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

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**Abstract**

Traditional energy sources, such as oil, coal, and gas, emit harmful pollutants into the atmosphere, such as CO2 and other hazardous gases and components. One of the most promising strategies to save the environment is to replace conventional energy with renewable energy (RE) sources such as Biofuels, geothermal, hydro, solar, tidal, waste and wind. The main impediment to RE systems is uninterruptible energy generation. Electricity storage is critical to addressing the issues associated with renewable energy sources. Technology progress and forecasting of energy generation from RE systems are presently the primary areas of research. There has been a surge of support for incorporating renewable energy into the energy mix as a priority measure for tackling energy security and climate change. The global move to renewable energy demonstrates a more powerful global response to climate change. These technologies have the potential to lower prices by up to 80%, save energy by up to 30%, and help to prevent future global warming. As a result, the countries may continue to be cost-effective while achieving long-term growth.

**Introduction**

The demand energy is increasing day by day. According to United Nations, the industrial countries have 28% of the world's population and utilise 77% of global energy production. The current global population is anticipated to grow 1.26 times to 9.7 billion by 2050. The emerging countries account for the majority of the world's population, accounting for 90% of population growth. Although wealthy countries will implement more effective energy conservation policies by 2050, their energy consumption will remain constant. People in underdeveloped countries, on the other hand, generally want to build their own energy-generating facilities (Salvarli and Salvarli, 2020).

It is projected that fossil fuel stocks would deplete naturally. As a result, alternative and renewable energies will become the most important energy resources in the near future. This condition will provide an impetus to create new jobs and build future industries. Because of rising industry and human labour, the environment is becoming increasingly contaminated. The utilisation of renewable energy, energy security, energy pricing, energy policy, renewable energy applications, and smart grid technology are all part of sustainable development. Two trends are currently related to the consumption of fossil resources and the global climate change. Renewable energy is fast emerging to both these problems (Salvarli and Salvarli, 2020).

Green renewable energy sources (RGEs) offer chances for Sustainable Development such as climate change mitigation, energy security and social and economic development. The three-pillar model, which includes the economy, ecological, and society, has been used to theorise the concept of sustainability. RGEs preserve natural capital as long as resource consumption does not reduce the prospect of a sustainable future. As part of the process of evaluating renewable green energy technologies, the contribution of RGE technologies to the goals of the three-pillar model, as well as the prioritisation of objectives in accordance with the framework of sustainable development, can both be evaluated. As a result, policymakers can utilise SD principles as frameworks to assess RGE's contribution to SD and establish appropriate economic, social, and environmental policies. SD of energy technologies has the potential to contribute significantly to the economies of countries that have a quantity and variety of renewable green energy sources such as solar, wind, hydro, geothermal, and tidal energy (Androniceanu and Sabie, 2022). As a result, governments and other authorities should encourage investment in sustainable green energy production and progress in order to provide a green energy replacement for fossil fuels and assure a more environment friendly and sustainable future. In 2019, India ranked fourth in the world for the most appealing renewable energy market. India has set an ambitious renewable energy target of 450 GW by 2030.This is the world's largest renewable energy expansion plan (Kumar and Majid, 2020).

This 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 like oil, coal, and gas, energy from uranium and bio-mass, energy from physical processes like solar radiation, wind 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 cumulative increase of 15.10% in 10 years (BP).

The largest energy consumers in the world are Norway, Iceland, The United States of America, Canada, Oman, Qatar, and Saudi Arabia. India ranked third in the world in primary energy consumption in 2017, accounting for 5.6%, of the growth rate as compared to the world average (BP). 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 sources like coal, oil, natural gas, and biomass, 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 issue and needs to be addressed on priority to meet ambitious climate mitigation goals. Hence recently, the international energy situation is going through the stage of new changes and adjustments (Nfah et al., 2007).

The recent trend of the international global energy policies is to realize the transition of the fossil energy-based system into a low-carbon energy-based system, and finally enter the era of sustainable green energy mainly based on renewable energy (Dizdaroglu, 2017).

In order to achieve a leap from the high-carbon era to the low-carbon one, International and domestic policies, market mechanisms, and legal systems should be synchronous with each other and should actively respond to energy issues to establish the best renewable energy production and consumption patterns.

**Current Achievements in Green Energy in India**

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

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

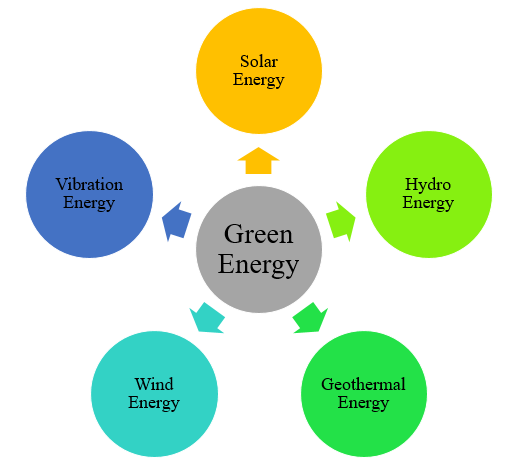
1. Centre for Wind Energy Technology has set up as a scientific and industrial research organization for wind resource assessment, equipment certification, and R&D at Chennai in Tamil Nadu.
2. Solar Energy Centre has been set up at Gurgaon in Haryana for the development of solar energy systems and devices.
3. Integrated Rural Energy Program has been implemented in 860 blocks.
4. Loan of Rs. 32,000 million has been provided so far by Indian Renewable Energy Development Agency Limited for 1600 renewable energy projects.
5. Rs. 25,000 million in direct subsidies has been given so far to beneficiaries/ users of renewable energy systems and devices, including subsidy for grid-connected renewable power projects
6. Solar Photovoltaic products of 30 MW capacity has been exported to various developed and developing countries.
7. 280 Energy Parks has been set-up for demonstration of renewable energy systems and devices in various educational institutions
8. Solar water heating systems has been installed in 7 lakh square meter collector area.
9. Over 4200 MW grid power is successfully generated from wind, small hydro, biomass and solar energy.
10. Largest solar–steam cooking system has been set up at Tirupati Tirumala Devasthanam for 15,000 persons/day.
11. 3.5 million biogas plants have been installed for cooking and lighting applications and 35 million wood stoves has been improved in rural homes.
12. 3600 remote villages/hamlets are electrified through solar energy including those in Sunderbans, Bastar, Ladakh and the North East.

**Types of Green Energy**

Renewable Energy sources are distributed over a wide geographical area and available throughout the year. These resources are not depleted and are quickly renewed through a natural process. It does not cause environmental pollution problems. The main advantage of using renewable resources is that by one-time investment one can draw energy for many decades without affecting the environment.

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 source of solar energy that provides energy to all the living organisms, flora, and fauna on earth. It is a renewable, clean, and direct energy source having the least impact on the environment. It does not produce harmful gases like carbon dioxide as a co-product and does not lead to global warming. It can be converted into useful energy directly using Parabolic Trough Systems and Solar Photovoltaic cells. Many everyday low-power consuming devices like calculators can be powered by solar energy effectively. It is a better source of energy for future generations as it last long forever.

1. **Hydro Energy**

Hydro energy is a power derived from the water cycle, which is a continuous process of falling and fast-running water to generate electricity. Hydroelectric power is major and established form of 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 one of the clean energy sources as it does not create any by-products during conversion. Hydroelectric power is a reliable, affordable, domestic, and vast source of allowing each state to produce its own energy without being reliant on international fuel sources.

1. **Geothermal Energy**

Geothermal energy is the energy generated from the radioactive decay of materials e.g. uranium inside the earth in the form of heat. The first geothermal power plant was built in Larderello. The US National Renewable Energy Laboratory (NREL) has reported that hot dry rock resources can provide around 4 million MW capacity of electricity, which is more than the electricity used by the United States today. Due to low emissions, it is considered to be an excellent 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 heating homes, offices, baths, preparing food, etc.

1. **Wind Energy**

The energy generated by the flowing wind using wind turbines is called wind energy. Wind in fact is a form of solar energy and is caused by the heating of the atmosphere by the sun, the earth’s surface irregularities, and the rotation of the earth. Wind turbines used for energy production are usually installed in large open-land farms. Empty land around wind turbines can be effectively used for agriculture and horticulture. Wind turbines do not produce any harmful atmospheric emissions that cause acid rain or greenhouse gases. It is a clean and renewable source of energy 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. Everything present in the world vibrates at some frequency some at low which are detectable and some at very high so that any human eye can’t detect them. The vibration produced in the surrounding by a large traffic on the road or a large crowd or by vibrations of tall buildings, vehicle systems, long bridges, railroads, and ocean waves can also be harvested efficiently. These vibration energies can be converted into electric energy and can be stored. This energy can be used to power many low-power electronic appliances. Usually, large vibration energy harvesting obtains 1 W to 100 kW energy (Chaturvedi and Garg, 2007). Vibration energy has been successfully used to replace the batteries in medical implants as traditional batteries contain toxic heavy metals. Vibration energy can be used to reduce the noise in the environment mainly happening in industries or due to air craft’s etc by vibration damping and vibration isolation.

**Strategies for a green sustainable energy future**

In 2019, India ranked fourth in the world for the most appealing renewable energy market. India has set an ambitious renewable energy target of 450 GW by 2030.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.

Denmark, the greenest of the five countries, is indeed considered one of the most energy secure and sustainable countries among the OECD (Sovacool and Brown, 2007) and the EU27 countries (Eurostat, 2013). Over the past 30 years, Denmark has achieved a swift decrease in its dependence on foreign energy sources from above 90% in the 1970s to practically zero and has become a net exporter of fuels and electricity (Sovacool and Tambo, 2016). At the core of Denmark’s successful approach is a commitment to energy efficiency; prolonged taxes on energy fuels, electricity, and carbon dioxide; and incentives and subsidies for Combined Heat and Power (CHP) and wind turbines (Sovacool, 2013). Denmark aims to go 100% renewable by 2050 (Sovacool, 2013; Danish Government. Energy Strategy, 2011).

Germany, one of the largest energy importers in the EU, is in the middle of an ambitious energy transition (Proskuryakova, 2018). Germany is considered the most successful country in the promotion of renewable energy (Liu, 2018). In 2014, Germans had the best energy security performance among the EU countries due to the reduction of shares of oil and coal and the increase of diversification of energy imports (Matsumoto et al., 2018). The German energy transition (Energiewende) is considered the best-known renewable-based national energy policy (Harjanne and Korhonen, 2018). The Energiewende aims to reduce the greenhouse gas emissions by 80–95% in 2050 (compared to 1990), increase the renewable share of final energy to at least 60%, and increase the renewable share of electricity demands to 80% (Hansen et al., 2019). Germany also intends to complete a nuclear phase-out by 2022 (Energiewende, 2019), a debatable move in the opinion of the authors of this chapter. Hansen et al. (2019) presented a strategy for achieving 100% renewable energy for the entire German energy system and maintained that this scenario is possible with the introduction of key policies.

China is the world’s largest energy consumer (British Petroleum, 2019), the biggest emitter of greenhouse gases (Yang et al., 2050), the fifth largest producer of oil, the seventh largest producer of natural gas, and the largest producer of coal (Zhang et al., 2017; Wang et al., 2018). China aims to cut the share of coal in its power mix, but coal consumption is growing, and more coal-fired power projects are under development. In fact, the percentage of fossil fuels in China’s total primary energy demand is expected to exceed 90%, with coal being the main fuel source (Matsumoto and Andriosopoulos, 2016). At the same time, China possesses the biggest amount of hydro resources globally, with a total theoretical hydropower potential of 694 GW (Zhang et al., 2017). By the end of 2015, China’s hydro power exceeded 25% of the world’s nonhydro renewable capacity, being 63.1 and 117.0% higher than the United States and Germany, respectively (Yang et al., 2016). Until the end of 2017, China’s installed generation capacity of renewable energy was 635 million kW, which constituted 35.7% of the total installed capacity of electric power (Liu, 2019).

Russia owns one of the largest fossil fuel resource stocks in the world and is the world’s fourth largest emitter (after China, the United States, and India). Russia has the second largest natural gas reserves and production in the world (after the United States) (British Petroleum, 2019), an endowment that allows it to play a major geopolitical role, for example, as the major supplier of natural gas to most European countries. At the same time, Russia is a country of vast geographic size and variability in terrain and climate, giving it the potential to develop virtually any kind of renewable energy (International Energy Agency, 2003). Russia is accelerating the deployment of solar and wind through auctions to create benefits for employment, science, technology, and energy security for isolated populations (Gielen et al., 2019). Although the country was an early leader in the technology of renewables, Russia’s strategy revolves around the development of fossil fuels and nuclear energy (Lanshina et al., 2018). In 2013, the Russian government launched a Capacity-Based Renewable Energy Support Scheme (CRESS) (Smeets, 2017). Per CRESS implementation, a maximum installed capacity of solar, wind, and small hydro projects each year could obtain financial guarantees on Russia’s wholesale electricity market (Boute, 2012). The energy security of Russia will remain linked to its natural gas deposits, while its ability to continue to supply it to the European and other markets will determine its position as an energy hegemon.

Renewable energy is more suited to distributed production, making it more secure than the fossil fuel paradigm. Renewable energy will help usher in an era of energy democracy, in which a network of decentralised prosumer systems will replace large-scale power generation.

**Energy security, sustainability challenge and expectations**

Recently, there has been a surge of support for incorporating renewable energy into the energy mix as a priority measure for tackling 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) mandates countries to implement their nationally defined contributions and gradually increase their goals in order to keep global mean temperature rise below 2°C (Rogelj et al., 2016). Renewable energy naturally takes front stage as new energy options must be less polluting than the sources they replace. Goldthau and Sovacool (2012) discussed three major energy challenges: energy security, energy justice, and a low-carbon transition. They emphasised the importance of considering energy security as a democratic issue, equity as a key part of accessibility, and global climate change as an important aspect of acceptability.

Sovacool and Rafey (2011) proposed a similar set of four dimensions of energy security: (1) availability, that is, diversifying fuels, preparing for disruption recovery, and minimising reliance on foreign supplies; (2) affordability, that is, providing affordable energy services and minimising price volatility; and (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.

Sovacool and Brown (2009) considered energy security to be defined according to the following criteria (i.e., dimensions), which may be measured with corresponding metrics: availability, measured by oil and natural gas import dependence and availability of alternative fuels; affordability, measured by retail electricity, gasoline, and petrol prices; energy and economic efficiency, measured by energy intensity, electricity use per capita, and average fuel economy of passenger vehicles; and environmental stewardship, measured by sulfur dioxide (SO2) and carbon dioxide (CO2) emissions.

The global transition to renewable energy shows a more robust global response to the threat of climate change. Most European countries have enacted policies that will have substantial social, political, and economic ramifications. This shift to low-carbon energy is likely to change the geopolitical landscape, altering the dynamics between producer and consumer countries (International Renewable Energy Agency, 2009) and establishing 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 from fossil fuels to renewable (and nuclear) 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). Among the technologies that have aided the expansion of renewables, power electronics has been a key enabler. The electronic converters enabled the coupling of renewable energy producers to legacy power systems, as shown schematically in Fig. 1, and enhanced energy harvesting efficiency through 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 undergone significant evolution over the years. A 50kW wind turbine was regarded enormous in the 1980s, although today's standard wind turbine is rated at 2 to 3 MW. The necessity for lower energy costs drove much of the development for larger units, while performance improvements, particularly in terms of grid connection, imposed some of the electric technology upgrades.

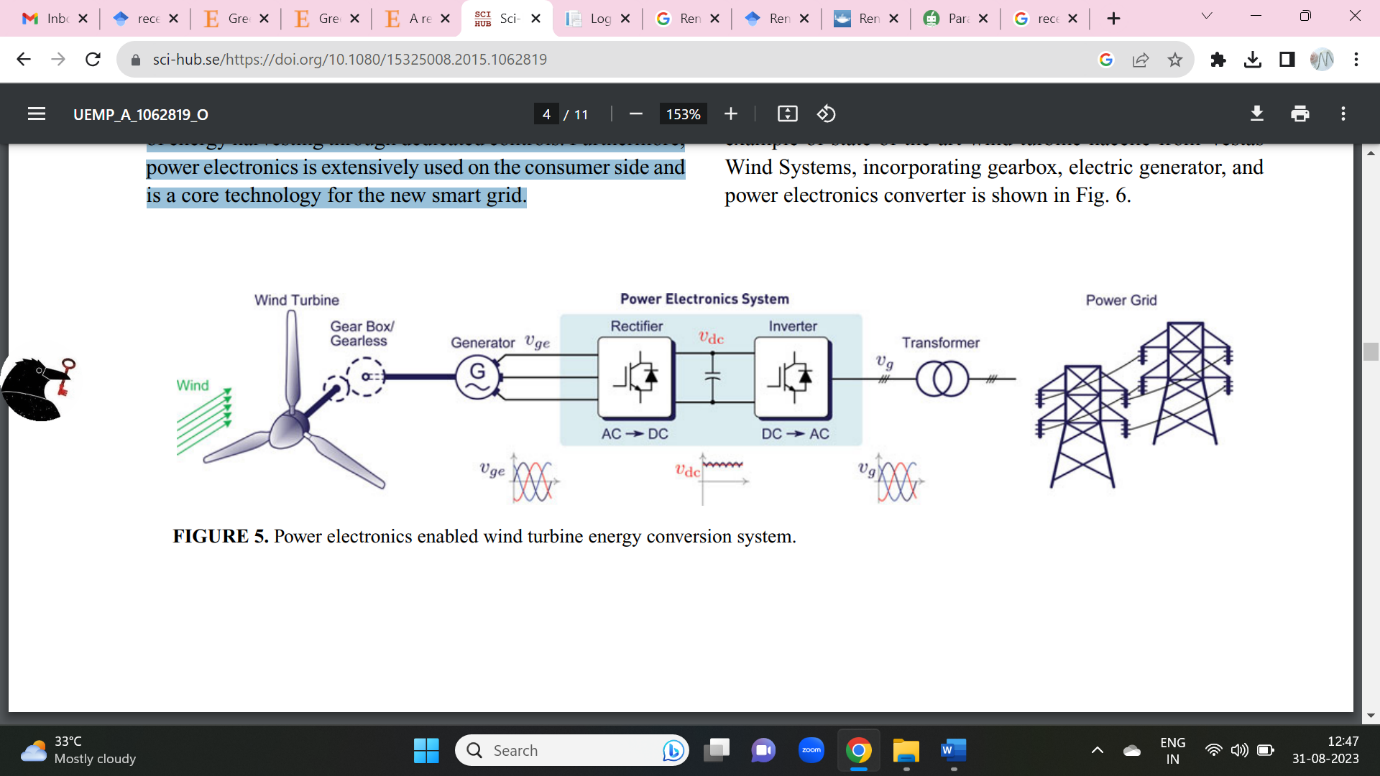


Figure 1: Power electronics enabled wind turbine energy conversion system (Source: Blaabjerg and Ionel, 2015)

Grid-connected photovoltaic (PV) systems, such as the one shown schematically in Fig. 2, include a power electronics DC/DC converter that assures maximum sun energy harvesting via maximum power point tracking (MPPT) regulation and a DC/AC converter for grid hookup. PV systems have grown in popularity not just for multi-MW utility scale power plants/farms, but also for roof top installations on business and residential buildings with ratings as low as hundreds of watts.

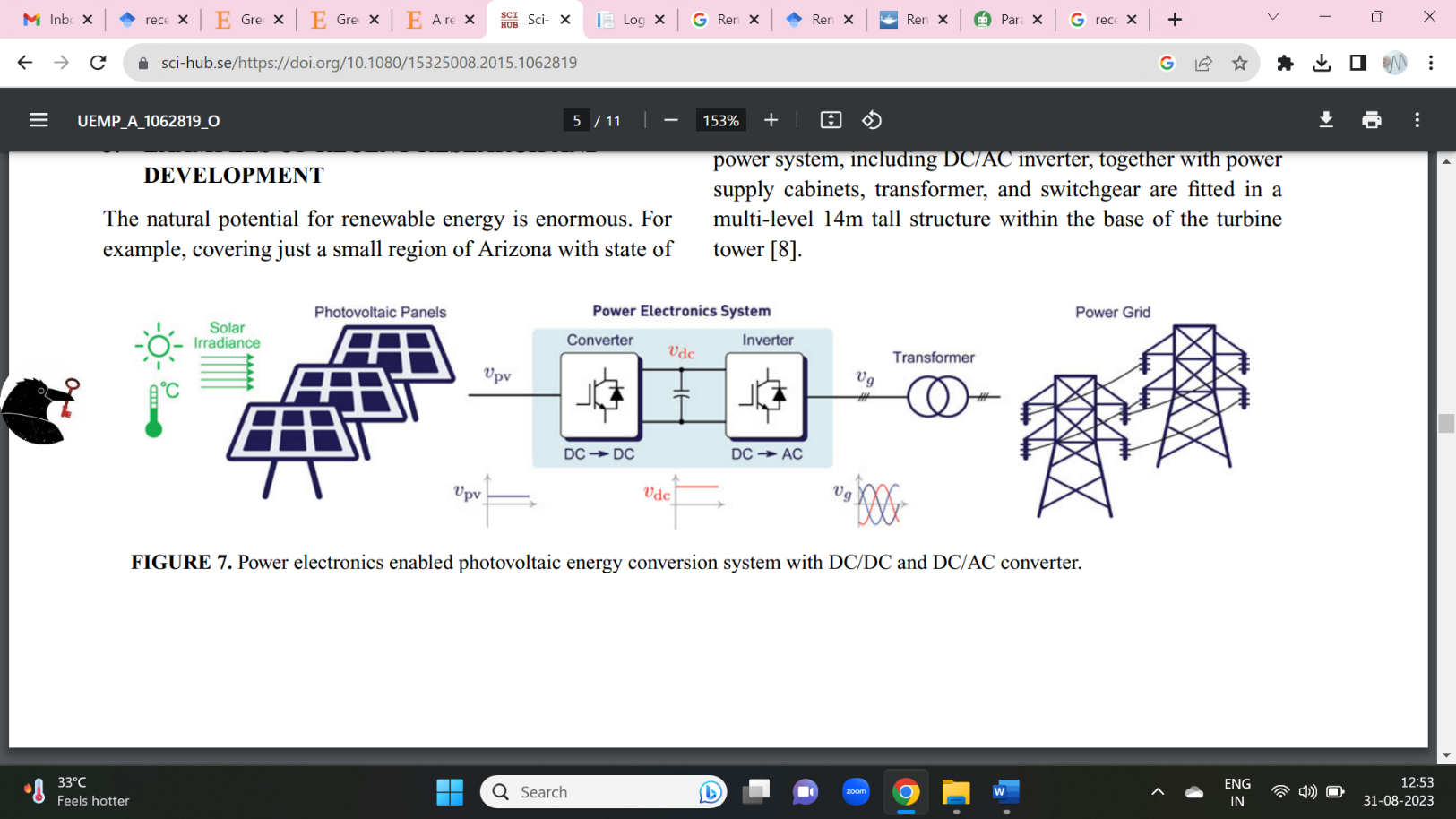


Figure 2: Power electronics enabled photovoltaic energy conversion system with DC/DC and DC/AC converter (Source: Blaabjerg and Ionel, 2015)

SASDAC system has four main components (1) desiccant dehumidifier, (2) sensible heat exchanger, (3) cooling unit, and (4) solar regeneration heat source. Main component of solid desiccant system basic working principle is elaborated below and pictorially presented in Figure 2. During process at stage (1–2) hot and humid air from outside enters in system and passed through desiccant wheel and becomes hot and dry as desiccant wheel absorbs moisture. This hot and dry air passes through heat recovery wheel (2–3) where heat exchange between return and primary air takes place. Then this air passes through humidifier at stage (3–5) moisture added to obtain desired cooling effect and enters in conditioned space. At stage (6–7), air returns from room and passed through humidifier where moisture added to reduce temperature. This moist air passes through heat recovery wheel at stage (7–8) and becomes hot. This hot air passes through heating coils at stage (8–10) and desiccant material regenerated by increasing the temperature using solar energy.

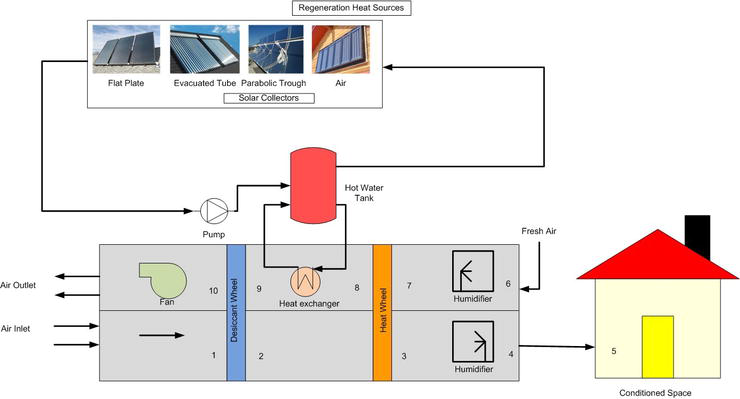


Figure: Working principle of solar-assisted solid desiccant cooling system [20].

Beside from the previously described technologies, methods, and devices, a special mention should be made of the significant ongoing efforts for integrating renewables into the power and energy system, where a correct balance between production and consumption occurs. Controlling the complete energy system as a whole, comprising not just the electrical power system, but also thermal energy and water flow, is an ongoing problem for science and society. Smart-grid functions and facilities, such as 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 usage and are on the rise around the world. Environmental pollution is unavoidable in this situation, and renewable energy plants make no direct contribution. Longer term, if investments in renewable technology continue, renewables have the potential to contribute significantly to energy needs.

Furthermore, various technologies include biofuels, and fuel cells can contribute to the heat, transportation, and energy markets. In 2023, the share of fossil fuels in total primary energy supply is predicted to be around 81%. Renewable energy will account for approximately 30% of global energy structure by 2050.

Many energy-efficient enabling technologies are used in power plants, buildings, industrial facilities, and transportation systems to consume less and cleaner energy. These technologies have the potential to reduce prices by up to 80%, save energy by up to 30%, and assist to halt global warming in the future. As a result, the countries may remain cost-effective while making long-term growth. Marketing renewable energy can also be characterised as the skill of comprehending consumers' wants and needs.

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