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Advancements in Renewable Energy: A Sustainable Solution for Global Energy Demands

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ABSTRACT

Energy is the ability to perform work, and in today's world, the need for sustainable energy solutions is more crucial than ever. Renewable energy sources, including solar, wind, and hydro, provide an eco-friendly alternative to conventional fossil fuels. These sources not only help conserve energy but also contribute to a cleaner environment by reducing dependence on non-renewable resources. Over the past few decades, environmental challenges have intensified, making the adoption of renewable energy technologies more necessary than ever. As the global population continues to grow, energy consumption is also increasing, underscoring the urgent need for alternative energy solutions. This study examines the role of various renewable energy sources and their relationship with a country's economic growth, as measured by real GDP per capita. India, in particular, has emerged as the fourth most attractive renewable energy market globally. The Indian government has been actively promoting sustainable energy initiatives, launching large-scale projects to accelerate the shift toward cleaner energy. The relationship between renewable energy and sustainable development, as well as future opportunities in this field, is discussed in detail. The findings suggest that factors such as renewable energy production, energy efficiency, economic growth, and carbon emissions have a significant influence on renewable energy consumption. To further promote the adoption of clean energy, the study recommends increasing investment in renewable energy production, enhancing energy efficiency, and advancing green technologies.

Keywords: renewable energy, solar energy, wind energy and biomass energy

INTRODUCTION

The demand for energy sources increases in tandem with population growth. The quantity of energy needed varies from nation to nation worldwide. In comparison to emerging countries, wealthy nations require more energy. Considering renewable energy sources (RES) are numerous on the earth, free of contaminants, reasonably priced and easily accessible, they are currently the source of the biggest concern among individuals. Utilising natural power reserves, such as sunlight, wind, marine energy, biomass, and minerals, is essential for technologies related to renewable energy. The

implementation of renewable energies for equitable growth has been the primary concern of the public for the past 20 years. Establishing sustainable growth is influenced by many variables. Environmental degradation resulting from the use of sustainable energy sources is a significant concern. Developing renewable energy sources is the primary source of potential. The primary advantages of using RES consist of enhanced environmental and wellness energy, increased energy safety, progress in society and the economy, and a reduction in global warming (Dey et al., 2022). Renewable energy solutions, which are renewable and pollution-free, have been established to protect the planet and prevent potential environmental hazards. Carbon-based fuels, radioactive materials, and green energy resources are the three basic types of energy sources. Renewable energy sources could have a significant impact on the future development of the globe. By producing virtually no greenhouse gases and air pollutants, renewable energy sources can generate energy that is free from these pollutants. It is a dependable, reasonably priced, and ecologically friendly method for harvesting localised renewable energy to meet modest and regional energy demands (Hussain et al., 2017). The consumption of fossil fuels, which results in the depletion of non-renewable resources and severe environmental effects, including global warming and climate change, has increased exponentially due to population growth and technological advancements. Consequently, scientists worldwide are seeking novel approaches to reduce or eliminate the use of fossil fuels. Three separate approaches can be utilized in order to minimize the use of fossil fuels and, consequently, their impact on global warming: (a) increasing the efficiency of traditional electricity the process devices/systems via waste heat recovery; (b) creating environmentally friendly energy conversion devices like fuel cells; and (c) moving toward renewable energy sources that are derived from the environment and have negligible adverse environmental effects (Sayed et al., 2023). Renewable resources are materials that provide energy and are constantly replenished by nature. They can come from the sun directly (in the form of heat, photochemical, and photoelectric power), informally (such as wind energy, hydroelectric power, and solar-driven energy stored in biomass), or from additional natural ecological movements and processes (including geothermal power and tidal energy). Energy sources derived from fossil fuels and by-products of fossil materials, as well as scrap materials from non-organic sources, are not considered renewable energy. Renewable energy sources are summarised in Figure 1. Utilisable types of energy, such as fuels, heat, and electricity, are produced from these natural energy resources using renewable energy systems (Ellabban et al., 2014). To resolve the present ecological crisis, Various renewable energy sources, including solar, wind, hydro, biomass, geothermal, and hydrogen, have been established to produce energy. As the community's commitment to environmental cleanliness grows, renewable energy

is gaining increasing attention due to its ecologically favourable qualities and capacity to produce electricity with virtually zero emissions of air pollution. Renewable energy has both economic and ecological significance. Because it utilises natural, renewable energies to generate power, it reduces the overall production cost, which benefits the economy (Ang et al., 2022).

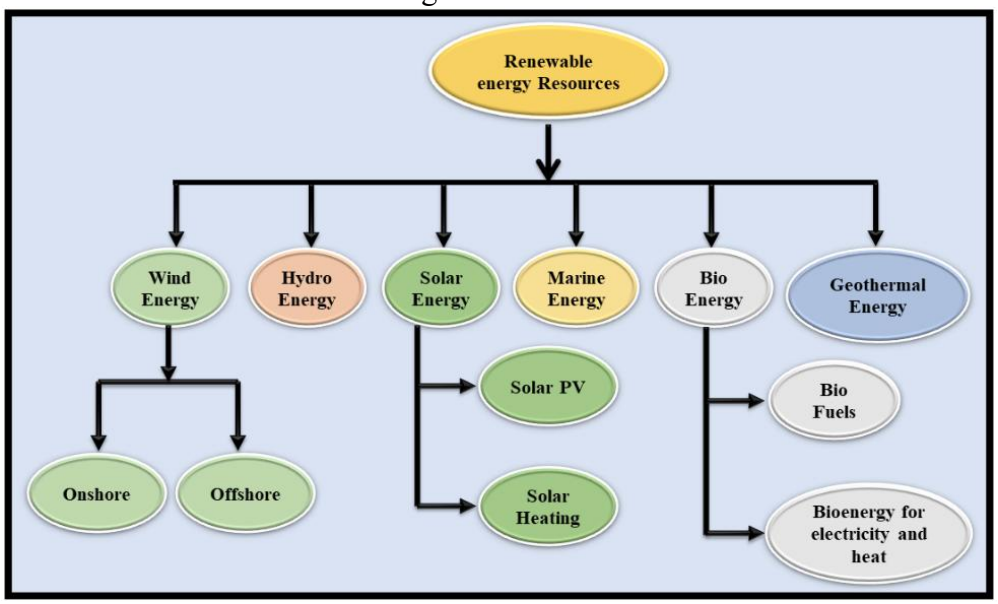

Figure 1. Overview of renewable energy sources.

DESCRIPTION OF RENEWABLE ENERGY SOURCES

Wind Energy

Wind energy is a form of energy that harnesses the kinetic energy of turbulent air. By converting kinetic energy into electrical energy, wind farms, along with additional wind transformation devices, make the process feasible. Wind energy can be operated directly in the form of mechanical power or indirectly as electrical power. A wind turbine is a crucial component of a wind power transformation system (WECS), which converts wind power into electrical power. The three primary components of WECS are (a) gear trains, which function in accordance with the wind's speed, (b) rectifiers, inverters, and control panels, which regulate the windmill's general execution, and (c) filters and transformers, which are employed to distribute the electrical energy produced to the grid efficiently (Figure 2).

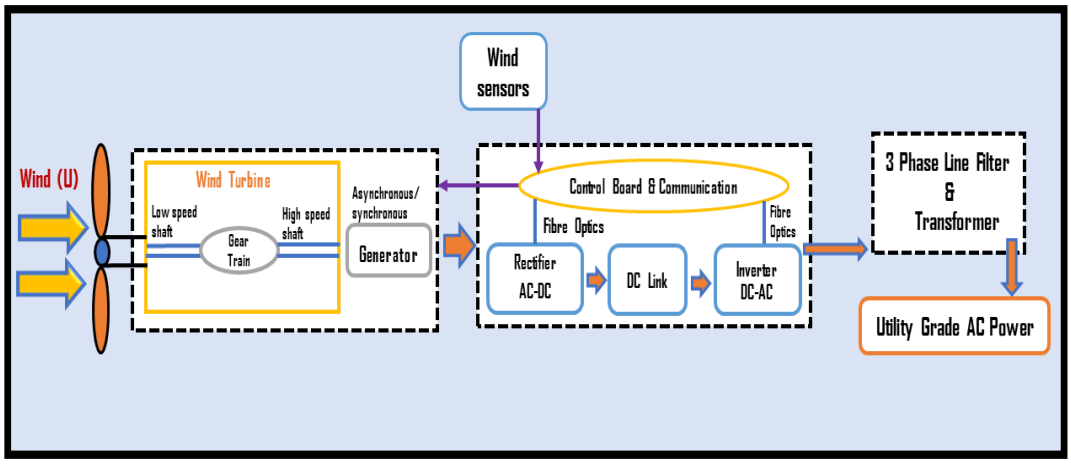

Figure 2. Wind turbine setups for generating electrical power.

To improve wind turbines in conjunction with additional engines, which are the primary components of the wind energy conversion system, researchers are working to enhance the efficiency of wind power conversion technology. To turn, a customised windmill blade uses the kinetic energy of the wind. The shaft facilitates the passage of mechanical energy from the rotating blades to the engine shaft. This dynamic energy is subsequently converted into electrical power via the generator. A converter can route this electrical energy to the distribution system or to a separate consumer. The efficient production of electrical power from wind energy depends on the entire control of WECS. Various WECS components and subsystems can use control mechanisms. The WECS control system is primarily composed of three elements (Jaiswal et al., 2022).

Biomass energy

The term "biomass" describes all biological material found in the ecosystem, including materials derived from plants and animals, as well as those produced by their natural or synthetic alteration. Biofuels are made from biomass, including nuts, wood shavings, and pellets, as well as fruit stones such as avocado and olive pits. Sliced and chopped firewood is the most minimally refined among these and is typically used straight in household heaters and burners. The chips, whose size varies according to the production or conversion procedure they have endured, are made from the broken biomass originating from agricultural and forest resources. Lastly, pellets, the most complex form of biofuel, are produced by pressing biofuels and binders into compact cylinders that measure between 6 and 12 mm in diameter and 10 to 30 mm in length. Particularly, pellets are utilised in fuels with volume ratios. Although their usage is less common compared to other conventional fuels, such as fuelwood, wood chippings, and pellets, fruit stones, seeds, and shells also constitute a growing amount of pure biofuel. In fact, research has demonstrated that peanut shells and mango stones. The Higher Heating Value (HHV) of the sunflower seed

husk is comparable to that of other commercially accessible biofuels, indicating its significant energy potential. This characteristic, along with the increasing global production of these waste products, makes them particularly attractive for generating thermal energy and reducing CO_2 emissions. Wood, sawdust, straw, seed waste, manure, paper waste, household trash, wastewater, and other items all contain biomass (Perea et al., 2019). Figure 3 shows the types of biomass. Biomass examples and their energy-related applications:

- Wood and wood analysis waste is burned to heat structures, to provide heat used in industry, and to produce power.
- Waste products and crops-burned as fuel or transformed into biofuel liquids.
- Garbage containing wood, yard waste, and food scraps is burned in power stations to produce electricity or converted into biogas in landfills.
- Human waste and animal manure are transformed into biogas that can be utilised as fuel.

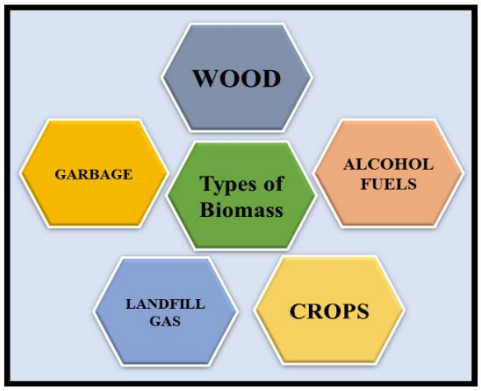

Figure 3. Types of Biomass

The combustion of biomass provides a method for releasing its energy and converting it into various forms of energy. Automotive fuels, such as biodiesel and ethanol, as well as various usable energy sources like methane gas, can be produced from biomass. Methane gas is a consequence of landfill gas, also known as biogas, which is produced when human, agricultural, and trash waste is decomposed in digesters or other dedicated containers. Corn and sugarcane are among the crops that undergo fermentation in order to produce fuel ethanol for automobiles. Animal- and plant-based oils are used to produce biodiesel, a type of fuel for transportation (Zohuri, 2018). The most significant contributor to economic growth and well-being is biomass waste, which is relatively abundant in many nations. Using biomass waste will not only provide energy but also preserve the environment. Along with improving local economies and offering work opportunities, it will also reduce the likelihood of forest fires and provide a raw material for energy generation through waste collection. The process of converting biomass waste into

energy has garnered significant interest from scientists lately. An important first step is to assess biomass as an initial resource for potential energy production, according to the findings of multiple researchers in the energy sector. Table 1 displays several earlier research projects on biomass waste. The process of converting biomass waste into gas and liquid fuels is known as bioethanol and biogas production. Waste conversion processes utilise bacteria, microbes, and enzymes. Biochemical techniques can transform biomass waste, including animal, agricultural, and municipal solid waste, into valuable goods. Biological systems can produce the conversion of many chemicals. Natural biomass, which contains lignin, cellulose, and hemicellulose, can be biochemically converted to produce solid, gaseous, and liquid molecules (Erdiwansyah et al., 2024).

Table 1. The origins of biomass waste employed to make fuel have been the subject of several recent research studies.

Type of Biomass	**Source of Biomass**	**Operating Parameters**	**Type of Analysis**	**Ref.**
Almond shell	Residues	Temp.: 500 °C, Retention time: 2 hours	Pyrolysis of catalytic	Din et al., 2023
Citrus Limetta	Waste from orange juice	Temp.: 550 °C, Retention time: 2 hours	Pyrolysis of catalytic	Muhammad et al., 2023
Waste of sesame	Harvest time	Temp.: 450 °C, Retention time: 1.5 hours	Pyrolysis of catalytic	Nizat et al., 2023
Peanut Shell	Residues	Temp.: 500 °C, Retention time: 2 hours	Pyrolysis	Islam et al., 2022

Geothermal energy

Conducting field research to assess these resources and their applicability is challenging due to the relative infancy of geothermal energy harvesting compared to other energy sources. The potential of geothermal energy has only been briefly discussed in a few studies, which have not provided sufficient detail to describe its potential global uses and procedures. Considering the sharp

rise in the world's energy demand, this would help meet the enormous energy demands of the future. Thus, an accurate evaluation of possible geothermal resources is necessary, as is an approach for utilising them efficiently. Geothermal energy is one of the most potent, organic, and sustainable energy sources in the world (Islam et al., 2022). Geothermal energy has emerged as a viable alternative to fossil fuels due to its environmentally friendly and renewable nature. In contrast to annual renewable energy sources that rely on specific periods and circumstances, geothermal power is a non-intermittent, renewable energy source (Hamlehdar et al., 2024). Geothermal energy (GE), a non-carbon renewable energy source derived from the flow of heat from the Earth's core, is a dependable, plentiful, and promising energy source. Currently, electricity is produced using profound geothermal power sources based on hot water and steam. In contrast, short geothermal heat pump technologies provide heating and cooling without using the heat that exists in the earth. Fluid administration is one environmental issue that needs to be addressed, even though GE has a lesser impact on the environment than traditional fossil fuels. Additionally, concerns during the execution of specific initiatives have prompted the development of particular structures for evaluating the sustainability of GE projects (Soltani et al., 2021). Figure 4 displays the primary parameters, including benefits and drawbacks, as well as potential geothermal energy system deployments. GE is typically regarded as a low-quality source, so to meet requests, a different energy source is required (Mahmoud et al., 2021).

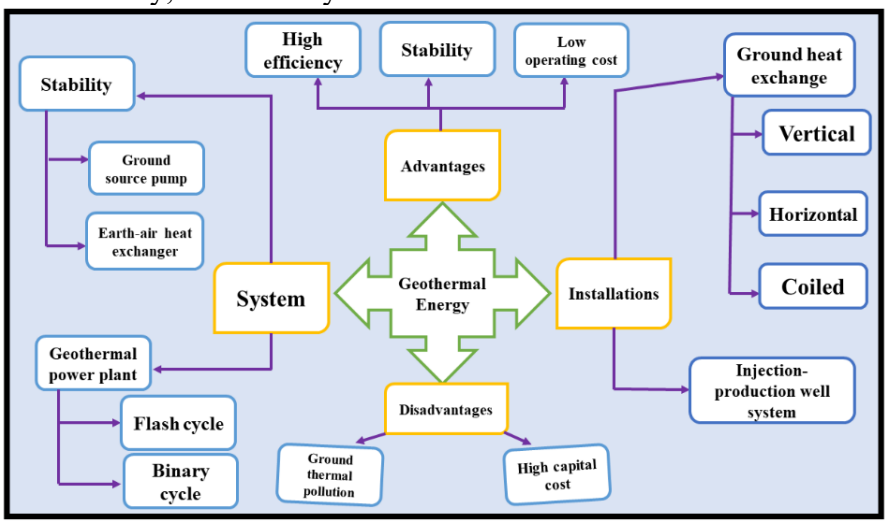

Figure 4. Properties and Applications of Geothermal Energy Systems.

Solar Energy

Solar energy is one of the most common natural resources on Earth among renewable energy sources. Solar energy is produced by using photovoltaic (PV) devices to transform sunlight into electricity or heat. Solar energy is renewable, discrete, endless, reliable, durable, and easy to operate. Due to these

benefits, solar energy is a viable option for meeting the world's growing electrical needs, which stem from both infrastructure development and population growth (Ludin et al., 2018).

Photovoltaic solar energy

The photovoltaic (PV) industry is one of the fastest-growing industries in the world. To keep up with this growth, innovations have been made in the areas of instrument development, manufacturing methods, material usage, the amount of energy needed for producing these substances, and new ideas to improve the cells' overall effectiveness. The term "photovoltaic solar energy" refers to electricity generated entirely through the transformation of solar energy. The photovoltaic impact, initially noticed by Becquerel in 1839, is responsible for converting solar energy into electrical power. This phenomenon happens in semiconductors, which are materials with two energy bands: the valence band, where electrons are permitted, and the conduction band, which is entirely "empty." See Fig. 5 for an illustration of this. The second most abundant naturally occurring element on Earth, silicon, is a semiconductor material that is employed more frequently. Its atoms are distinguished by their four electrons, which form a crystalline structure by connecting to their counterparts. The photovoltaic effect occurs when sunlight provides the outermost electron with sufficient energy to migrate from the material's valence band to its conduction band, producing electricity in the process. As in silicon, particularly, electrons must have 1.12 eV (electron volts) in order to surpass the GAP. It is also said that a significant portion of the sun's spectrum must be available to be absorbed by the semiconductor material (Sampaio & Gonzales, 2017).

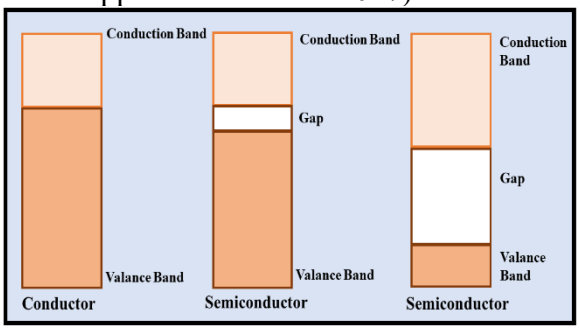

Figure 5. illustrates the valence band, band gap (GAP), and conduction band for different materials: insulators, conductors, and semiconductors.

When light hits a PN junction (an N-type semiconductor region towards the sun), incoming photons with energy equal to the semiconductor material's energy gap are captured, forming electrons and holes as charge carriers. The fundamental potential causes these electrons and holes to be divided.

They detect this product's voltage. This DC voltage is converted into an AC voltage for usage in industries or to power different household devices (Dambhare et al., 2021).

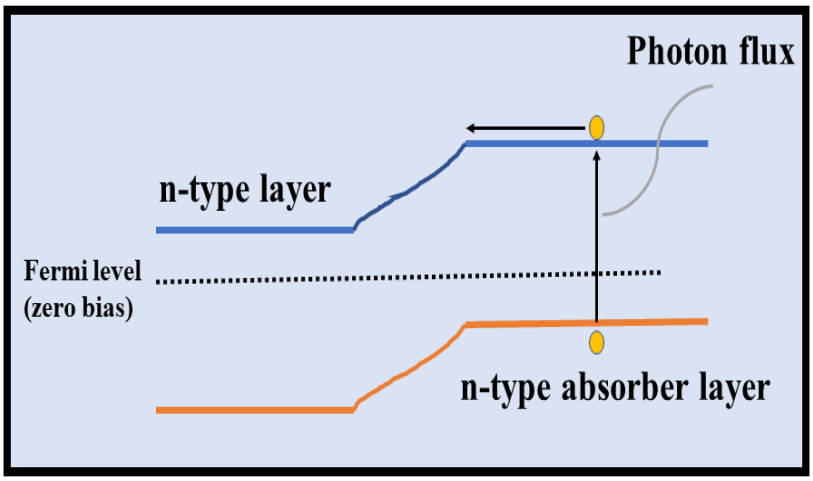

Figure 6. A PN junction absorbs an incident photon, leading to energy transfer

Solar thermal plates

Solar power plates are a method of generating thermal energy to heat water, utilising solar energy as a form of photovoltaic power. There are two categories of solar energy. Two types of solar energy exist: passive and active. Employing the sun's heat both directly and indirectly is known as passive solar energy. Utilising solar radiation to generate electrical energy is known as active solar energy (Alrikabi, 2014). Typically, solar panels and concentrators are utilised in households, businesses, or industrial facilities to collect, store, and utilise solar energy for heating water or air.

The transformation of solar radiation into mechanical power is illustrated schematically in Fig. 7. The position, collector category, working fluid, and system size are variables that must be considered for unique applications, as well as the necessary storage quantity and the storage quantity required to calculate the load and design the heat exchanger. The air or water is heated using solar panels as the heat transfer medium in order to improve the efficiency of solar energy systems. However, every collection is intended for a specific use (Mekhilef et. al., 2011).

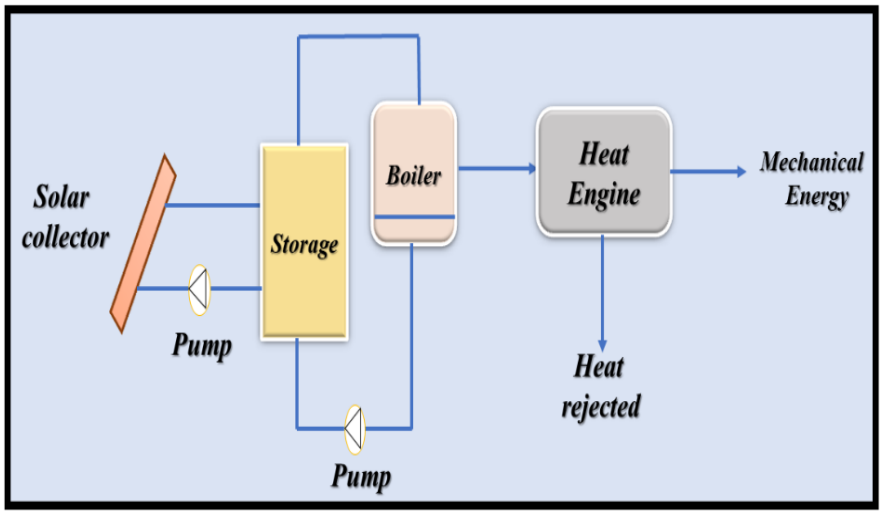

Figure 7. Diagram of a solar-thermal energy conversion system.

Hydropower energy

A key element in the production of energy and the replacement of fossil fuels is hydrogen energy. It is becoming an increasingly popular power source for the future. This form of energy is trivial to operate and safe. Coal, natural gas, and oil have been utilised to generate hydrogen gas. Using the processes of combustion and rapid burning, hydrogen gas can be generated from biomass. Hydrogen innovations are currently undergoing cycles of increased anticipation, followed by disappointment. It is anticipated that hydrogen will play a crucial role as an energy carrier in the development of global energy systems. As the supply of fossil fuels increases, so does environmental damage, and hydrogen is likely to surpass all other molecular energy carriers (Dey et al., 2022). Energy storage using hydrogen Systems is gaining traction as a reasonably priced means of storing RE for commerce and transport. Hydrogen energy storage system develops a 100% RE system that serves as a foundation for the hydrogen economy. In almost every area of the energy system, including transportation and generation, the case for a hydrogen economy is growing stronger. The transition to a low-carbon energy system appears to be achievable through the development of a hydrogen economy. Hydrogen as an efficient source of power is not a novel idea (Arsad et al., 2022). The distribution and storage of hydrogen energy are both present and emerging problems. Transportation and preservation activities are equally crucial as manufacturing procedures. In the hydrogen economy, these procedures are crucial. Hydrogen energy storage is intended to be effective and safe, and it can be utilised at any time and anywhere. When hydrogen is pure, it has an elevated gravimetric energy content and a small volumetric energy density. Hydrogen can be stored in three different ways. Solid-state storage techniques, heated gas physical storage, and frozen liquid

hydrogen physical preservation are all available (Tarhan et al., 2021).

Marine Energy

A world that is becoming progressively more populated along the coasts, with warming temperatures, the demand for a healthy atmosphere, and occasionally economic factors, is the primary factor fueling the ongoing and expanding interest in renewable energy technology. Approximately 71% of the Earth's surface is composed of water, which serves as an immense reservoir of energy. According to estimates, the world's marine renewable energy (MRE) reserves are more abundant than our current and anticipated future energy requirements. MRE has immense potential to grow and is likely to be essential to the sustainable energy structure of the environment in the future. MRE might involve ocean renewable energy, offshore wind power, and offshore solar energy. The preservation of energy is an essential component of MRE devices today. However, marine renewable energy storage equipment is still in its early stages due to the particular conditions of the ocean and the slower rate of MRE innovation (Wang et al., 2019). Global interest in harnessing marine energy (ME) from storms, waves, or oceanic currents as a renewable power source is high, but little is known about the potential hazards and benefits. Throughout their establishment, existence, or use, ME gadgets (stressors) can communicate with and have an impact on biodiversity and environmental components (receptors). The impact of the environment must be evaluated in order to produce ME. However, it is challenging to detect stressor-receptor correlations accurately due to the small number of operational devices that are obtainable for observation. Observation of ME equipment has consistently produced significant data. Since environmental assessments are expensive and time-consuming, there is an excellent demand for targeted and efficient monitoring. By creating evaluation and monitoring requirements, regulators can expedite the approval (consenting) of future instrument installation, cut down on the time and resources required for the development of new projects, and make it easier to compare innovations (Buenau et al., 2022).

RENEWABLE ENERGY AND SUSTAINABLE GROWTH

The effects of energy from renewable sources on revenue generation and human growth are directly related to environmental sustainability. In addition to mitigating the adverse effects on the environment and human health, clean energy sources offer opportunities for enhanced energy security, economic growth, and increased access to energy. Figure 8 illustrates the way renewable energy sources can contribute to a sustainable future.

Energy access

An important component of social and economic growth is energy. The term “energy access” refers to the capacity to consume energy, which can include electrical power, LPG, charcoal, or another type of energy. Similarly, the “term access to energy

services" has been used to refer to "the capacity to utilize energy solutions, which are defined as "the support that energy-consuming equipment offers, such as illumination, heating for making and space heating, power for transportation, water delivery, crushing, and many more things that fuels, power, and mechanical strength make attainable. Frequently, there is a distinction made between household access, where one can use electrical power in the home, and grid access, which may be defined as part of the "contact rate," which is just the percentage of a region that is served by the grid, independent of the number of households served. The affordability of energy in places not served by the grid is frequently referred to as "access to electricity." In this instance, renewable sources of energy or a decentralised, isolated generator provide the electricity (Brew et al., 2010).

Energy security

The concept of energy security is frequently employed, but its exact meaning is subject to debate. However, the assumption that there is a constant source of energy, which is essential for the operation of a currency, is the foundation of concerns about energy security. Since economic expansion and energy usage are interdependent, obtaining access to a steady energy source is crucial for both political and economic reasons, presenting developed and emerging countries alike with financial and technical challenges. Extended disruption would result in significant issues for the fundamental functions and economies of most societies. Globally, sources of clean energy are equally dispersed, and they are generally exchanged infrequently on the market compared to fossil fuels. Energy exports decrease, the range of available alternatives diversifies, and a society's susceptibility to price instability is reduced, thereby improving global energy security through the use of renewable energy. Moreover, the deployment of renewable energy might help improve the dependability of energy services, particularly in regions that frequently experience inadequate grid access. In addition to effective administration and system structure, an assortment of power sources can contribute to increased security (Owusu & Asumadu 2016).

Social and economic growth

With a proven connection between revenue growth and increased energy use, the energy industry has often been recognised as a crucial factor in financial progress. Economic expansion has been the primary driver of increasing energy demand in recent decades, and a positive correlation exists between annual income and per capita energy usage worldwide. Consequently, it generates jobs; a 2008 report on renewable energy technology indicated that they created over 2.3 million jobs globally and enhanced gender equality, educational achievement, and sustainability.

Climate change mitigation and reduction of environmental and health impacts

The implementation of renewable energies in energy production

contributes to reducing greenhouse gas emissions, which helps prevent global warming, as well as the medical and ecological concerns associated with pollution from energy sources like fossil fuels. The impact of climate change has become a significant worldwide concern that affects innovation, the environment, energy, and finances. Global warming is expected to rise more than 2 degrees Celsius beyond the age of civilisation unless additional steps are taken to limit global greenhouse gas emissions. The depth of the ocean and the global environment would be significantly impacted by this growth, which would also affect the socioeconomic development of nations worldwide. As a result, it is essential to determine strategies for managing greenhouse gas emissions in the leading generating nations, which are governed by both national and international agreements (Zheng et al., 2019).

CONCLUSION

Energy is at the core of issues related to combating poverty and equitable growth. Almost every facet of the economy and society is impacted, including water, agriculture, earnings, population, education, health, employment, and challenges related to gender. Natural resources and the environment are directly harmed by the current trends in generating and utilising energy on an individual, local, and global scale. Energy is not an aim in itself; rather, it is a crucial first step toward accomplishing the objectives of the three cornerstones of sustainable development: environmental preservation, economic growth, and social equality. A wide range of fuel sources and applications is encompassed by renewable energy. The cost of various renewable energy technologies varies widely, as does the application of each one. Specific renewable energy sources, like biomass, are readily available and extensively utilised. Individuals who are interested in geothermal energy are often employed in areas where it is available. Some renewable energy sources, like wind and solar, have much unrealised potential but are not yet widely utilised.

REFERENCES

Dey, S., Sreenivasulu, A., Veerendra, G. T. N., Rao, K. V., & Babu, P. S. S. A. (2022). Renewable energy present status and future potentials in India: An overview. *Innovation and Green Development, 1*, 100006. https://doi.org/10.1016/j.igd.2022.100006

Hussain, A., Arif, S. M., & Aslam, M. (2017). Emerging renewable and sustainable energy technologies: State of the art. *Renewable and Sustainable Energy Reviews, 71*, 12–28. https://doi.org/10.1016/j.rser.2016.12.033

Sayed, E. T., Olabi, A. G., Alami, A. H., Radwan, A., Mdallal, A., Rezk, A., & Abdelkareem, M. A. (2023). Renewable energy and energy storage systems. *Energies, 16*(3), 1415. https://doi.org/10.3390/en16031415

Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources:

Current status, future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews, 39*, 748–764. https://doi.org/10.1016/j.rser.2014.07.113

Ang, T.-Z., Salem, M., Kamarol, M., Das, H. S., Nazari, M. A., & Prabaharan, N. (2022). A comprehensive study of renewable energy sources: Classifications, challenges and suggestions. *Energy Strategy Reviews, 43*, 100939. https://doi.org/10.1016/j.esr.2022.100939

Jaiswal, K. K., Chowdhury, C. R., Yadav, D., Verma, R., Dutta, S., Jaiswal, K. S., & Karuppasamy, K. S. K. (2022). Renewable and sustainable clean energy development and impact on social, economic, and environmental health. *Energy Nexus, 7*, 100118. https://doi.org/10.1016/j.nexus.2022.100118

Perea-Moreno, M.-A., Samerón-Manzano, E., & Perea-Moreno, A.-J. (2019). Biomass as renewable energy: Worldwide research trends. *Sustainability, 11*(3), 863. https://doi.org/10.3390/su11030863

Zohuri, B., & Zohuri, B. (2018). Types of renewable energy. In *Hybrid energy systems: Driving reliable renewable sources of energy storage* (pp. 105–133). Springer. https://doi.org/10.1007/978-3-319-96196-0_5

Erdiwansyah, Gani, A., Mamat, R., Bahagia, Nizar, M., Yana, S., Yasin, M. H. M., Muhibbuddin, Rosdi, S. M., & Mat, S. (2024). Prospects for renewable energy sources from biomass waste in Indonesia. *Case Studies in Chemical and Environmental Engineering, 10*, 100880. https://doi.org/10.1016/j.cscee.2024.100880

Din, M. I., Amanat, A., Hussain, Z., Khalid, R., & Rauf, A. (2023). Pyrolysis of almond shell biomass: Effect of temperature and catalyst on product yield. *International Journal of Environmental Analytical Chemistry, 103*(11), 2827–2840. https://doi.org/10.1080/03067319.2021.2006557

Muhammad, F., Nisar, J., Ali, G., Anwar, F., Hussain, S. T., & Khan, S. W. (2023). Improved bio-oil yield from thermo-catalytic pyrolysis of Citrus limetta waste over pumice: Determination of kinetic parameters using Kissinger method. *Bioresource Technology Reports, 24*, 101635. https://doi.org/10.1016/j.biteb.2023.101635

Nisar, J., Ullah, R., Ali, G., Shah, A., Din, M. I., Hussain, Z., & Amin, R. (2023). Thermocatalytic decomposition of sesame waste biomass over Ni-Co-doped MCM-41: Kinetics and physicochemical properties of the bio-oil. *Energies, 16*(9), 3731.

https://doi.org/10.3390/en16093731

Kumar, M., Rai, D., Bhardwaj, G., Upadhyay, S. N., & Mishra, P. K. (2021). Pyrolysis of peanut shell: Kinetic analysis and optimization of thermal degradation process. *Industrial Crops and Products, 174*, 114128. https://doi.org/10.1016/j.indcrop.2021.114128

Islam, M. T., Nabi, M. N., Arefin, M. A., Mostakim, K., Rashid, F., Hassan, N. M. S., Rahman, S. M. A., McIntosh, S., Mullins, B. J., & Muyeen, S. M. (2022). Trends and prospects of geothermal energy as an alternative source of power: A comprehensive review. *Heliyon, 8*(12), e11891. https://doi.org/10.1016/j.heliyon.2022.e11891

Hamlehdar, M., Beardsmore, G., & Narsilio, G. A. (2024). Hydrogen production from low-temperature geothermal energy – A review of opportunities, challenges, and mitigating solutions. *International Journal of Hydrogen Energy, 77*(5), 742–768. https://doi.org/10.1016/j.ijhydene.2023.10.243

Soltani, M., Kashkooli, F. M., Souri, M., Rafiei, B., Jabarifar, M., Gharali, K., & Nathwani, J. S. (2021). Environmental, economic, and social impacts of geothermal energy systems. *Renewable and Sustainable Energy Reviews, 140*, 110750. https://doi.org/10.1016/j.rser.2021.110750

Mahmoud, M., Ramadan, M., Pullen, K., Abdelkareem, M. A., Wilberforce, T., Olabi, A.-G., & Naher, S. (2021). A review of grout materials in geothermal energy applications. *International Journal of Thermofluids, 10*, 100070. https://doi.org/10.1016/j.ijft.2021.100070

Ludin, N. A., Mustafa, N. I., Hanafiah, M. M., Ibrahim, M. A., Mat Teridi, M. A., Sepeai, S., Zaharim, A., & Sopian, K. (2018). Prospects of life cycle assessment of renewable energy from solar photovoltaic technologies: A review. *Renewable and Sustainable Energy Reviews, 96*, 11–28. https://doi.org/10.1016/j.rser.2018.07.048

Sampaio, P. G. V., & González, M. O. A. (2017). Photovoltaic solar energy: Conceptual framework. *Renewable and Sustainable Energy Reviews, 74*, 590–601. https://doi.org/10.1016/j.rser.2017.02.081

Dambhare, M. V., Butey, B., & Moharil, S. V. (2021). Solar photovoltaic technology: A review of different types of solar cells and its future trends. *Journal of Physics: Conference Series, 1854*(1), 012053. https://doi.org/10.1088/1742-6596/1854/1/012053

Alrikabi, N. (2014). Renewable energy types. *Journal of Clean Energy Technologies, 2*(1), 61–64.

https://doi.org/10.7763/JOCET.2014.V2.92

Mekhilef, S., Saidur, R., & Safari, A. (2011). A review on solar energy use in industries. *Renewable and Sustainable Energy Reviews, 15*(4), 1777–1790. https://doi.org/10.1016/j.rser.2010.12.018

Arsad, A. Z., Hannan, M. A., Al-Shetwi, A. Q., Mansur, M., Muttaqi, K. M., Dong, Z. Y., & Blaabjerg, F. (2022). Hydrogen energy storage integrated hybrid renewable energy systems: A review analysis for future research directions. *International Journal of Hydrogen Energy, 47*(38), 17285–17312. https://doi.org/10.1016/j.ijhydene.2022.03.208

Tarhan, C., & Çil, M. A. (2021). A study on hydrogen, the clean energy of the future: Hydrogen storage methods. *Journal of Energy Storage, 40*, 102676. https://doi.org/10.1016/j.est.2021.102676

Wang, Z., Carriveau, R., Ting, D. S., Xiong, W., & Wang, Z. (2019). A review of marine renewable energy storage. *International Journal of Energy Research, 43*(14), 6108–6150. https://doi.org/10.1002/er.4436

Buenau, K. E., Garavelli, L., Hemery, L. G., & García Medina, G. (2022). A review of modelling approaches for understanding and monitoring the environmental effects of marine renewable energy. *Journal of Marine Science and Engineering, 10*(1), 94. https://doi.org/10.3390/jmse10010094

Brew-Hammond, A. (2010). Energy access in Africa: Challenges ahead. *Energy Policy, 38*(5), 2291–2301. https://doi.org/10.1016/j.enpol.2009.12.016

Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering, 3*(1), 1167990. https://doi.org/10.1080/23311916.2016.1167990

Zheng, X., Streimikiene, D., Balezentis, T., Mardani, A., Cavallaro, F., & Liao, H. (2019). A review of greenhouse gas emission profiles, dynamics, and climate change mitigation efforts across the key climate change players. *Journal of Cleaner Production, 234*, 1113–1133. https://doi.org/10.1016/j.jclepro.2019.06.140