**Green Technology and Sustainable Development: Advancement and Strategies**

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**Abstract**

Traditional energy sources are responsible for releasing harmful pollutants and hazardous gases in the atmosphere. One of the most promising strategies to save the environment is to replace conventional energy with renewable energy sources that are obtained from the sun, wind, water, tides, and geothermal. The main impediment to renewable energy systems is uninterruptible energy generation especially electrical energy. The latest trend in research is also focused on developing novel methods to generate electrical energy from renewable sources. Lot of funding from government agencies is also available to promote research in these areas to tackle energy security issues and climate change. Such innovative routes have the potential to save about 30% of energy with 80% lower prices thereby reducing global warming. This is also viable and cost-effective way to achieve long-term growth and environment sustainability.

**Introduction**

The demand for energy has witnessed a rapid increase in recent time. According to United Nations, the industrial countries have 28% world's population but utilise 77% global energy. The current population worldwide is anticipated to grow 1.26 times by 2050 to 9.7 billion. The emerging countries account for nearly 90% of population growth. Although developed countries have implemented effective energy conservation policies to be achieved by 2050, yet their energy consumption has remained constant. Researchers in underdeveloped countries, are struggling to build their own energy-generating facilities (Salvarli and Salvarli, 2020).

It is projected that fossil fuel stocks will deplete naturally. As a result, alternative viable renewable energies are need of the hour in near future. This condition will provide an impetus to creating new jobs and building future industries. Rising industry, technological advancement and human labour have increasingly contaminated the environment causing global climate change. Inorder to attain sustainable development, renewable energy sources should be wisely harnessed with focus on its pricing, policies, applications and technology transfer (Salvarli and Salvarli, 2020).

Green renewable energy sources (RGEs) offer chances for Sustainable Development such as energy security,social and economic development,and climate change mitigation.The popular three-pillar model, which includes economy, ecology, and society, has been used to theorize the concept of sustainability. RGEs preserve natural capital as long as resource consumption does not reduce the prospect of a sustainable future.There should be a perfect harmony between the three-pillar model and RGE technologies for evaluating renewable green energy technologies and to frame appropriate economic, social, and environmental policies. This will definitely contribute significantly to the economies of countries rich in renewable green energy sources (Androniceanu and Sabie, 2022).Governments and other authorities should also encourage generous investment in sustainable green energy production to assure a more environment friendly and sustainable future.In 2019, India ranked fourth in world for the most appealing renewable energy market. By 2030, India is aspiring to achieve world's largest renewable energy expansion target of 450 GW (Kumar and Majid, 2020).

The present chapter includes an overview of Global energy consumption, current achievements, and types of green energy.The study also summarises potential trends over the next decade.

**Global Primary Energy Consumption**

Primary energy consumption has increased constantly in the world. Primary energy is the energy available in raw form before its actual conversion into either heat or electricity or any other type of fuels viz. fossil energy sources obtained from coal, oil, and gas, energy from uranium and bio-mass, energy from physical phenomenon like wind, solar radiation, and hydraulic power. The available primary energy sources have witnessed a visible transformation over last few centuries. Almost all new sources of energy have been explored to date beginning from fossil fuels to the use of nuclear and hydropower energy. The quantity produced and subsequently consumed has also increased manifold since the Industrial Revolution. Although Global energy consumption growth slowed down in 2022 (+2.1%) it is growing at the rate of around 1% to 2% per year with a aggregate increase of around 15.10% in 10 years.

The largest energy consumers in the world are Norway, Iceland, USA, Canada, Oman, Qatar, and Saudi Arabia. India holds third position with 5.6% of the growth rate in the world in primary energy consumption in 2017. Statistics reveal that energy consumption growth in 2022 slowed down in the two largest consuming countries China and USA. On the contrary, primary energy consumption declined in Europe due to fears of recession after Russia’s invasion of Ukraine and surging energy prices.

Activities related to power generation from primary energy sectors, deforestation, transportation, and industrial and technological advancements are responsible for CO2 emissions. Hence high energy consumption is coupled with an increase in global CO2 emission. It is a serious agenda that needs immediate solution to meet ambitious climate mitigation goals. Hence recently, at international level rigorous changes and adjustments are happening (Nfah et al., 2007).

To popularize sustainable green energy among the masses, the prime agenda of the international global energy policies now is to focus on the transition of the fossil energy-based system to low-carbon energy-based system (Dizdaroglu, 2017). In order to achieve a breakthrough from the high-carbon energy-based system to the low-carbon one, national and international policies, market mechanisms, and legal systems should be synchronous with each other and should actively acknowledge the energy issues to establish the best consumption model and renewable energy production.

**Current Achievements in Green Energy in India**

The Government of India have initiated ample national programs in different areas of the renewable energy sector to deploy and popularize renewable energy systems among the general public. Government and private institutes such as the Ministry of New and Renewable Energy, The Energy Resource Institute, Centre for Wind Energy Technology, Indian Oil Corporation Ltd., IITs, NITs, Universities are involved in Research & Development of renewable sources of energy. For smooth implementation, delivery, and outreach of renewable energy projects, the government has constituted District Advisory Committees , and developed Akshay Urja Shops, Renewable Energy Clubs, and Energy parks (Purohit and Michaelowa, 2008; Maithani, 2008;Chaturvedi and Garg, 2007).

The major achievements of India in the field of renewable energy is as follows.

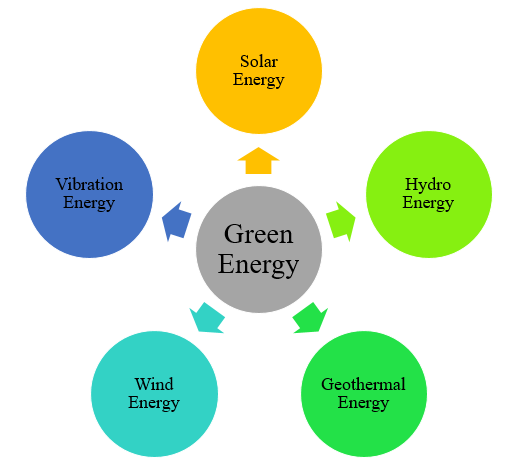
1. Wind Energy Technology Centre at Chennai has created a scientific and industrial research cell for assessment of wind resources, equipment certification, and R&D.
2. Solar Energy Centre at Gurgaon, Haryana is specialized for solar energy systems development.
3. Integrated Rural Energy initiative has been administered in 860 blocks.
4. Sixteen hundred renewable energy projects has funded by Indian Renewable Energy Development Agency Limited.
5. Solar Photovoltaic products of 30 MW capacity has been exported to countries all over the world.
6. 280 Energy Parks has been established for illustration of renewable energy devices in various educational institutions
7. Heating systems powered by solar energy has been equipped in 7 lakhs m2 collector domain.
8. Over 4200 MW grid power is successfully generated from wind, small hydro, biomass and solar energy.
9. Largest solar–steam cooking system is installed at Tirumala Devasthanam, Tirupati for fifteen thousand persons per day.
10. Biogas plants worth 3.5 million for cooking and lighting applications and wood stoves worth 35 million has been improved in rural abodes.
11. 3600 remote villages/hamlets including those in Ladakh and the North East are electrified through solar energy.

**Types of Green Energy**

Renewable Energy sources are distributed over a wide geographical area and available throughout the year. These resources do not exhaust and can be easily revived by a natural phenomenon. It does not cause contamination of environment. The advantage of availing renewable resources is that by one-time investment one can take benefit without affecting the environment for many decades.

There are five main types of green energy:

1. Solar energy
2. Hydro energy
3. Geothermal energy
4. Wind energy
5. Vibration energy

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**Fig 1: Types of Green Energy**

1. **Solar Energy**

Sun is an abundant solar energy source providing vital energy to the living organisms, flora, and fauna on earth. It is a sustainable, clean, and direct energy with minute impact on the surrounding. It does not produce harmful gases like carbon dioxide as a co-product and therefore do not contribute to global warming. It can be successfully harnessed into useful energy using Parabolic Trough Systems and Solar Photovoltaic cells. Many everyday low-power absorbing devices like calculators can be efficiently powered by solar energy. It’s also a longer lasting energy source for future generations because it lasts forever.

**Hydro Energy**

Hydro energy is electricity generated from the water cycle by continuous process of falling and fast-running water. Hydroelectric power is major reliable, affordable, domestic and well established renewable energy that meets approximately 19% of the world’s electricity requirements (Maithani, 2008). Large-scale schemes and projects are undertaken by the government to harness hydroelectric power in the world. It is also specific clean energy sources as it does not lead to any by-products during conversion.

1. **Geothermal Energy**

Geothermal energy is produced inside the earth in the form of heat from the radioactive decay of radioactive materials like uranium. The pioneering geothermal power plant was constructed in Larderello. The US National Renewable Energy Laboratory reported that hot dry rocks have potential to supply around 4 million MW capacity electricity, which is higher than that used by the United States today. Due to negligible emissions, it is considered to be an exceptional alternative over traditional fossil fuel energy sources for mitigation of global warming. It is the cost-effective, reliable, affordable, renewable, and sustainable source of energy used for household purposes.

1. **Wind Energy**

The energy produced using wind turbines by the flowing wind is called wind energy. Wind is actually type of solar energy. It is created by heating of the earth atmosphere by the sun and by the rotation of the earth. Wind turbines used for energy production are usually installed in huge open-land farms. Empty land around wind turbines can be effectively used for agriculture and horticulture. Wind turbines do not contribute to acid rain or greenhouse gases. It is a clean and renewable energy source and requires less cost.

1. **Vibration energy**

This mechanical phenomenon in which the vibration occurs at equilibrium is known as vibration energy. The study on vibration energy came into focus in recent years. The vibration produced in the surrounding by a large traffic on the road or a large crowd or by vibrations of skyscrapers, vehicle systems, bridges, railways, and ocean waves can also be harnessed efficiently. These vibrational energies can be transformed into electric energy that can be stored. This energy can be used to power electronic appliances required low-power. Usually, harvesting of vibrational energy from large sources produces about 1W to 100 kW energy (Chaturvedi and Garg, 2007). Vibration energy has been successfully used to replace the batteries in medical implants as traditional batteries loaded with toxic heavy metals. Vibration energy can be used to control the noise in the environment generated by industries, air craft’s etc by vibration damping and isolation.

**Strategies for a green sustainable energy future**

In 2019, India ranked fourth in the world for the most appealing renewable energy market. An progressive target of 450 GW of renewable energy by 2030 has set by India. This is the world's largest renewable energy expansion plan. India has three of the top Five largest solar parks in the world. It also includes the second-largest solar park in the world at Kurnool, Andhra Pradesh, with a capacity of 1000 MW. In Rajasthan the world's largest solar power plant, Bhadla Solar Park exist with a capacity of 2255 MW.

According to Organization for Economic Cooperation and Development (OECD) and European Union 27 (Eurostat, 2013), Denmark is regarded as one of the most energy stable and sustainable country (Sovacool and Brown, 2007). Denmark has expeditiously reduced (from 90% to almost zero in the 1970s) its reliance on external energy sources, and has become a net exporter of fuels and power (Sovacool and Tambo, 2016). The heart of effective approach of Denmark is obligation to liability to energy efficiency, increased taxes on energy fuels, electricity, carbon dioxide, subsidies for Combined Heat and Power (CHP) and wind turbines (Sovacool, 2013). Denmark's goal is to achieve 100% renewable energy by 2050 (Sovacool, 2013; Danish Government. Energy Strategy, 2011).

Germany, one of the EU's top energy importers, is undergoing bold energy revolution (Proskuryakova, 2018). Germany is considered as the most prosperous country in terms of promoting renewable energy (Liu, 2018). Germans outperformed the rest of the EU in terms of energy security in 2014, due to lower oil and coal shares and increased diversification of energy imports (Matsumoto et al., 2018). The energy transition policy (Energiewende) of German is widely regarded as the most popular sustainable national energy policy (Harjanne and Korhonen, 2018). The Energiewende seeks to 80-95% reduction (relative to 1990) in greenhouse gas emissions by 2050, at least 60% increase in the sustainable energy, and 80% increase in the renewable part of power demand (Hansen et al., 2019). By 2022, Germany also wants to finish its nuclear wind-up (Energiewende, 2019). According to Hansen et al. (2019), to achieve 100% renewable energy for the whole energy system of German, implementation of crucial regulations is essential policy.

China is the major energy user in the world (British Petroleum, 2019), the largest emitter of greenhouse gases (Yang et al., 2050), the world's fifth largest producer of oil, the world's seventh largest producer of natural gas, and the world's largest producer of coal (Zhang et al., 2017; Wang et al., 2018). China intends to reduce the share of coal from the fuels used in electricity production, but use of coal is increasing day by day as more power projects are being planned based upon use of coal. Indeed, in total primary energy consumption of China the proportion of fossil fuels is predicted to approach 90%, with coal serving as the dominant source of fuel (Matsumoto and Andriosopoulos, 2016). At the same time, China has the most hydropower resources in the world, with a total theoretical hydropower potential of 694 GW (Zhang et al., 2017). By the end of 2015, China's hydropower capacity has surpassed 25% of the world's nonhydro renewable capacity, accounting for 63.1 and 117.0% more than the US and Germany, respectively (Yang et al., 2016). Until the end of 2017, the total installed sustainable energy generation capacity of China's was 635 million kW, accounting for 35.7% of total installed electric power capacity (Liu, 2019).

Russia has one of the world's largest fossil fuel reserves and is fourth highest (after China, the United States, and India) emitter of greenhouse gases in the world. Russia is second largest producer of natural gas in the world after The United States (British Petroleum, 2019) and play a significant role in primary supply of natural gas to most of European countries. As Russia is also a large country with a diverse topography and climate, providing it the opportunity to generate nearly every type of renewable energy (International Energy Agency, 2003Russia is expediting the implementation of solar and wind energy through auctions in order to help isolated populations in terms of employment, research, technology, and energy security (Gielen et al., 2019). Despite being a pioneer in sustainable energy technology, main strategy of Russia is focused on the expansion of fossil fuels and nuclear energy (Lanshina et al., 2018). The Russian government introduced the Capacity-Based Renewable Energy Support Scheme (CRESS) in 2013 (Smeets, 2017). Each year, a maximum installed capacity of solar, wind, and small hydro projects might acquire financial guarantees on Russia's wholesale power market under CRESS implementation (Boute, 2012). Russia's energy security will continue to be connected to its natural gas supplies, and its capacity to export it to Europe and other countries will determine its status as an energy hegemon.

Renewable energy is better adapted to distributed production than the fossil fuel paradigm, making it more secure. Renewable energy will contribute to the emergence of an era energy democracy, in which a system of decentralised prosumer systems will replace large-scale power generation.

**Energy security, sustainability challenge and expectations**

Recently, there has been a rising support for integrating sustainable energy into the energy supply as a primary measure for addressing energy security and climate change (Hache, 2018). Energy security planning is becoming increasingly focused on developing a low-carbon economy and meeting climate mitigation targets (Hamed and Bressler, 2019).

Article 2 of the Paris Agreement (United Nations, 2015) directs the different countries to implement their nationwide contributions and gradually increase their goals in order to keep mean global temperature rise level below 2°C (Rogelj et al., 2016). Renewable energy is naturally leading energy option as new energy must be less polluting than the sources it replaces. Goldthau and Sovacool (2012) discussed three major challenges of energy: energy security, energy justice and a low-carbon transition. They emphasised the role of energy security as a democratic issue, equity as an important part of accessibility and global climate change as key characteristic of acceptability.

Similarly, Sovacool and Rafey (2011) proposed a four aspects of energy security: (1) availability, that is, alternative fuels, preparing for disruption recovery, and reducing dependence on foreign supplies; (2) affordability, that is, providing affordable energy services and minimising price variability (3) efficiency and development, which includes increasing energy efficiency, changing consumer attitudes, and building energy infrastructure; and (4) environmental and social stewardship, which includes safeguarding the natural environment, communities, and future generations.

According to Sovacool and Brown (2009), energy security is defined by the following criteria i.e. availability, affordability, energy and economic efficiency and environmental stewardship. Availability is evaluated by reliance on import of oil and natural gas import and availability of alternative fuels. Whereas affordability is measured by retail of electricity, gasoline and petrol prices. Energy intensity, electricity use per capita, and average fuel economy of automobiles are parameters for Energy and economic efficiency measurement. Environmental stewardship is measured by sulfurdioxide (SO2) and carbon dioxide (CO2) emissions.

The worldwide move to sustainable energy demonstrates a more powerful global response to change in climate. Maximum European countries have enacted strategies that will have substantial economic, social and political ramifications. This shift to environment friendly energy will change the geopolitical landscape, alter the dynamics between producer and consumer countries (International Renewable Energy Agency, 2009) and establish new energy norms for exporting countries (Overland, 2019). The renewable energy revolution will be one of the major characteristics and pillars of the low-carbon transition. Transitions from coal to natural gas as well as transitions from non-renewable to renewable energy will be important (Matsumoto and Andriosopoulos, 2016).

**Recent advancements in green energy**

Renewable energy (RE) sources include biofuels, geothermal, hydro, solar, tidal, waste, and wind. The main impediment to RE systems is uninterruptible energy generation. The most unpredictable are solar and wind and as compared to other RE sources, their variability is substantial (Ghosh, 2022). The power electronics have been the main promotor among the technologies that have supported the expansion of renewables. The electrical converters enabled the coupling of renewable energy producers to legacy power systems, as shown schematically in Figure 1, and enhanced energy harvesting efficiency via customised controls. Furthermore, power electronics is widely used on the consumer side and is a key component of the future smart grid. Wind turbine systems have evolved significantly over the years. In the 1980s, a 50kW wind turbine was considered large, although now normal wind turbine is rated at 2 to 3 MW. The development for larger units was driven due to need of lower energy costs, whereas improvements in performance particularly in terms of grid connection, require upgradation of the electric technology.

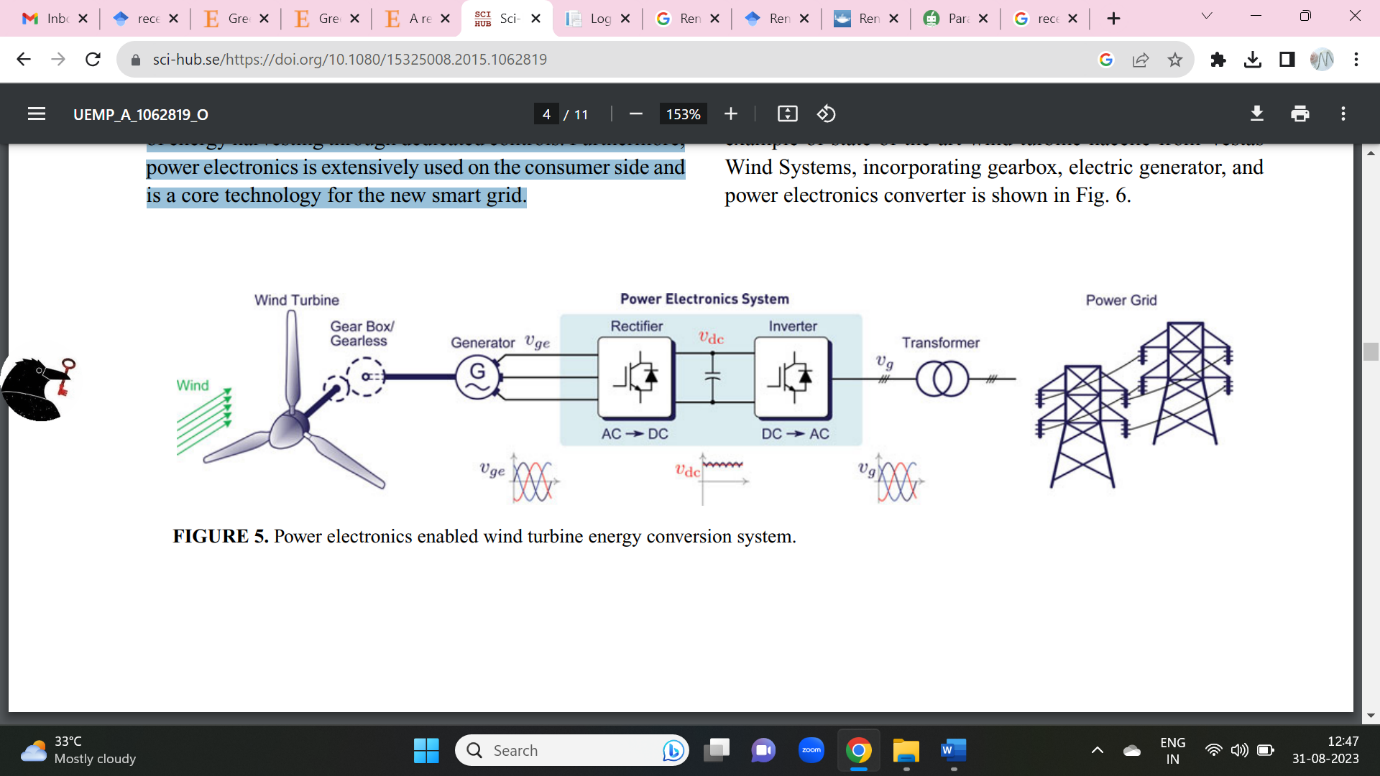


Figure 1: Power electronics enabled wind turbine energy conversion system (Source: Blaabjerg and Ionel, 2015)

Grid-connected photovoltaic (PV) systems, shown schematically in Figure 2, consists of a power electronics DC/DC converter for maximum sun energy harvesting through maximum power point tracking (MPPT) regulation as well as a DC/AC converter for grid hookup. PV systems are becoming in demand not only for multi-MW utility scale power plants/farms, but also for roof top installations on commercial as well as residential buildings with ratings as low as hundreds of watts.

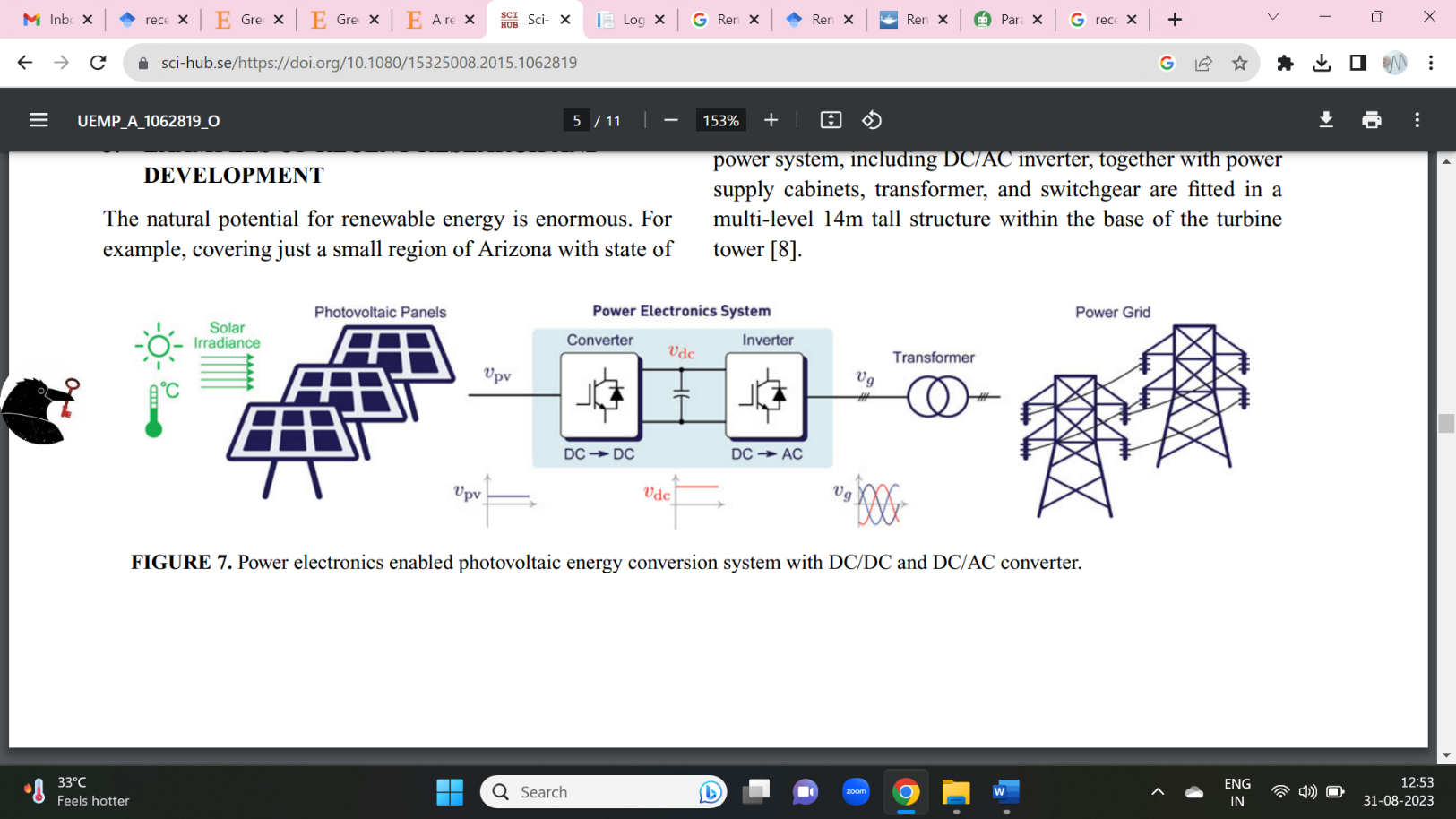


Figure 2: Power electronics enabled photovoltaic energy conversion system with DC/DC and DC/AC converter (Source: Blaabjerg and Ionel, 2015)

The SASDAC system consist of four primary components: a desiccant dehumidifier, a sensible heat exchanger, a cooling unit and a solar regeneration heat source. The essential functioning concept of the major component of a solid desiccant system is illustrated in Figure 3. From the outside, the hot and humid air enters the system, then passes through the desiccant wheel and become hot and dry as the desiccant wheel absorbs moisture. This hot and dry air from the desiccant wheel flows through the heat recovery wheel and here heat exchange occurs between the primary and return air. Then air passes through a humidifier that adds moisture to achieve the appropriate cooling effect, suitable for the conditioned environment. After this, air returns from the room and directed through a humidifier, which adds moisture to the air to cool down. Then, the moist air passes via a heat recovery wheel and becomes hot. At final step, the hot air flows through heating coils and desiccant material is regenerated by increasing the temperature with solar energy.

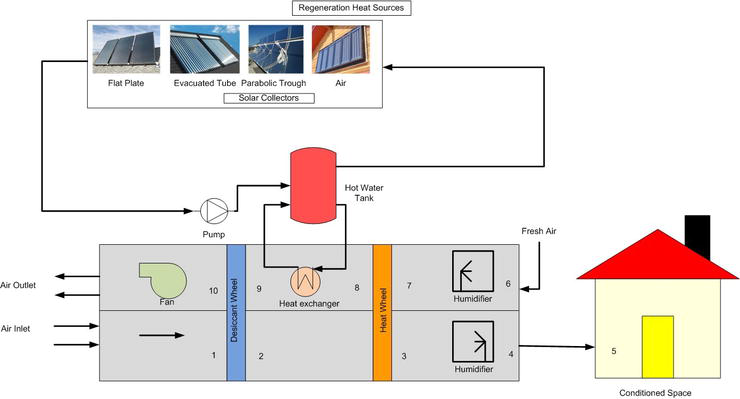


Figure 3: Working principle of solar-assisted solid desiccant cooling system [20].

Beside from the previously described technologies, methods, and devices, a special mention should be made of the significant continuous efforts for integrating renewables sources into the power and energy system, which make an accurate balance between production and consumption. Controlling the complete energy system consisting of electrical power, thermal energy as well as water flow system is an ongoing problem for science and society. In this context, Smart-grid functions and facilities i.e., communications and energy storage, are considered as solution enablers in this context, but there is still a long way to go.

**Conclusion**

Fossil fuels continue to account for the majority of energy consumption and increasing around the world. In this case, environmental pollution is unavoidable and renewable energy plants have no direct impact. For a long term plan, if investments in renewable technology continue, renewable sources have the potential to contribute considerably to fulfil energy needs.

Furthermore, many technologies including biofuels and fuel cells can contribute to the heat, transportation and energy markets. In 2023, the contribution of fossil fuels in total primary energy supply is predicted to be approximately 81%. By 2050, renewable energy will account for approximately 30% of the global energy structure.

Now a days, various energy-efficient technologies are used in power plants, industries and transportation systems to consume less and cleaner energy. These technologies have the potential to reduce costs by up to 80%, save energy by up to 30% and help to halt global warming in the future. As a result, the countries may remain economical while planning long-term growth. Marketing renewable energy can also be defined as the ability to understand the requirements of consumers.

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