

# Review of the Development of Modern Green Energy Generators and Systems

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**Abstract:** Green energy (GE) is a type of renewable energy (RE) that is obtained from natural sources that are constantly renewed and do not pollute the environment or do so minimally. The main green energy sources (GES), which are considered the cleanest forms of energy or types of renewable energy sources (RES), are wind, water, sun and earth. While the world, particularly in the most developed countries, has made significant progress in adopting and applying the various forms of green energy (GE), in Georgia this field is in its initial stage and it is not possible to predict when the first major positive developments will be made. Currently, more than 10% of the world's primary energy consumption comes from green energy (GE) technologies, namely: hydropower with approximately 5.1%, followed by wind power with 2.5%, solar power with 1.5% and other types of green energy with 0.9%. The development of cheap, dominant and fast-growing technologies and the development of cheap, intelligent and smart green energy generators and systems will ensure the increase of all types of green energy (GE) in the future. The paper provides a brief review of the historical development of different types of green energy systems, (GES) with a special focus on the historical development of wind turbines (WT). It also provides an review and analysis of several types of intelligent and smart green energy systems (GES), which include: Internet of Things (IoT), intelligent and smart sensors and other components of systems.

**KEYWORDS:** ENERGY, RENEWABLE ENERGY (RE), RENEWABLE ENERGY SOURCES (RES), GREEN ENERGY (GE), GREEN ENERGY GENERATORS (GEG), GREEN ENERGY SYSTEMS (GES), SUSTAINABLE ENERGY (SE), CLEAN ENERGY (CE).

## 1. Introduction

Energy is the capacity of a body or system to accomplish work. There are different forms of energy, namely: kinetic, potential, thermal (also known as heat), internal, electrical, chemical, elastic potential energy and many others.

Electricity, as a fundamental aspect of nature, is among the most widely utilized forms of energy. Considering the time possibility of exhaustion, natural or primary sources (forms) of energy can be divided into [9, 28, 47, 49, 63-66]:

1. Non-renewable energy sources (NRES) and
2. Renewable energy sources (RES).

Non-renewable energy sources (NRES) are sources that are consumed much faster than they can be naturally renewed. This means that they are depleted over time and cannot be regenerated in the short term. Their quantity is limited, so they are considered unsustainable in the long term. These are: Fossil fuels (coal, oil, natural gas, oil shale), Nuclear fuels, etc.

Renewable energy sources (RES) are natural resources (sources) of energy that are constantly replenished and cannot be depleted through use within a reasonable period of time. Their key advantage is that they come from processes in nature that occur continuously, and therefore represent a sustainable and environmentally friendly way of obtaining energy. Unlike non-renewables (oil, coal, gas), they are environmentally friendly and contribute to reducing pollution and CO<sub>2</sub> emissions. These are [9, 28, 37, 47, 49]: Water power or Hydropower energy; Biomass and biogas (including wood and waste); Solar energy; Solar radiation energy; Wind energy; Earth's internal heat (geothermal energy); Tidal energy; Wave energy, etc.

Renewable energy sources (RES) in the last thirty years represent a new trend in the use and production of various forms of energy in all areas.

The largest portion of global energy consumption currently goes to industry, accounting for approximately 50%. Transport follows with approximately 25%, while households and the commercial sector together consume the remaining 25%.

The consumption and production of energy worldwide are steadily increasing each year, closely linked to the continual growth of the global human population. Currently, the overwhelming majority of global energy production, (exceeding 80%) comes from non-renewable sources, leading to adverse environmental effects. To address this, sustainable development (SD) principles advocate reducing reliance on fossil fuels in energy production and consumption. Consequently, there is a persistent need to substantially increase the use of renewable energy sources (RES) in the future. This shift is imperative due to the diminishing reserves of non-renewable energy sources (NRES) and their escalating environmental impact observed in recent years.

This means that, globally, there is a growing trend towards generating electricity from renewable energy sources (RES) due to environmental considerations.

In addition to RE, the following terms are often used in the literature: green energy (GE), sustainable energy (SE) and clean energy (CE) [9, 20, 22, 28, 31, 37, 47, 49]. The question arises as to whether there is a difference between: GE, SE, CE and RE energy and what is the difference.

The analysis and application of energy and the energy system in Georgia is presented in the papers [13, 15-17, 23, 46, 57, 64], while the works describe the current state and future prospects for the development and application of various types of renewable energy sources (RES) in Georgia [14, 29, 48, 52, 63, 65-66].

Due to the increasing use of green energy, the aim of this paper is to describe the variety of forms and types of generators and systems for green energy.

## 2. Green Energy and Green Energy Sources

Green energy (GE) is a type of renewable energy (RE) that is obtained from natural sources that are constantly renewed and do not pollute the environment or do so minimally [8, 18, 21, 52, 65, 66, 68, 71]. It is actually clean (CE), renewable (RE) and sustainable energy (SE).

The main types of green energy (GE) are:

- Solar energy (SE) [25, 51, 63], is a type of energy that uses the energy of the Sun or the sun's rays to obtain useful forms of energy (most often electrical or thermal energy), through solar panels and collectors.
- Wind energy (WE) [4, 27, 55, 56], is a type of renewable or green energy that is obtained by exploiting the movement of air (wind). It occurs as a result of uneven heating of the Earth's surface by the Sun, which leads to differences in pressure and movement of air masses. This process is based on converting the kinetic energy of the wind into electrical energy, most often by means of wind turbines (WT). It is realized in such a way that: The wind moves the blades of the turbine; The blades turn the rotor; The rotor drives the generator and The generator produces electricity.
- Hydropower energy (HPE) [63-66], is a type of energy that is obtained by exploiting the movement or fall of water (rivers, streams, water is stored or accumulated by means of dams and used as needed) in hydropower plants. It is realized in such a way that: Water from the river or reservoir (dam) is directed through pipes; The flow of water drives the

turbine; The turbine drives the generator and the Generator produces electricity. With the HPE form of electricity, the production is completely stable and reliable.

- Energy from biomass [63-66], is a type of renewable (RE) or green energy (GE) obtained from organic materials (wood, plants, agricultural waste, etc.).
- Geothermal energy [63-66], is a type of energy that represents heat from the Earth's interior, etc.

The advantages of using green energy (GE) are multiple, compared to other types of energy, such as:

- There is no direct air pollution and carbon dioxide (CO<sub>2</sub>) emissions are reduced;
- Reduces the amount of waste;
- It is a type of renewable energy (RE), which means that natural resources are not depleted, unlike oil, coal, gas, etc.;
- Helps fight climate change etc.

Green energy's history spans from ancient civilizations utilizing wind and water power to modern solar and wind technologies. Key milestones include 19th-century solar cell invention, early 20th-century hydroelectricity growth, and accelerating 21st-century adoption driven by climate action, resulting in today's cheap, dominant, and rapidly expanding renewable technologies [7, 60].

On Fig. 1 shows the timeline evolution of wind turbines (WT) for the period 19th century to 2025, with the characteristics and increase power of wind turbines (WT) on a time scale [7].

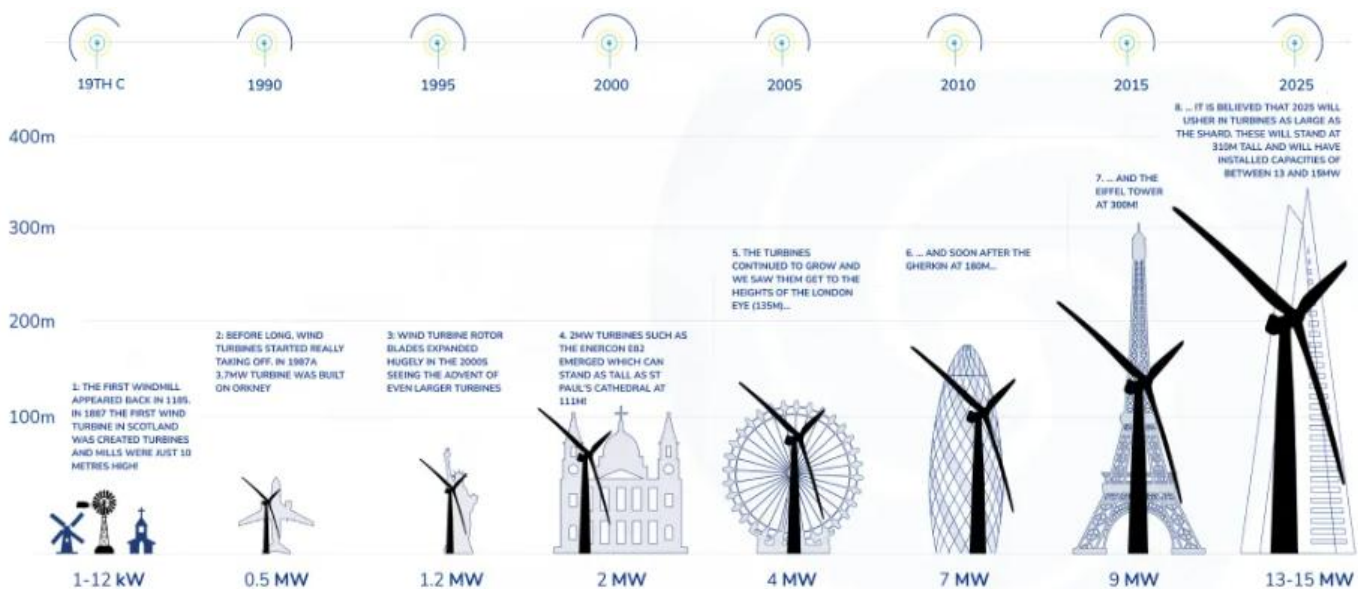
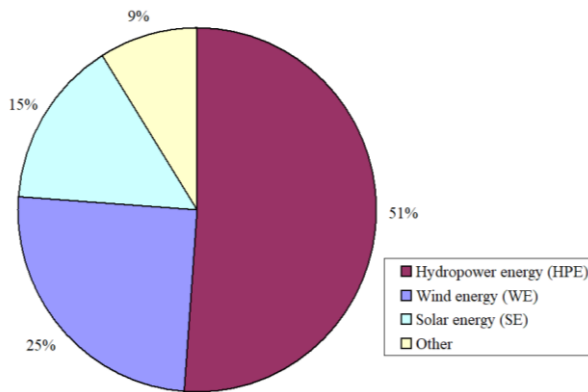


Fig. 1: The history of Wind Turbines (WT) [7]

Currently, more than 10% of the world's primary energy consumption for heating, transport and electricity comes from green energy (GE) technologies. Hydropower

energy (HPE) accounts for the majority of green electricity production with approximately 51%, followed by wind energy with 25% and solar energy with 15% (Fig. 2).



**Fig. 2:** Graphics representation the world's primary energy consumption by major types of green energy (GE) technologies

In the last few decades, the global demand for renewable (RE) and green energy (GE) has been continuously growing, which is mainly driven by environmental protection and sustainable energy development [14, 43].

Currently, many of the world's most developed countries have significantly advanced the adoption of various forms of green energy (GE).

A large number of research and studies describe in detail the current state and future prospects of the development and implementation of various types of renewable energy sources (RES) and green energy (GE) in different countries around the world [9, 11, 33, 36-37, 41, 45, 52-55, 62, 65-66, 69].

The current global political, economic, and energy crisis has led to increased energy prices, worsening economic recession, triggering geopolitical tensions, and worsening environmental problems, with a serious impact on the global economy. This situation in the world encourages scientists, manufacturers, and business people to turn and direct their thoughts to the use of renewable (RE) and green energy (GE).

### 3. Green Energy Generators and Systems

The energy system (ES) is the entire process of transforming or converting natural energy resources into effective energy required for human social production and life.

Similar to the energy system (ES), for the process of transforming or converting natural green energy resources into efficient green energy (GE) needed for human social production and life uses various types of green energy generators (GEG) and systems (GES) [44, 59].

There are two types of green energy generators (GEG) and systems (GES) and they are:

- Different types of traditional and modern green energy generators (GEG) and systems (GES) that directly depend on the type of green energy (GE) they convert. They all work on the principle of converting natural (renewable or green) energy from the environment into electricity without significant pollution. The most common traditional

and modern green energy generators (GEG) and systems (GES) are for:

- Solar energy (SE): Solar energy generators (SEG) and systems (SES); Solar energy generation systems (SEGS); Solar PV (Photovoltaic) Power Generators (SPPG); Solar PV (Photovoltaic) Systems (SPVS); Solar PV (Photovoltaic) panels (SPVP); Solar thermal power plants (STPP) etc.;
- Wind energy (WE): Wind turbines (WT); Wind energy generators (WEG) and systems (WES); Wind power generation systems (WPGS) etc.;
- Hydropower energy (HPE): Hydropower systems (HPS); Hydropower plants (HPP) etc.;
- Energy from biomass: Biomass systems (BMS); Biogas plants (BGP); Cogeneration power plants (CPP) etc.;
- Geothermal energy (GTE): Geothermal systems (GTS) Geothermal power systems (GTPS) etc.
- Hybrid green energy generators (HGEG) and systems (HGES).

Recently, a large number of different types of modern solar energy generators and systems have been developed [2-3, 10, 19, 30, 32, 34-35, 38-40, 43, 70], such as:

- Smart solar PV (photovoltaic) generator (SSPG) or Smart solar PV (photovoltaic) system (SSPS), is an advanced version of the classic solar system for electricity production, which uses modern technologies (sensors, software, automation, IoT, AI etc.) to work more efficiently, reliably and economically.
- Sustainable solar PV (photovoltaic) generator (SSPG) or Sustainable solar PV (photovoltaic) system (SSPS), is an electricity generation system that uses solar energy, but is designed to be long-term efficient, environmentally friendly and economically profitable.
- Smart solar PV (photovoltaic) power generator (SSPPG), is a system for the production of electricity or thermal energy from solar energy which integrate Internet of Things (IoT) technologies, Artificial intelligence (AI) and advanced inverters to maximize efficiency, automate maintenance and improve grid stability. These systems allow for real-time monitoring of energy production, weather forecasting, and automatic monitoring to increase power output, often increasing efficiency by over 20%.
- Smart solar energy generator (SSEG) or Smart solar energy system (SSES), is an advanced system for generating and managing electricity from the sun that uses digital technologies, automation and often artificial intelligence to operate more efficiently and economically.

- Sustainable solar energy generator (SSEG) or Sustainable solar energy system (SSES), is a system for the production of electricity or thermal energy from solar energy that is designed to be environmentally friendly, economically profitable and socially beneficial in the long term etc.

Recently, a large number of different types of modern Wind turbines (WT), Wind turbine generators (WTG), wind energy generators (WEG) and systems (WES) have been developed [34, 38, 61], such as:

- Horizontal axis wind turbine (HAWT), is a type of wind turbine (WT) in which the axis of rotation is parallel to the ground (horizontal), and the blades rotate around that axis;
- Vertical axis wind turbine (VAWT), is a type of wind turbine where the axis of rotation is placed upright (vertical) in relation to the ground.;
- Intelligent wind turbine (IWT), is a modern type of wind farm that uses advanced digital technologies to automatically optimize electricity production and system operation.
- Smart wind turbine (SWT), is an advanced wind turbine (WT) that uses modern technologies such as sensors, automation, artificial intelligence (AI) etc. to optimize its operation and electricity production by itself.
- Sustainable wind turbine (SWT), is a wind turbine (WT) that is designed, built and used in a way that minimizes the negative impact on the environment, while ensuring long-term and efficient production of energy from the wind etc.

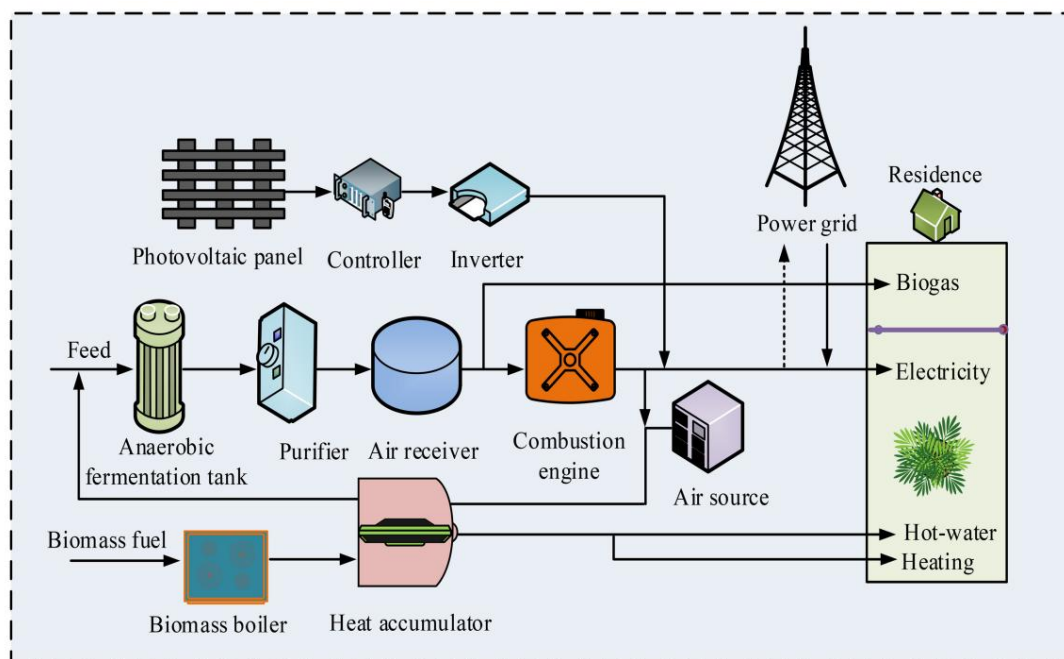
Hybrid green energy generators (HGEG) and systems (HGES) are a type of green energy systems (GES) that combines multiple sources (e.g. solar + wind + batteries).

HGES have gained attention as an effective approach to address the variability and intermittency issues of standalone renewable energy technologies, while increasing the stability and reliability of energy production. In papers is given analysis and applications hybrid green energy systems (HGES) and hybrid renewable energy systems (HRES) [1, 6, 12, 26, 42-45, 58, 67, 71-75].

Several hybrid green energy systems (HGES) will be presented and described below.

The **RES-GES** (RES (renewable energy sources) GES (green energy system)) represents a system of green energy (GE) based on the complementary integration of renewable energy sources (RES) (Fig. 3) [72], which can form different types of integrated energy systems based on different forms of drive devices, input and output energy. The RES-GES system contains a variety of green energy and integrates multiple renewable energy sources (RES): solar, wind and biomass, which contribute to minimizing fossil fuel consumption, improve the richness of energy structure, and promote green environmental protection [71].

In paper [44] is presentation of study that presents a model and optimization approach for a green energy system through the complementary integration of renewable energy sources (RES-GES). The energy system model incorporates solar, wind and biomass energy, along with distributed functional subsystems. The optimization objective is formulated using environmental sustainability, economic profitability and efficient use of energy as key evaluation criteria.

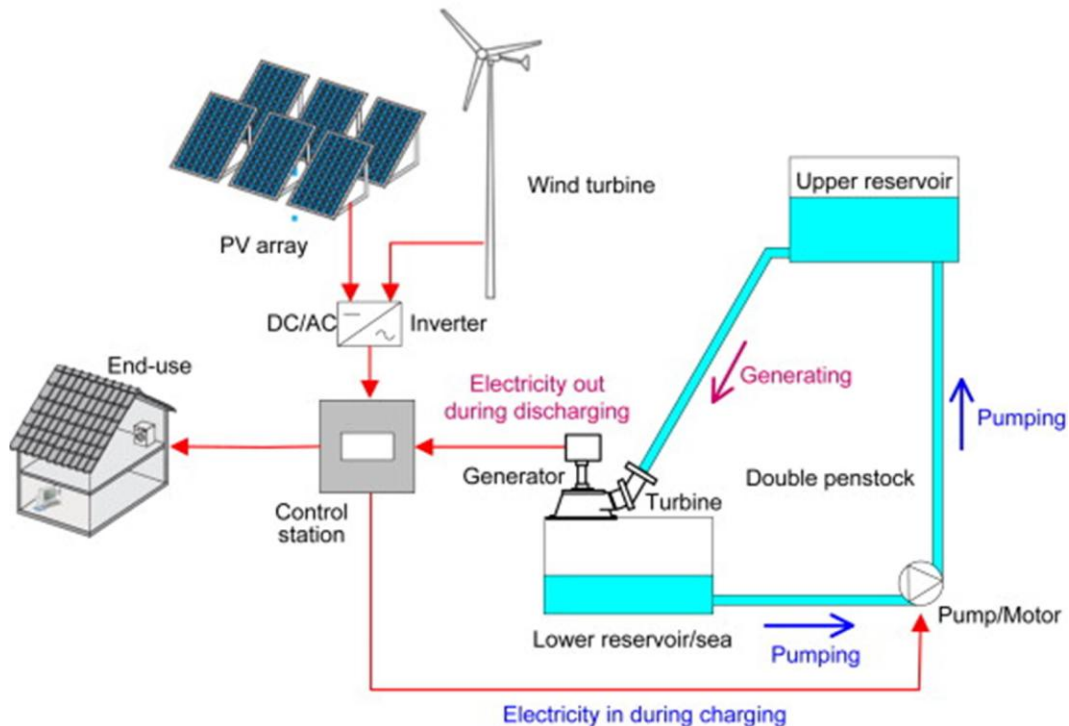


**Fig. 3:** A green energy system (GES) model based on complementary integration of renewable energy sources (RES) [44, 72]

The **HRES-MESS** (HRES (hybrid renewable energy sources) with MESS (mechanical energy storage system)) represents an integral variant of a green energy system (GES) which coupled HRES with the MESS system, thus enhances energy reliability and long-term sustainability [42]. In paper [42] was given of special focus to the primary technical, economic and environmental challenges associated with MESS, including high capital costs, conversion inefficiencies, environmental impacts and site-specific constraints.

The **HRES-PHES** (HRES (Hybrid renewable energy sources) with PHES (pumped hydro energy storage))

represents an integral variant of a green energy system (GES) for improve energy reliability, stability and sustainability, especially in off-grid and remote regions [74]. By utilizing the complementary characteristics of solar and wind energy, together with the large storage capacity of PHES, these systems can effectively reduce fluctuations in renewable energy generation, minimize fossil fuel use, and improve grid independence. An example of an integrated HRES-PHES system is shown in Fig. 4 [42, 74].



**Fig. 4:** Schematic diagram of a photovoltaic wind pumped hydro energy storage system [42, 74]

Due to the development and application of various variants of electricity generation systems, many authors use various multi-objective optimization (MOO) methods for the selection of green energy sources (GES) and green energy generators (GEG) and systems (GES) [21, 24, 38, 44, 58, 67, 73, 75]. Energy optimisation refers to the optimal allocation of energy structure to determine the optimal energy supply system solution [44].

The development and application of modern smart remote monitoring systems (SRMS) for renewable energy systems (RES) using the Internet of Things (IoT) are presented in [5, 50].

#### 4. Conclusion

The development of modern green energy generators (GEG) and systems (GES) represents one of the key directions of modern technological and social progress. During the last decades, significant progress has been made in the efficiency, reliability and availability of green energy sources (GES), as a part renewable energy sources

(RES), such as solar, wind, hydropower, biomass systems etc. The integration of smart technologies, automation, artificial intelligence (AI), Internet of Things (IoT) etc., has further improved the management of energy production and consumption, making these systems more flexible and adaptable to modern needs.

In addition to technical development, economic and ecological aspects also play a significant role, because green energy contributes to reducing the emission of harmful gases, preserving natural resources and mitigating climate change. Although challenges remain, such as energy storage and initial investment, trends clearly indicate that green energy systems (GES) will play an increasing role in the future energy mix.

In this context, further development of innovation, investment in infrastructure and support through regulation and education will be crucial for a complete transition towards sustainable and environmentally friendly energy solutions.

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