries in the world for the phrases "solar energy" ∨ "solar panel" within Scopus

The situation is similar in the application and publication of patents in the field of solar energy (SE). According to data from the World Intellectual Property Organization (WIPO), in the last decade (2010-2019), the largest number of filed patent applications in the field of solar energy (SE) have the following five countries: Japan with 5.360 registered patents, U.S. (United States) with 3.876 registered patents, China with 1.892 registered patents, South Korea with 1.803 registered patents, Germany with 1.534 registered patents and etc.

Although Japan leads the way in terms of the total number of patents filed, China is experiencing the fastest growth, as most of its applications (58.9%) were filed in the second half of the decade. In addition, China is ranked best in the number of patent families (which is a collection of patent applications filed in multiple countries to protect a single invention), which can be considered that its products have the potential for worldwide commercialization.

3. Solar Panels and Solar Energy Systems

To obtain solar electricity, solar panels (SP) [26,40,52], solar energy systems (SES) or solar energy storage systems (SESS) [13,25,39], solar power plants (SPP) [46,47,51,53] and solar thermal power plants (STPP) or

solar thermal power stations (STPS) [34,48] are used, which convert sunlight directly into electricity.

Solar panels (SP) with photovoltaic (PV) cells [5,14, 16,19,23,63] are a key technology for generating electricity from sunlight. In order to maximize the efficiency of PV solar panels, two aspects of this technology can be improved: keeping the surface of the solar panels orthogonal to the direction of sunlight and cleaning it of dust deposits and other contaminants that can absorb part of the incoming solar radiation.

Solar panels (SP) work on the principle of the photovoltaic effect, which is a process in which sunlight is converted into electricity. So these systems are key technology for generation of electric energy from sunlight. A simple explanation of the operation of solar panels (SP) consists of several steps:

1. Sun light falls on the solar cells (the panel consists of many photovoltaic cells, usually silicon, and then the Sun's photons (particles of light) hit those cells);
2. Release of electrons (when photons hit the silicon photovoltaic cells, they transfer their energy to the electrons in the material and the electrons are "detached" and start to move freely);
3. Generation of electric current (cells have layers that direct the released electrons so that they move in only one direction, so that direct current (DC) is created);
4. Converting electricity from DC to AC using an inverter (since alternating current (AC) is used in households and many other applications, an inverter converts DC to AC) and
5. Use and/or storage of energy (electricity can be used immediately for lighting and other purposes, starting devices and machines, etc. or if there is an excess, it is stored in batteries or delivered to the electrical network).

To maximize the efficiency of PV solar panels, two aspects of this technology can be improved: keeping the solar panel surface orthogonal to the direction of sun light and cleaning it of dust deposits and other contaminants that can absorb some of the incoming solar irradiance [38].

Practical solutions of solar panels (SP), which convert sunlight into electricity, are described in the literature [3,17,18,30,46,47,55-58], and examples of two practical examples are shown in Fig. 2 [55] and Fig. 3 [34,45].

On Fig. 2 shows solar photovoltaic panels providing green energy for agricultural growth [55].

On Fig. 3 shows the Nellis Solar Photovoltaic Power Plant with power 14.2 MW located in 2007 within Nellis Air Force Base (NAFB) in Clark County, northeast of Las Vegas (Nevada – USA) [34, 45], as largest solar plant in this region. It covers an area of 140 hectares and consists of 72.000 solar modules that follow the movement of the sun during the day (trackers). It is estimated to produce 32 GWh per year of electricity annually and supplied more

than 25% of the power used at the base and reduce CO₂ emissions by 24.000 tons per year.



Fig. 2: Solar photovoltaic panels providing green energy for agricultural growth [55]



Fig. 3: Nellis Solar Photovoltaic Power Plant with power 14.2 MW (USA) [34,45]

While Fig. 4 shows the infrastructure for the production and distribution of solar energy [7], which includes several integral components that work together to capture solar energy and deliver it to end users. The key role of photovoltaic (PV) panels is to convert solar radiation into direct current (DC) electricity, which is then transformed into alternating current (AC) via an inverter, facilitating integration with the electrical grid. The generated AC current is then connected to the grid via substations and all necessary voltage transformations.

Within the new technological trends in the development of solar panels (SP), they defined several new forms of panels, which relate to the long-term availability and use of solar energy, such as:

- adaptive solar panels (ASP) [20,36],
- advanced solar panels (ASP) [32],
- concentrated solar panels (CSP),
- deployable solar panels (DSP) [8],
- flexible solar panels (GSP),
- foldable solar panels (GSP),

- green solar panels (GSP),
- hybrid solar panels (HSP),
- integrated solar panels (GSP),
- low-cost solar panels (LCSP),
- portable solar panels (PSP),
- satellite solar panels (SSP),
- smart solar panels (SSP) [38],
- space solar panels (SSP) or space-based solar panels (SBSP),
- sustainable solar panels (SSP) [13,16],
- transparent solar panels (TSP) etc.

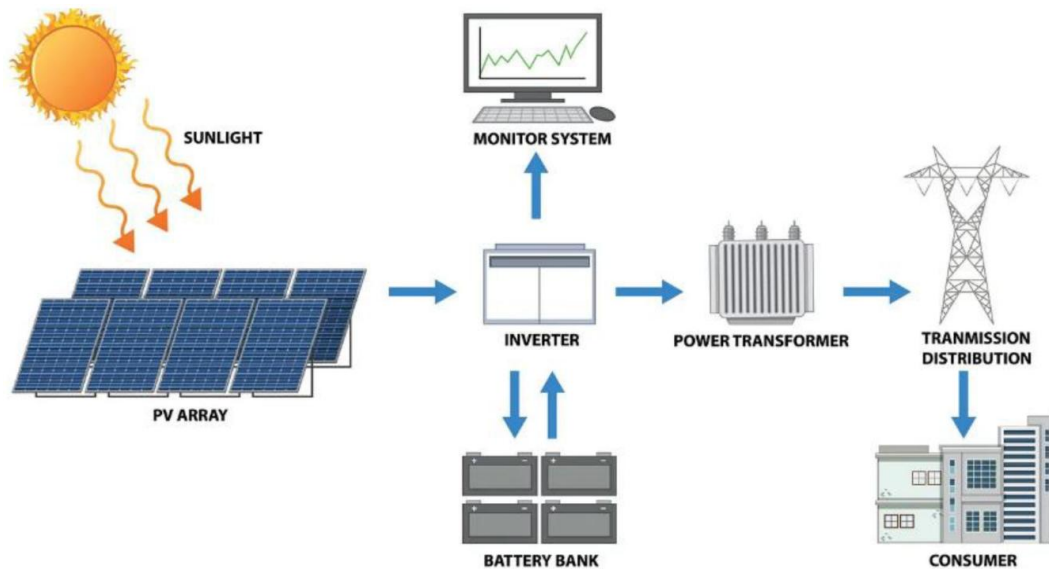


Fig. 4. Solar power generation and distribution process [7]

On Fig. 5 shows a preliminary design of a smart solar panel (SSP) system that represents an improvement of PV solar panels intended for applications in the space environment [38]. The configuration of smart solar panels (SSP) is based on standard solar panels mounted on a mechanical structure that is equipped with mechanisms and actuators intended to realize the functions of tracking the Sun and self-cleaning. To achieve maximum energy output from a solar panel, it must remain properly aligned with the Sun and its active surface kept very clean, free of dust or other impurities. To accomplish this task autonomously, the panels are equipped with robotic systems that allow them to track the Sun's motion and remove any contaminants that accumulate on their surface. Smart solar panels (SSPs) can be used both in stationary power plants and in mobile platforms (e.g. landers and rovers) designed for the exploration of solar system bodies, primarily the Moon and Mars, while also offering benefits for Earth-based sites in remote desert or mountainous regions, where maintenance operations are difficult [38].

Currently, the world is paying a lot of attention to hybridization (which represents the combination of more than one technology for the production of electricity) and the development of hybrid energy systems. In the field of solar energy (SE), this would mean a combination of solar energy (SE) with some other type of renewable energy (RE), i.e. the combination of different solar panels (SP) or solar energy systems (SES) with some other type of renewable energy system (RES), in order to improve the

overall efficiency and create a reliable and sustainable energy source.

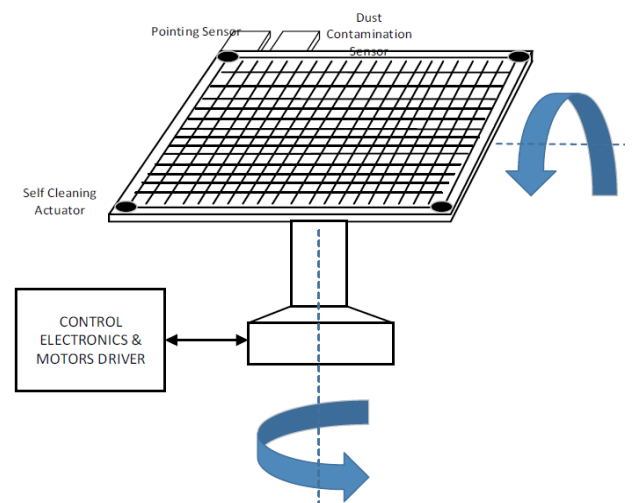


Fig. 5. SSP architecture [38]

So, in the scientific and engineering literature, different types of such hybrid energy systems can be found, such as: solar-wind systems (SWS), solar-geothermal systems (SGTS), solar-biomass systems (SBS), solar-coal systems (SCS), solar-natural gas systems (SNGS), thermal-electrical systems (TES or PV/T) etc.

4. Trend Analysis of Using of Solar Energies (SE) in Georgia

Georgia is country from 3.7 million people, nestled between Russia, Turkey, Armenia and Azerbaijan. About 70 [%] of the electricity in the country comes from

hydropower. The 20 [%] is garnered from coal and natural gas, and the rest is covered by imports from Russia [27,49]. Which means that the use of renewable energy sources (RES) and green energies (GE) in Georgia is insignificant, but the construction of new wind parks and photovoltaic devices is planned [27,49].

For trend analysis of using of green energies (GE) in Georgia until 2040, data that exist in state bodies (Ministry of Economy and Ministry of Energy of Georgia) and the

public were used to predict the use of different forms of green energies (GE) for Georgia for the following period: 2025, 2030 and 2040, retrospectively (Fig. 6) [27,49,57].

From Fig. 6, it can be seen that the development and use of solar energy (SE) in Georgia with a plan of 250 MW for the year 2025 will increase according to the forecast for the year 2030 to 810 MW, with a value of CAGR of 26,51 [%] and for the year 2040 to 1.330 MW, with a value of CAGR of 11,79 [%] for that period.

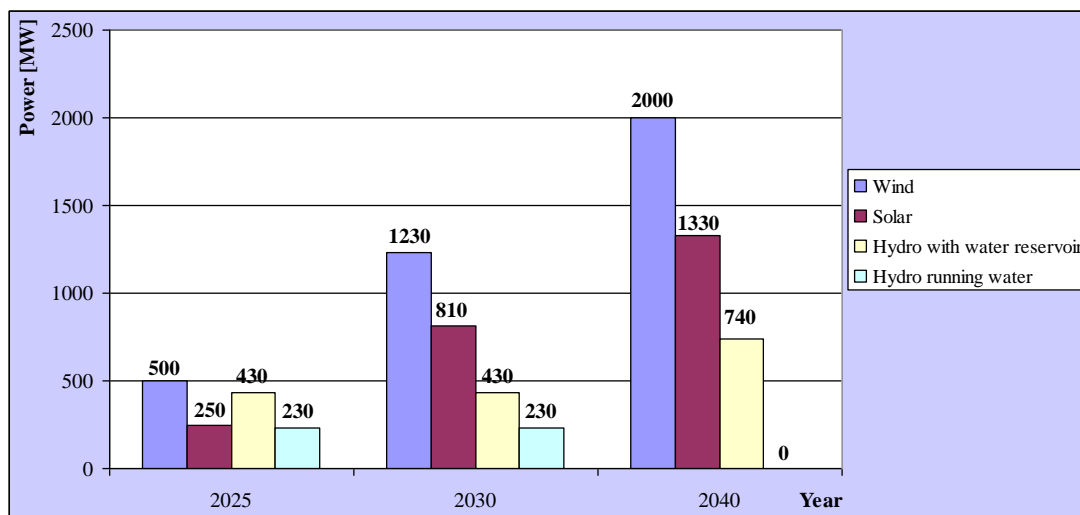


Fig. 6. Grafički prikaz vrednosti korišćenja različitih oblika zelene energije (GE) u [MW] u Gruziji do 2040 []

The following Figures show several examples of the use of solar energy (SE) in Georgia in various fields of application.

On Figure 7 shows an energy-efficient residential building named Solar Energy Apartments (SEA) located in Old Tbilisi, in the Ortachala region, which uses rooftop solar panels for electricity [50].



Fig. 7. Energetski efikasna stambena zgrada Solar Energy Apartments (SEA) in Tbilisi [50]

On Fig. 8 shows Hotel Kolkhida in Ureka, on the shores of the Black Sea, with installed solar panels (SP) that fully meet the resort's electricity needs, powering the hotel as well as the spa and rehabilitation center. Since

previously energy costs during the winter were high, which meant that the spa and rehabilitation center could only work during the summer months, with the implementation of this project Hotel Kolkhida can offer a complete range of services throughout the year, thus generating income even outside the summer months. This renewable energy pilot project in Georgia is supported by the United States Agency for International Development (USAID) [35].



Fig. 8. Hotel Kolkhida in Ureki, on the shores of the Black Sea, with installed solar panels (SP) [35]

On Fig. 9 shows solar panels (SP) of 100 kW installed in Krcanisi Park near Tbilisi, which serves to supply the area with renewable energy, irrigate 50 hectares of protected forest and ecosystem restoration. It was implemented with the support of the United Nations Development Program (UNDP) and funded by the Global Environment Facility (GEF) and in close partnership with

Georgia's Ministry of Environmental Protection and Agriculture (MEPA) and its National Wildlife Agency (NWA) [10].



Fig. 9. Solar panels (SP) from 100 kW installed in Krcanisi Park near Tbilisi [10]

On Fig. 10 shows the energy-efficient system of solar energy (SE) of company's Solar Energy Ltd., from Tbilisi (Georgia) [60].



Fig. 10. Energy-efficient system of solar energy (SE) of company's Solar Energy Ltd., from Tbilisi (Georgia) [60]

5. Conclusion

Fossil fuels such as: coal, oil or gas are a group of non-renewable energy sources (NRES) which are becoming less and less (slowly disappearing) and also cause undesirable consequences for the environment and their harmful influence has become more and more pronounced in the last few years. Whereas, non-renewable energy sources (RES) and solar energy (SE) will not disappear because they are naturally renewable and at the same time have no harmful impact on the environment. Renewable energy sources (RES) and solar energy (SE) are predicted

to become economically competitive with conventional energy sources in due course.

The role of renewable energy sources in global energy production is growing, especially when it comes to solar energy (SE), which is used today probably more than ever before for electricity generation. Thanks to increasing innovations and cost reductions in this area, many scientists believe that solar energy (SE) is currently on track to become the world's dominant energy source by 2050 [42].

The growing interest among people is an obvious consequence of subsidizing the installation of solar panels (SP) in households by an increasing number of countries, as well as the more affordable prices of these systems.

The growth of solar energy (SE) use in Georgia is significant, increasing from the current 250 [MW] in 2025 to 1330 [MW] in 2040, with a CAGR of 11.79 [%] for that period (or app. 5.32 times today's value).

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