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The role of renewable energy in achieving sustainable development goals

Victoria Agbakwuru [1,*], Peter Ofuje Obidi [2], Ojonimi Segun Salihu [3] and Ogwu Chinelo MaryJane [4]

[1] *University of North Carolina at Charlotte, United States.*
[2] *Department of Mechanical and Aerospace Engineering, Missouri University of Science and Technology, United States.*
[3] *Department of Sociology, Western Michigan University, United States.*
[4] *Eastern Illinois University, Charleston, Illinois, United States.*

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Abstract

Renewable energy is a critical enabler of global efforts to achieve the United Nations' Sustainable Development Goals (SDGs), serving as a foundation for addressing social, economic, and environmental challenges. This review explores the multifaceted role of renewable energy in driving progress across several SDGs, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), while also contributing to goals such as poverty alleviation (SDG 1), improved health outcomes (SDG 3), economic growth (SDG 8), and sustainable cities (SDG 11). The transition to renewable energy sources—such as solar, wind, hydropower, and geothermal—offers pathways to reduce global carbon emissions, mitigate climate change, and ensure universal access to clean energy. In addition, renewable energy projects promote economic empowerment through job creation and rural electrification, driving inclusive growth in underserved communities. The integration of renewable energy in urban planning also supports sustainable development in cities. However, the adoption of renewable energy faces barriers such as high initial investment costs, technological limitations, and regulatory challenges. This review discusses strategies to overcome these obstacles, emphasizing the importance of supportive policy frameworks, international cooperation, and public-private partnerships. It highlights successful case studies from countries that have leveraged renewable energy to make significant strides toward the SDGs, offering valuable insights for global implementation. As the world approaches the 2030 deadline for the SDGs, renewable energy remains a vital driver of sustainable development, providing innovative solutions to complex global issues while fostering a cleaner, more equitable future.

Keywords: Renewable Energy; Sustainable Development Goals (SDGs)

1 Introduction

The Sustainable Development Goals (SDGs) are a set of 17 global objectives established by the United Nations in 2015 as part of the 2030 Agenda for Sustainable Development (Halisçelik and Soytas, 2019). These goals are designed to address a wide range of challenges that humanity faces, including poverty, inequality, climate change, environmental degradation, and the need for peace and justice (Menton *et al*., 2020; Bassey and Ibegbulam, 2023). The SDGs are distinctive in that they are all-encompassing and acknowledge the interdependence of the social, economic, and environmental facets of development. Striking a balance between enhancing human well-being and preserving the planet's resources for next generations is their goal. Targets and indicators are attached to each goal in order to provide direction for national programs and encourage quantifiable advancement.

One of the key aspects of achieving the SDGs is the role of energy, particularly renewable energy, in driving sustainable development (Nastasi *et al*., 2022). Among the goals, SDG 7 specifically focuses on ensuring access to affordable, reliable, sustainable, and modern energy for all. Renewable energy, which includes sources such as solar, wind, hydropower,

* Corresponding author: Victoria Agbakwuru

geothermal, and biomass, offers a clean and sustainable alternative to conventional fossil fuels that have long driven economic growth but have also contributed significantly to environmental degradation and climate change (Jaiswal *et al*., 2022; Bassey *et al*., 2023). As the world transitions away from fossil fuels, renewable energy is seen not only as a tool to mitigate climate change (SDG 13: Climate Action) but also as a pathway to achieving other goals, such as poverty alleviation (SDG 1), improving health and well-being (SDG 3), promoting sustainable economic growth (SDG 8), and fostering sustainable cities and communities (SDG 11).

One cannot exaggerate the role that renewable energy plays in maintaining global sustainability. With serious ramifications for ecosystems and human cultures, the energy industry is a major contributor to greenhouse gas emissions, which are the primary cause of climate change (Lamb *et al*., 2021). Energy security, economic opportunity, and social advantages can all be obtained while lowering emissions and decarbonizing the energy system through the use of renewable energy technology. Expanding renewable energy is crucial to ensuring that development happens within the planet's environmental bounds as energy demand rises, especially in developing economies. Furthermore, the shift to a circular economy—where resources are used more wisely and waste is reduced requires the utilization of renewable energy (Mutezo and Mulopo, 2021).

The purpose of this review is to explore the critical role that renewable energy plays in achieving the Sustainable Development Goals. While the direct link between renewable energy and SDG 7 is clear, this review also highlights the broader impact of renewable energy on several other SDGs. By examining the relationship between renewable energy and goals such as climate action, poverty reduction, health improvement, economic development, and urban sustainability, this review aims to provide a comprehensive understanding of how renewable energy can drive progress across the SDGs. It will also discuss the challenges and barriers that hinder the adoption of renewable energy technologies and propose strategies for overcoming these obstacles. The review will incorporate case studies of successful renewable energy initiatives, providing insights into how countries and regions have effectively leveraged renewable energy to advance sustainable development. Renewable energy is a powerful driver of global sustainability, offering solutions to some of the most pressing challenges humanity faces. This review will demonstrate how renewable energy can be harnessed to achieve multiple SDGs, contributing to a cleaner, more equitable, and prosperous world. As the 2030 deadline for the SDGs approaches, the expansion of renewable energy will be key to ensuring that the global community meets its ambitious development targets while safeguarding the planet for future generations.

2 Understanding Renewable Energy

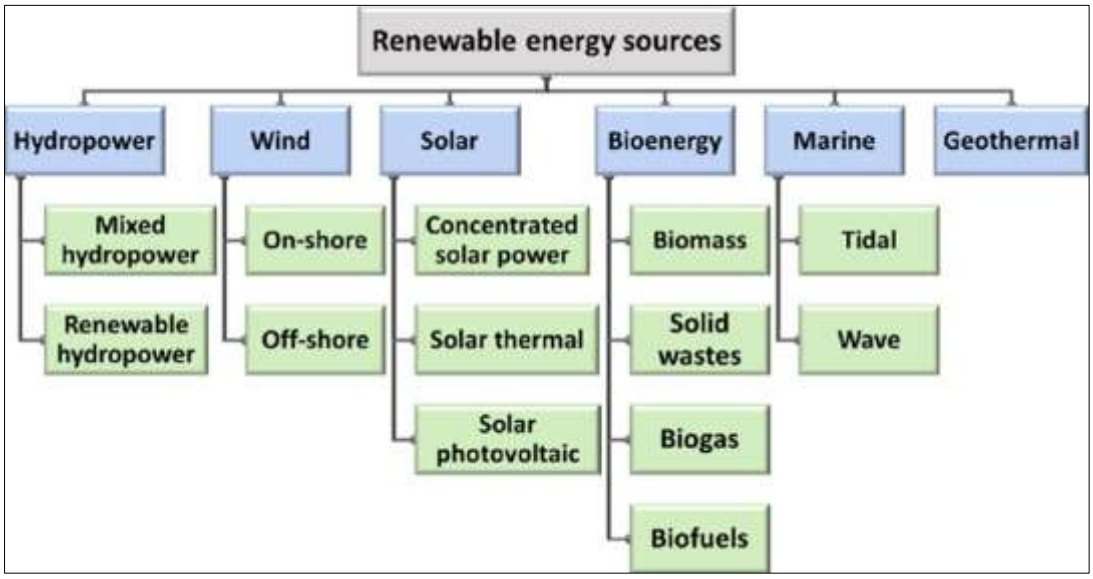

Figure 1 Several forms of renewable energy (Rahman *et al*., 2022)

According to Dey et al. (2022), renewable energy is defined as energy obtained from natural resources that replenish on a human timescale, making it environmentally beneficial and sustainable. Renewable energy sources are continuously renewed by natural processes, in contrast to fossil fuels like coal, oil, and natural gas, which are limited and contribute to environmental degradation. Solar radiation, wind patterns, water cycles, Earth's core geothermal heat, and biological activities in plant matter are a few of these. The ability of renewable energy to generate power

continuously with little to no negative environmental impact especially in terms of greenhouse gas emissions is one of its main features. Solar, wind, hydropower, geothermal, and biomass energy are the main forms of renewable energy as explain in figure 1 (Rahman et al., 2022).

Each of these has unique characteristics and applications. Solar power harnesses the energy from sunlight using photovoltaic (PV) cells or solar thermal systems. PV cells convert sunlight directly into electricity, while solar thermal systems use the heat from the sun to generate steam, which then drives turbines to produce electricity (Ajarostaghi and Mousavi, 2022). Solar energy is one of the most abundant and widely distributed renewable resources, and its scalability from small rooftop installations to large solar farms makes it versatile for various applications. Wind power is generated by capturing the kinetic energy of wind through turbines that convert it into electricity. Wind energy is particularly effective in areas with consistent wind patterns, such as coastal regions and open plains. Technological advancements in turbine design have increased the efficiency and cost-effectiveness of wind energy, making it one of the fastest-growing renewable energy sources worldwide (Tyagi, 2021). Hydroelectric power, or hydropower, is generated by using the gravitational force of flowing or falling water to turn turbines that produce electricity. Hydropower plants can range from large-scale dams that store water in reservoirs to small, run-of-the-river systems that generate energy without significant environmental disruption. Hydropower is currently the largest source of renewable electricity globally (Wasti *et al*., 2022). Geothermal power utilizes heat from beneath the Earth's surface to generate electricity or provide direct heating. Geothermal energy plants tap into underground reservoirs of hot water or steam to drive turbines. This energy source is most effective in geologically active regions, such as Iceland or the western United States, where geothermal resources are more accessible. Biomass energy comes from organic materials such as wood, agricultural residues, and animal waste (Babu *et al*., 2022). Through processes like combustion, anaerobic digestion, or gasification, these materials can be converted into electricity, heat, or biofuels. Biomass energy is considered renewable because plants and other organic matter can be regrown, making it a potentially sustainable energy source if managed responsibly.

The need for energy security, technological breakthroughs, and growing awareness of climate change have all contributed to the spectacular rise of the worldwide renewable energy sector in recent years (Al-Shetwi, 2022; Bassey, 2023). The International Renewable Energy Agency (IRENA) estimates that in 2021, renewable energy generated about 29% of the world's electricity, and that percentage will only rise in the ensuing decades. The future of renewable energy is being shaped by a few major factors. The biggest growth has been in solar and wind energy, mostly because of decreased costs and increased efficiency (Sadorsky, 2021). Solar power, in particular, has become increasingly competitive with fossil fuels, and large-scale solar farms are being developed across the globe. Wind energy has also expanded rapidly, with offshore wind farms becoming more prevalent, especially in Europe and Asia. One of the primary challenges of renewable energy is its intermittency solar power is only generated during the day, and wind power fluctuates based on weather conditions (Asiaban *et al*., 2021). However, advancements in energy storage technologies, such as lithium-ion batteries, are helping to address this issue by storing excess energy for use during periods of low generation. Grid modernization and smart grid technologies are also being developed to better integrate renewable energy into national power systems. Governments and international organizations have increasingly recognized the importance of renewable energy in meeting climate goals, such as the Paris Agreement's target of limiting global warming to below 2°C. As a result, many countries have implemented policies, subsidies, and tax incentives to encourage the adoption of renewable energy technologies. Investments in renewable energy have surged, with private sector participation growing as well. There is a growing shift towards decentralized energy systems, where local communities and individual households generate their own renewable energy through rooftop solar panels or small-scale wind turbines (Chwieduk *et al*., 2020). These systems reduce reliance on centralized power grids and enhance energy resilience, particularly in rural or underserved areas.

Renewable energy is playing an increasingly pivotal role in the global energy transition. With diverse sources such as solar, wind, hydro, geothermal, and biomass energy, renewables offer a sustainable and low-carbon alternative to fossil fuels. The rapid growth of this sector, bolstered by technological innovation and policy support, positions renewable energy as a critical tool in addressing the challenges of climate change and achieving long-term sustainability (Lucas *et al*., 2021; Bassey *et al*., 2024).

2.1 Linking Renewable Energy to Specific SDGs

Renewable energy plays a crucial role in achieving the United Nations' Sustainable Development Goals (SDGs), as it directly addresses pressing social, environmental, and economic challenges (Lee *et al*., 2020). By linking renewable energy to specific SDGs, we can explore how it drives sustainable development and helps fulfill global objectives.

Ensuring that everyone has access to modern, affordable, dependable, and sustainable energy is the main goal of SDG 7. In order to accomplish this, renewable energy is essential since it offers a plentiful, clean, and increasingly affordable substitute for fossil fuels as explain in figure 2 (Bogdanov *et al*., 2021; He *et al*., 2022). In many parts of the world, access to renewable energy helps close the energy gap, especially in areas where access to traditional energy sources is restricted. Increased energy access in isolated or impoverished places can be directly achieved through the use of renewable energy sources like solar and wind. In rural electrification initiatives, for instance, solar panels are being employed to give off-grid communities a reliable source of energy. Additionally, renewable energy fosters increased energy efficiency. Modern renewable technologies, like smart grids and energy storage systems, optimize energy use, reducing waste and making power systems more efficient (Tan *et al*., 2021). Investment in energy infrastructure, particularly in renewable energy, supports the transition from carbon-intensive energy systems to sustainable, resilient ones.

SDG 13 calls for urgent action to combat climate change and its impacts (Cohen *et al*., 2021). Renewable energy is a pivotal tool in this effort, as it helps reduce carbon emissions by replacing fossil fuels in energy production. The deployment of renewable energy sources such as wind, solar, and hydropower drastically cuts greenhouse gas emissions, making them essential for achieving global climate targets like those set by the Paris Agreement. Renewable energy not only contributes to mitigation strategies by reducing emissions, but it also plays a role in climate adaptation. Communities vulnerable to climate change, such as island nations and arid regions, can benefit from renewable energy systems that are more resilient to environmental shocks (Sarma and Zabaniotou, 2021). For instance, decentralized solar systems and microgrids can maintain energy security during extreme weather events, providing an essential adaptation strategy in the face of growing climate risks.

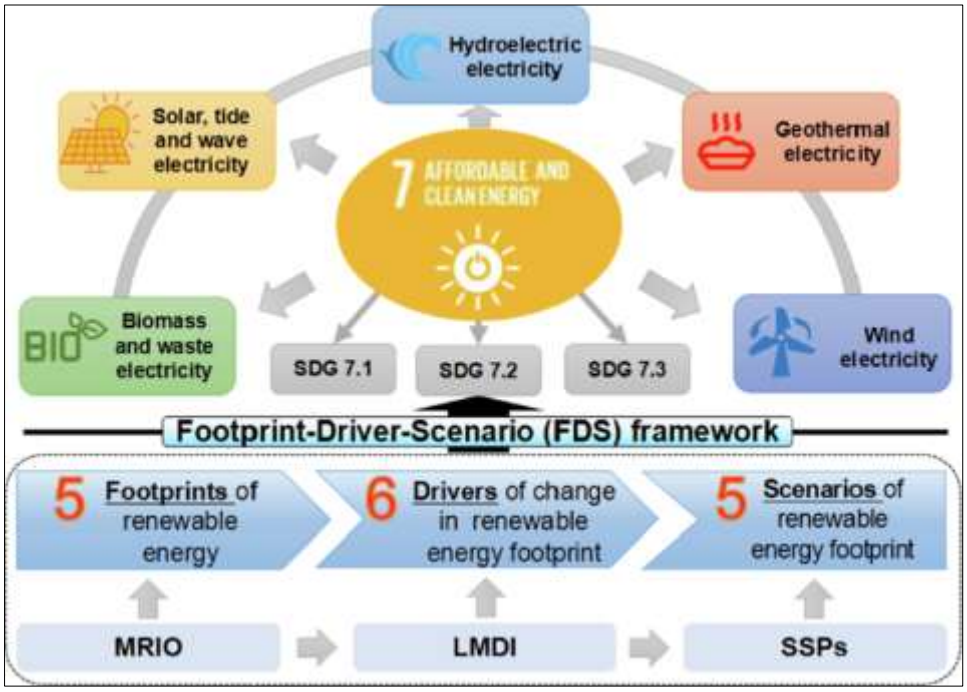

Figure 2 Diagram illustrating the Footprint-Driver-Scenario (FDS) system (He *et al*., 2022)

Renewable energy is a powerful tool for poverty alleviation, aligning with SDG 1, which aims to eradicate extreme poverty. Renewable energy projects create job opportunities in construction, manufacturing, and maintenance, especially in rural areas where poverty is most prevalent (Clausen and Rudolph, 2020). According to the International Renewable Energy Agency (IRENA), the renewable energy sector created over 11 million jobs globally by 2020, many of them in low-income regions. This influx of employment opportunities supports economic growth and improves living standards. Decentralized renewable energy systems, such as solar home systems or mini-grids, are crucial for economic empowerment in rural communities. These systems provide affordable, reliable energy to households and small businesses, enabling local entrepreneurs to thrive. The availability of renewable energy also stimulates education and healthcare services, helping to break the cycle of poverty.

Renewable energy also contributes to public health, aligning with SDG 3, which focuses on ensuring healthy lives and promoting well-being (Fernandez, 2020). Fossil fuel combustion is a significant source of air pollution, contributing to

respiratory diseases, heart conditions, and other health issues. By replacing polluting energy sources with cleaner alternatives like solar and wind, renewable energy can significantly reduce air pollution and improve public health outcomes. In addition, renewable energy systems are being implemented in healthcare facilities, particularly in remote areas where access to conventional electricity is limited. Solar-powered health centers, for example, enable reliable electricity for lighting, medical equipment, and refrigeration of vaccines, improving healthcare services and reducing preventable deaths in underserved regions (Osho and Sareen, 2021; Olatomiwa *et al*., 2022).

SDG 8 promotes sustained, inclusive economic growth and decent work for all. The renewable energy sector is a major driver of job creation, particularly in fields such as solar panel manufacturing, wind turbine installation, and maintenance. Jobs in renewable energy are diverse, ranging from highly skilled positions in engineering and design to entry-level roles in assembly and installation, providing a wide range of employment opportunities (Stefek *et al*., 2022). Furthermore, investment in renewable energy stimulates economic growth by creating new markets and reducing energy costs. Countries investing in renewable energy are diversifying their energy supply, increasing energy security, and fostering economic resilience. This growth also attracts further investment in research, development, and infrastructure, contributing to long-term economic stability.

In order to achieve SDG 11, which aspires to create inclusive, safe, resilient, and sustainable cities and communities, renewable energy is essential. Renewable energy is becoming a more integral aspect of urban regions' sustainability initiatives. Cities are incorporating renewable energy into their infrastructure in a number of ways, including energy-efficient smart grids, solar panels on buildings, and electric public transportation systems run on renewable energy (Sabory *et al*., 2021). Renewable energy is also being used by smart city projects to improve urban living. For example, renewable energy sources are frequently used by smart networks, which optimize electricity delivery and minimize energy waste. Cities can use these technologies to better control energy use, lessen their carbon footprint, and become more resilient to power outages or shortages.

Renewable energy is intricately linked to several SDGs, driving progress across a range of sectors including energy access, climate action, poverty alleviation, health, economic growth, and urban sustainability. By expanding the use of clean, sustainable energy sources, countries and communities worldwide can make significant strides toward achieving the 2030 Agenda for Sustainable Development (Mondejar *et al*., 2021). The continued investment in and deployment of renewable energy will be crucial to ensuring a sustainable, prosperous future for all.

2.2 Challenges and Barriers to Renewable Energy Adoption for SDG Achievement

Despite the vital role of renewable energy in achieving the Sustainable Development Goals (SDGs), several challenges and barriers hinder its widespread adoption (Bishoge *et al*., 2020). These challenges are multifaceted, encompassing technological, financial, policy, and social factors, all of which must be addressed to realize the full potential of renewable energy in supporting global sustainability efforts.

One of the primary challenges to renewable energy adoption is the technological limitations associated with certain renewable energy systems. While significant advancements have been made in solar, wind, and other renewable technologies, issues related to energy storage, grid integration, and the intermittent nature of renewable sources persist. Energy storage is a key challenge, as many renewable energy sources, particularly solar and wind, are intermittent, depending on weather conditions or time of day (Sánchez *et al*., 2022). Advances in battery technologies, such as lithium-ion batteries, have improved energy storage capacity, but the technology is still expensive, and the storage duration remains limited. Without effective storage solutions, maintaining a stable energy supply from renewables alone is difficult. Grid integration is another technological barrier, as most existing energy grids were designed for centralized, fossil-fuel-based power generation. Integrating decentralized renewable energy sources into these grids requires significant upgrades and re-engineering, particularly to accommodate variable energy flows. Furthermore, renewable energy systems need robust grid infrastructure and smart grid technologies to manage supply and demand effectively, which are not yet widely available in many regions (Alotaibi *et al*., 2020).

The cost of transitioning to renewable energy remains a significant barrier, particularly in developing countries. While the costs of renewable technologies like solar panels and wind turbines have decreased dramatically in recent years, the initial investment required for renewable energy projects remains high (Sens *et al*., 2022). This includes costs for infrastructure, installation, and maintenance, as well as the development of supporting technologies such as energy storage systems and smart grids. Financing renewable energy projects can also be difficult, especially in regions with unstable economies or inadequate financial institutions. Many developing countries face challenges in attracting investment due to perceived risks, such as political instability or unclear regulations. Even when funding is available, access to credit or financial incentives for smaller projects, such as decentralized solar installations in rural

communities, can be limited (Falchetta *et al*., 2022). As a result, the financial barrier to renewable energy adoption remains one of the most significant impediments to achieving SDG 7: Affordable and Clean Energy.

Policy and regulatory frameworks play a crucial role in renewable energy deployment. In many countries, the lack of clear or supportive renewable energy policies hinders investment and innovation in the sector (Wen *et al*., 2022). Inconsistent policies, such as fluctuating subsidies or unclear long-term commitments to renewable energy, create uncertainty for investors and developers, slowing down project implementation. In addition to national-level policies, international cooperation is crucial for the global transition to renewable energy. However, regulatory misalignment between countries, such as differing standards for energy production, storage, and distribution, can obstruct cross-border renewable energy projects. Policy challenges also arise in the context of phasing out fossil fuel subsidies, which continue to skew the energy market in favor of non-renewable sources (Kabel and Bassim, 2020). According to the International Energy Agency (IEA), fossil fuel subsidies amounted to $426 billion in 2018, significantly reducing the competitive edge of renewable energy in many regions.

Social and cultural acceptance of renewable energy also presents significant challenges, particularly in areas where people are accustomed to conventional energy sources. In many communities, there is resistance to adopting new technologies due to a lack of awareness or understanding of the benefits of renewable energy (Segreto *et al*., 2020). Misconceptions about the reliability and efficiency of renewable energy systems contribute to this reluctance, as people may perceive renewable energy as inadequate for their energy needs. Moreover, cultural norms and behaviors surrounding energy consumption can be slow to change. For example, in many rural areas, traditional energy sources such as biomass (e.g., wood and charcoal) are deeply ingrained in daily life. Shifting to modern renewable technologies like solar panels or wind turbines requires education, awareness campaigns, and sometimes incentives to overcome cultural inertia. Large-scale renewable energy projects can also face opposition from local communities due to concerns about environmental impact, land use, or disruption to traditional ways of life. Wind farms, for instance, are sometimes opposed due to their perceived visual impact or noise (Ki *et al*., 2022). Therefore, community engagement and transparent communication are essential to gain public support for renewable energy initiatives.

Even though renewable energy has a lot of potential to help achieve the SDGs, there are a few obstacles that need to be removed before it can reach its full potential. More innovation and funding are needed to address technological challenges including grid integration and energy storage. It is necessary to remove financial obstacles, especially in poor nations, by improving capital availability and offering financial incentives (Chien *et al*., 2021). To establish a more stable and encouraging environment for the deployment of renewable energy, policy and regulatory frameworks must be reinforced. Lastly, community involvement and education are needed to overcome social and cultural obstacles, such as aversion to change and ignorance. In order for renewable energy to propel global progress toward a sustainable future, these obstacles must be overcome.

2.3 Strategies for Enhancing the Role of Renewable Energy in Achieving SDGs

Since renewable energy tackles important concerns including energy access, climate change, and economic development, it plays a crucial part in accomplishing the Sustainable Development Goals (SDGs) (Cheng *et al*., 2021). Nonetheless, a number of tactical measures must be taken in order to optimize the contribution of renewable energy to the accomplishment of the SDGs. These consist of technology innovation, public-private partnerships, international cooperation, policy frameworks, and capacity-building programs. Every one of these tactics helps break down obstacles and promote the use of renewable energy.

A robust policy framework is essential for promoting renewable energy. Governments play a key role in establishing policies that encourage the adoption of renewable energy technologies as explain in figure 3 (Lerman *et al*., 2021). Policies such as feed-in tariffs, tax credits, and renewable portfolio standards are examples of mechanisms that can promote investment in clean energy. Feed-in tariffs guarantee a fixed payment to renewable energy producers for the electricity they generate, encouraging small-scale producers to enter the market. Similarly, tax incentives reduce the cost burden on investors, making renewable energy projects more financially viable. Furthermore, governments must phase out fossil fuel subsidies, which currently undermine the competitiveness of renewable energy. Redirecting subsidies toward renewable energy technologies can accelerate the transition to a sustainable energy system (Neacsa *et al*., 2022). Clear long-term policy commitments are also crucial. By setting ambitious targets for renewable energy adoption, such as 100% renewable energy by 2050, governments can provide the certainty that investors and developers need to plan and implement large-scale renewable energy projects.

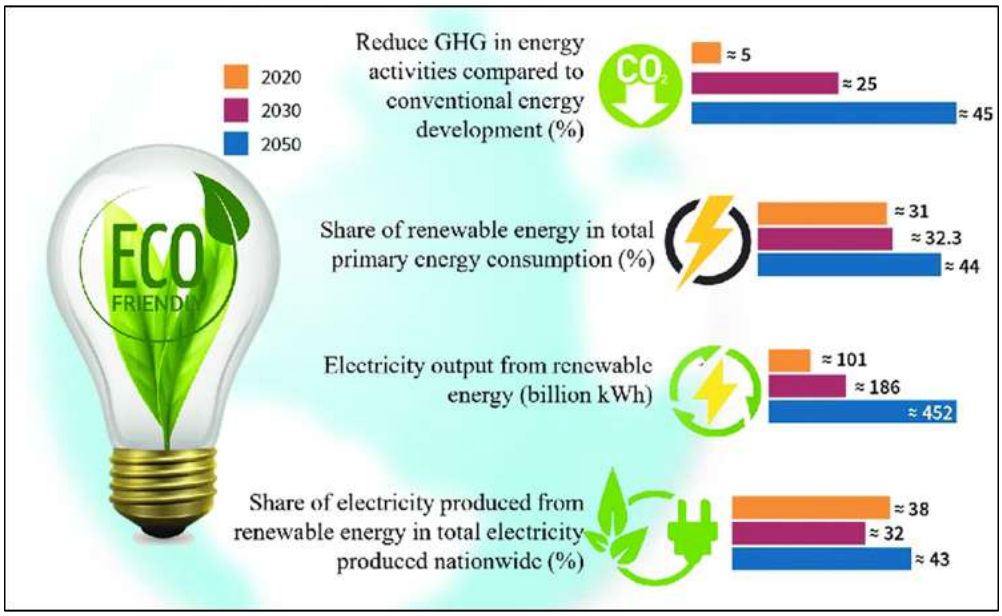

Figure 3 Techniques for boosting the share of renewable energy sources in production and usage (Nguyen *et al*., 2021)

Achieving the SDGs requires significant international cooperation, particularly in financing renewable energy projects in developing countries. Many low-income nations lack the financial resources to implement renewable energy infrastructure, even though they often have abundant renewable resources like sunlight and wind (Amir and Khan, 2022). International financial institutions, such as the World Bank and the Green Climate Fund, play a key role in providing financing for renewable energy projects in these regions. Innovative financing mechanisms, such as climate bonds and green funds, can also channel investment into renewable energy projects. Climate bonds, for instance, raise capital specifically for projects that have a positive environmental impact, including renewable energy. International cooperation through technology transfer is equally important. Developed countries can support the transition to renewable energy in developing nations by sharing technological innovations and expertise, helping to bridge the gap between advanced and emerging economies in terms of energy access and sustainability.

Public-private partnerships (PPPs) are crucial for expanding renewable energy infrastructure and innovation (Othman and Khallaf, 2022). In a PPP, the public sector collaborates with private companies to develop, finance, and implement renewable energy projects. Governments can leverage private sector expertise and capital to scale up renewable energy deployment while reducing public sector financial risk. Successful examples of PPPs in renewable energy include large-scale solar farms, wind energy projects, and bioenergy facilities. In these partnerships, the private sector often brings the technical know-how and capital, while the government provides regulatory support, land rights, or incentives. For example, India's Jawaharlal Nehru National Solar Mission, which aims to deploy 100 GW of solar energy by 2022, has heavily relied on PPPs to meet its ambitious goals. PPPs are particularly effective in creating the necessary infrastructure for renewable energy, such as grid modernization and storage solutions, which are vital for integrating renewable sources into existing energy systems (Stephanie and Karl, 2020).

Innovation and technological advancements are central to overcoming the challenges of renewable energy deployment. Continuous improvements in renewable energy technologies, such as more efficient solar panels and wind turbines, have already made these energy sources more competitive with fossil fuels (Husin and Zaki, 2021). However, more research and development (R&D) are needed to address remaining issues, such as energy storage and grid integration. Energy storage technologies, such as advanced batteries and pumped hydro storage, are critical for addressing the intermittency of renewable energy sources like solar and wind. Technological breakthroughs in this area will allow renewable energy to provide a more stable and reliable power supply, further facilitating its integration into energy systems (Gawusu *et al*., 2022). Additionally, smart grid technologies enable better management of electricity flows from decentralized renewable energy sources, enhancing grid resilience and efficiency. Innovation also extends to the development of new renewable energy sources, such as ocean energy, which harnesses the power of tides and waves (Ravinuthala *et al*., 2022). This emerging technology holds great potential for diversifying the global energy mix and supporting SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action).

Capacity-building and education are essential strategies for enhancing the role of renewable energy, particularly in underserved communities. Many regions, especially in developing countries, lack the technical expertise and knowledge to implement and maintain renewable energy systems (Zebra *et al*., 2021). Education programs and training initiatives can empower local communities to take ownership of renewable energy projects, ensuring their long-term sustainability. For instance, programs that train local technicians to install and maintain solar panels or wind turbines not only create jobs but also build local expertise, reducing dependence on external contractors. Furthermore, raising public awareness about the benefits of renewable energy can enhance social acceptance and accelerate adoption. Public campaigns that highlight the environmental, economic, and health benefits of clean energy can foster broader support for renewable energy initiatives (Bayulgen, 2020). In addition to technical training, education on energy efficiency and sustainable practices can further enhance the impact of renewable energy systems. Communities that are educated on energy conservation can maximize the benefits of renewable energy by reducing overall energy demand (Ceglia *et al*., 2020).

A multifaceted strategy is needed for the successful integration of renewable energy into international development initiatives. Financial incentives and policy frameworks are essential for fostering an atmosphere that encourages investment in and use of renewable energy (Yang and Park, 2020). The development of renewable energy in underdeveloped nations requires the backing of creative funding methods and international cooperation. Green energy initiatives can be expanded through public-private partnerships, which combine the advantages of both industries. While capacity-building and education programs make sure that communities are prepared to accept and sustain renewable energy systems, technological innovation will continue to play a crucial role in solving the difficulties associated with energy storage and grid integration. By using these tactics, renewable energy may make a substantial contribution to the SDGs' accomplishment and guarantee a sustainable future for everybody (Lohani *et al*., 2023).

2.4 Case Studies and Success Stories in Renewable Energy and SDG Progress

One of the main components of the international endeavor to accomplish the Sustainable Development Goals (SDGs) is the shift to renewable energy (Jayachandran *et al*., 2022). The successful adoption of renewable energy technology by a number of nations and areas has aided in their advancement toward these objectives. We can gain a better understanding of the achievements and lessons gained from renewable energy efforts by looking at case studies from Kenya, Germany, and Costa Rica.

Costa Rica is globally recognized as a leader in renewable energy and sustainable development (Teske *et al*., 2020). The country has consistently generated more than 98% of its electricity from renewable sources since 2014, primarily hydropower, wind, geothermal, and biomass. This achievement is directly linked to SDG 7 (Affordable and Clean Energy), as Costa Rica has successfully provided its citizens with universal access to clean and reliable energy (Gatto and Drago, 2021). Costa Rica's focus on hydropower is particularly significant, as the country’s natural geography with abundant rivers and rainfall supports the generation of large-scale hydropower. Complementing this are investments in wind and geothermal energy, which help to diversify the energy mix and ensure a stable electricity supply. This renewable energy-driven model has reduced the country's reliance on fossil fuels and significantly contributed to the reduction of carbon emissions, addressing SDG 13 (Climate Action). Costa Rica’s success demonstrates the importance of utilizing natural resources strategically and aligning energy policies with sustainability goals (Gruber, 2022). A combination of strong political will, public support, and long-term investments in renewable energy infrastructure has been essential to Costa Rica’s achievements. The country also benefits from favorable natural conditions, but its commitment to renewable energy despite challenges, such as variability in hydropower due to seasonal fluctuations, showcases the importance of a diverse energy portfolio (Gulagi *et al*., 2020; Salem *et al*., 2022).

Germany’s "Energiewende" (energy transition) is one of the most comprehensive national plans for transitioning to renewable energy. Germany has made significant progress toward SDG 7 and SDG 13 by scaling up renewable energy, particularly wind and solar power, while phasing out nuclear and coal energy (Wittmann *et al*., 2021). As of 2022, over 46% of Germany’s electricity comes from renewable sources, with wind energy accounting for a significant share. The Energiewende has also had broader economic and social impacts, contributing to SDG 8 (Decent Work and Economic Growth) by creating new jobs in the renewable energy sector. The German government has supported this transition through a robust policy framework, including feed-in tariffs and subsidies for renewable energy projects, which have encouraged significant private sector investment in clean energy technologies (Lu *et al*., 2020; Qadir *et al*., 2021). Germany’s success highlights the importance of strong government policies and incentives for renewable energy. The Energiewende also illustrates the value of long-term planning and public engagement. However, the transition has not been without challenges, including balancing energy demand with supply from intermittent renewable sources and ensuring that the transition is socially equitable, particularly for workers in the coal and nuclear industries. Germany’s

experience underscores the need for complementary strategies, such as grid modernization and energy storage solutions, to ensure stability in energy supply (Shen *et al*., 2021).

Kenya has emerged as a renewable energy leader in Africa, with over 90% of its electricity generated from renewable sources, including hydropower, geothermal, wind, and solar. The country's geothermal energy resources, in particular, have been a major driver of Kenya's renewable energy success. Located along the East African Rift Valley, Kenya has capitalized on its geothermal potential to provide a stable and reliable energy supply, contributing directly to SDG 7. In addition to increasing energy access, Kenya's renewable energy programs have contributed to SDG 1 (No Poverty) by creating jobs and promoting rural electrification (Christley *et al*., 2021). The development of decentralized renewable energy systems, such as mini-grids and solar home systems, has expanded access to electricity in remote areas, supporting local economic development and improving quality of life. Kenya's investment in renewable energy has also reduced its dependence on imported fossil fuels, enhancing energy security and promoting economic growth (SDG 8). Kenya's experience demonstrates that renewable energy can be a powerful tool for economic development, particularly in low-income countries. The success of decentralized renewable energy systems highlights the potential of these technologies to improve energy access in rural areas where grid expansion is not feasible. Kenya's commitment to renewable energy also emphasizes the importance of leveraging natural resources and investing in sustainable energy infrastructure to foster long-term economic resilience (Apfel, 2022; Njogu, 2022).

The case studies of Kenya, Germany, and Costa Rica show how important renewable energy is to achieving the SDGs, especially when it comes to issues like economic growth, access to clean energy, and climate action. These achievements teach us several important lessons. Adoption of renewable energy must be pushed by robust government policies, which should include long-term goals and incentives for investments in renewable energy. By lowering the vulnerabilities brought about by reliance on a single energy source, a combination of renewable energy sources helps guarantee a steady and dependable energy supply. Mini-grids and other decentralized renewable energy systems can increase electricity access in rural locations and foster social and economic development (Bukari *et al*., 2021). Collaboration between governments and the private sector is crucial for scaling renewable energy projects and mobilizing the necessary investment. By learning from these examples, other countries and regions can adopt similar strategies to accelerate their progress toward the SDGs through renewable energy deployment (Bishoge *et al*., 2020).

2.5 Future Prospects for Renewable Energy in Achieving the SDGs

With renewable energy at the forefront of global efforts to fulfill the Sustainable Development Goals (SDGs) by 2030, what's happening? Emerging technologies, their growing significance in promoting global sustainability, and their incorporation into the circular economy will all influence the direction of renewable energy in the future (Kylili *et al*., 2021). When taken as a whole, these components offer tremendous potential to increase the contribution of renewable energy to the advancement of international development objectives.

Technological innovation is a key driver in the advancement of renewable energy systems. Among the most promising developments are energy storage solutions and smart grid technologies, both of which are critical in addressing the intermittency of renewable energy sources like wind and solar power. Energy storage technologies, such as advanced lithium-ion batteries, solid-state batteries, and hydrogen-based storage systems, allow for the storage of excess energy generated during periods of high renewable energy production (Zhang *et al*., 2021; Hannan *et al*., 2022). These technologies help to stabilize the grid by ensuring a steady supply of electricity during times when renewable sources are not producing energy, such as during nighttime or periods of low wind. Breakthroughs in energy storage could significantly expand the role of renewables in global energy systems by making them more reliable and cost-effective. Smart grids utilize advanced digital technology to optimize energy distribution and consumption. They enable more efficient integration of renewable energy into the electricity grid by adjusting supply and demand in real-time. Smart grids can also facilitate decentralized energy production, allowing households and communities to generate their own renewable energy, improving access to clean energy (SDG 7) and reducing the carbon footprint of energy production (SDG 13) (Zalengera *et al*., 2020; Piterou and Coles, 2021). These emerging technologies will play a crucial role in transforming the renewable energy landscape, providing the infrastructure and tools necessary to support the widespread adoption of renewables (Streimikiene *et al*., 2021).

As the world approaches the 2030 deadline for the SDGs, renewable energy will be a key enabler in driving sustainable development across multiple sectors. Renewable energy has the potential to accelerate progress on a range of SDGs, beyond SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) (Brauch *et al*., 2022). For example, increased access to affordable renewable energy can spur economic growth (SDG 8), enhance education by providing electricity to schools (SDG 4), and support health outcomes by powering healthcare facilities (SDG 3). The expansion of renewable energy systems, particularly in developing countries, will also contribute to SDG 1 (No Poverty) and SDG 10 (Reduced

Inequalities). By providing electricity to rural and underserved communities, renewable energy projects help to create economic opportunities, support local businesses, and improve access to essential services. As renewable energy technologies become more cost-effective and accessible, they will play an increasingly critical role in enabling equitable progress toward the SDGs (Tiwari *et al*., 2021).

The notion of a circular economy, which aims to reduce waste, optimize resource utilization, and establish sustainable production and consumption systems, is closely associated with the prospects of renewable energy (Friant *et al*., 2020; Jain *et al*., 2022). A circular economy approach to renewable energy entails designing and putting into place systems that put sustainability and resource efficiency first along the whole energy value chain. For example, by using recycled materials and designing components for easy recycling at the end of their lives, the production of solar panels and wind turbines can be streamlined to lessen their environmental impact. Additionally, the use of bioenergy and waste-to-energy technologies aligns with circular economy principles by converting organic waste into a renewable energy source, reducing the overall waste generated by human activities (SDG 12) (Boloy *et al*., 2024; Fernando *et al*., 2022). Furthermore, energy-efficient technologies and practices, such as using smart meters to monitor and reduce energy consumption, help to create a more sustainable energy system that complements the circular economy. By embedding renewable energy in a circular economy framework, societies can ensure that the transition to clean energy is both environmentally and economically sustainable.

The future of renewable energy is marked by exciting technological advancements and its potential to further accelerate progress toward the SDGs (Kumar and Rathore, 2023). Emerging technologies such as energy storage and smart grids will enhance the reliability and scalability of renewable energy systems, making them a more viable solution for both developed and developing countries. As we move toward 2030, renewable energy will play an increasingly important role in addressing global challenges such as poverty, climate change, and inequality, all while contributing to a circular economy that promotes resource efficiency and long-term sustainability. The integration of renewable energy into a circular economy framework ensures that the energy transition is not only focused on reducing emissions but also on creating sustainable, resilient systems for future generations (Mishra *et al*., 2022; Kristia and Rabbi, 2023).

3 Conclusion

In summary, renewable energy is crucial in advancing global efforts to achieve the Sustainable Development Goals (SDGs). It directly supports SDG 7 (Affordable and Clean Energy) by providing sustainable, reliable, and affordable energy solutions. Furthermore, renewable energy contributes to SDG 13 (Climate Action) through the reduction of carbon emissions and helps meet global climate targets. Its impact on SDG 1 (No Poverty) and SDG 8 (Decent Work and Economic Growth) is evident in job creation, rural electrification, and economic empowerment. Renewable energy also improves public health (SDG 3) by reducing air pollution and powering healthcare facilities, while contributing to sustainable urban planning (SDG 11).

Continued investment and strong policy support are essential to expanding the role of renewable energy. Financial backing from governments and private sectors, along with incentives like subsidies and tax credits, will help overcome existing barriers such as high initial costs, technological limitations, and regulatory challenges. Policies that promote research, innovation, and infrastructure development will accelerate the transition to renewable energy, creating economic and environmental benefits.

The interconnectedness of renewable energy and the SDGs highlights its role as a catalyst for sustainable development. Beyond providing clean energy, renewable energy contributes to poverty reduction, improved health outcomes, economic growth, and climate resilience. By aligning renewable energy investments with global development priorities, the world can progress more rapidly toward achieving the SDGs, ensuring a sustainable and equitable future for all.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest disclosed.

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