

# Future Green Energy: A Global Analysis

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**Abstract:** The main problem confronting the world is human-caused climate change, which is intrinsically linked to the need for energy both now and in the future. Renewable (green) energy has been proposed as a future solution, and many renewable energy technologies have been developed for different purposes. However, progress toward net zero carbon emissions by 2050 and the role of renewable energy in 2050 are not well known. This paper reviews different renewable energy technologies developed by different researchers and their potential and challenges to date, and it derives lessons for world and especially African policymakers. According to recent research results, the mean global capabilities for solar, wind, biogas, geothermal, hydrogen, and ocean power are 325 W, 900 W, 300 W, 434 W, 150 W, and 2.75 MWh, respectively, and their capacities for generating electricity are 1.5 KWh, 1182.5 KWh, 1.7 KWh, 1.5 KWh, 1.55 KWh, and 3.6 MWh, respectively. Securing global energy leads to strong hope for meeting the Sustainable Development Goals (SDGs), such as those for hunger, health, education, gender equality, climate change, and sustainable development. Therefore, renewable energy can be a considerable contributor to future fuels.

**Keywords:** net carbon emissions; green renewable energy; renewable energy; climate change; renewable energy progress; renewable energy technologies

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## 1. Introduction

The world is experiencing an energy crisis of major depth and complexity, with shortages highlighting the importance of energy [1]. However, this crisis also presents an opportunity to undertake a step change and decarbonize the energy system, making the energy system more resilient, secure, and affordable for all. In Europe, industry and transportation are the two sectors that emit the most CO<sub>2</sub> [2]. However, even within these hard-to-abate sectors, technological solutions are available, and the main obstacle to transitioning to renewable energy is the cost. The manufacturing of batteries, solar panels, electric cars, nuclear plants, energy efficiency solutions, heat pumps, and hydrogen energy is flourishing around the world [3]. The United States has introduced a major green energy package as part of its Inflation Reduction Act, and Europe is forming a similar response. These countries aim to prime their economies by increasing the energy balance, which is the only way to lower the cost of energy, through increasing the supply of green energy, which is the only energy that becomes cheaper with more users, thereby stealing a march on the rest of the world [4]. Elsewhere, USD 3.4 trillion of investment is needed to fund the infrastructural gap in Africa alone. It is extremely important to ensure that renewable energy projects be funded in an inclusive way (i.e., without excluding any technology or fuel that is important for the future). It would be quite difficult for one player in the industry to decarbonize a complete value chain alone. A platform created by the World Energy Fund (WEF) seeks to unite a group of industry players who collectively decarbonize the value chain and thus spread the risk. However, energy is not only about supply [5]. There is much discussion about fossil fuels versus renewable energy but less about working on the demand side (i.e., lowering demand so that less energy needs to be supplied). In

reality, the technology, knowledge, and capital to increase the supply of renewable energy and decrease energy demand already exist. In the latter case, electricity meters with built-in two-way communication between the customer's location and the energy provider (smart meters) can help lower energy prices, improve energy efficiency, and provide near-real-time data on energy consumption, which benefits both the energy supplier and the consumer. However, there are also drawbacks to this technology. First, because smart meters rely on wireless connectivity, there is a risk of hacking and other security risks regarding the data transmitted between the utility and the smart meter [6], raising privacy and data protection concerns. Second, smart meters need a constant internet connection, with interruptions in the connection having a major effect on their use. Third, utility costs may rise, as smart meters provide the potential to bill clients according to peak and off-peak usage because they can detect energy usage more precisely than standard meters. Some consumers may see a considerable increase in their energy costs as a result, and more households may find it difficult to make ends meet. High initial costs, incompatibility with current electrical systems, malfunctions due to electromagnetic interference, increased electronic waste and environmental impact, inefficiency in unfavorable network conditions, and the inability to reduce energy bills alone are other drawbacks of smart energy meters [7].

From the above, it can be inferred that utilization of renewable energy resources around the globe depends upon the country and is limited, but there is insufficient information on the actual situation. The objective of this study was thus to provide an overview of the missions and objectives for renewable energy by 2050 and primarily to prompt global (especially African) policymakers to consider the future of renewable energy. The novelty of this study lies in describing renewable energy locations at a global level and making recommendations for effective exploitation of these in the future. Achieving the SDGs requires collaboration and partnerships at all levels, including governments, businesses, civil society, and individuals. The goals are interconnected, and progress in one area can contribute to progress in others.

The remainder of this paper is structured as follows. A literature review is presented in Section 2, the methods used in this analysis are summarized in Section 3, and the findings are presented and discussed in Section 4. Some conclusions are drawn in Section 5, and some recommendations are made in Section 6.

## 2. Literature Review

More than 50% of the world's population lives in urban areas, and that figure could rise to nearly 70% by 2050. Big cities have major requirements for water, food, and energy [8]. This heavy demand on resources poses daunting challenges to researchers in a world grappling with climate change. Future cities and towns will need large amounts of energy [9], and revolutionizing the complex energy supply system is one of the greatest challenges in the global transition to renewable (green) energy. For most people, it is also probably the most tangible challenge [10].

It is important for those responsible for policies in the world's cities to take a leading role, since it is possible for cities to change [11]. There is a general consensus that we urgently need to move to an economy that is simultaneously renewable, circular, and nature-positive, as there is little time left to save the planet [12]. To assess how a sustainable energy supply can work in practice, we reviewed relevant cases from around the world.

In the United States, the city of Lancaster in California is aiming to become the first carbon-neutral city in the country. Lancaster has around 175,000 residents, and in 2009, officials started a journey to "go green", fundamentally transforming the city's economy and infrastructure [13,14]. A technological overhaul was undertaken, and more importantly, there was a shift in mentality whereby the purpose of the city authority became to assist people in going green and not delay them. For example, it used to take a minimum of six months for a household to obtain a permit to put solar panels on their roof [15]. Lancaster's mayor, Rex Parris, began by having photovoltaic panels installed on all municipal buildings, with the electricity generated used for public lighting, which saved the city a great amount

of money. This money was put toward installing even more photovoltaic panels on the roofs of private residences, while this system became mandatory for new buildings. Bit by bit, Lancaster created an alternative energy network. Excess electricity started being used to generate hydrogen to fuel public transportation, and thanks to the sunny weather in California, green energy and hydrogen production continued to expand. The low-cost electricity and cheap hydrogen attracted new, large companies, solidifying Lancaster's reputation as a green boomtown. When Lancaster began the process of transforming its energy system in 2009, the unemployment rate was at 17%, but by 2023, it had dropped to around 6%. Lancaster is now a self-sufficient green energy powerhouse and highly profitable, and both the city of Lancaster and Mayor Parris have received many awards for their achievements.

In the German state of Bavaria, Wunsiedel, a rural region where the forest industry is key, took a different approach to going green. When Marco Krasser took the helm of the regional energy supplier, he shifted Wunsiedel to a circular system that effectively linked its regionally strong timber industry with the local energy system. The aim was to reuse as much energy as possible multiple times, with excess energy accumulated (e.g., in the form of wood waste or waste heat from machines) being harnessed rather than lost. Surplus energy generated from solar and wind power is used to press forestry waste into wood pellets, which are burned to generate heat or power a turbine for electricity in a cascade system comprising solar and wind energy, battery storage, and combined heat and power. Through this system, the construction industry is linked to the timber industry, and the timber industry is linked to agriculture or forestry. This creates local circular energy economies that can be scaled up to all levels, which in turn satisfy energy demand in the form of electricity and heat, as well as electricity in terms of mobility [16].

Wunsiedel in Bavaria and Lancaster in California have both tapped into locally available resources as best they can, and both have created infrastructures in which green energy is used as efficiently as possible in an ongoing cycle. Of course, such systems should ideally be integrated into construction projects from the very start. In Copenhagen, a newly built district called Nordhavn served as the testing ground for the "Energy Lab" project, a living laboratory for research into innovative and more efficient energy cycles. The buildings there are well insulated and retain heat, saving money and reducing demand for energy, which are especially important at peak hours in the early morning [17]. Additionally, commercial businesses in the neighborhood use compressors powered by electricity for cooling down goods. By using slightly more electricity when there is a surplus from wind turbines or photovoltaic cells, these businesses can actually optimize operation of the compressors and produce extra energy which can be used to heat nearby buildings. Thus, the waste heat system is actually a smart component in a coupled energy system, which is an ingenious cycle. The energy put into the system is used several times, and the whole neighborhood benefits. The goal of a modern circular economy is to save energy and increase efficiency. The cycles described are optimized to make energy competitive in price while serving as an extension or even an alternative to large, centralized grids [18].

Norway and its capital of Oslo are among the pioneers in the green energy transition. Oslo is aiming to reduce CO<sub>2</sub> emissions to zero by 2030, and Mayor Marianne Borgen helped to draft and pass a series of concrete measures to achieve this. Oslo is now considered the world capital of e-mobility [19] and has made significant headway in making its construction sector carbon-neutral through advances in heating and building materials [20]. To achieve the city's ambitious zero emissions goal, residents and businesses are both playing an active part.

In 2019, an office building called the "powerhouse", commissioned by Sonja Horn's company, was inaugurated in the Norwegian city of Trondheim. The roof is covered with 3000 square meters of solar panels which are angled optimally to capture the sun's rays in northern Europe [21]. Through these, the powerhouse produces an annual average of 500,000 kWh of electricity, which is more than double the amount it consumes [22]. The surplus electricity is sent to a local micro-grid to supply neighboring buildings, electric

buses, and cars. This pioneering project is the first of its kind, and the powerhouse is an attractive place for young people to sit and work.

When a new building is planned in Oslo, the focus is on three main aspects. The first of these is to use less resources and materials (i.e., the reuse of materials and recycled materials must be considered before sourcing new materials) [23]. Many construction sites in Oslo are now zero-emission sites because the technology is in place through challenging establishments and the industry, thus leading the way [24]. Like Oslo, the rest of Norway is aiming to be carbon-neutral by 2030. The country has a large oil and gas sector but also a wealth of hydrogen power [25]. Norwegian Minister Espen Barth Eide is confident that the necessary transition to a carbon-neutral economy will bring opportunities rather than risks for domestic industries. Already, the service industry that developed because of 50 years of the petroleum sector is quite eager to enter this new area. Since it can run oil or gas platforms in the North Sea in 10 m high waves and extreme conditions, it can create, for example, floating wind power, and since it was good at building fossil fuel ships with advanced technology, it can be good at building hydrogen- or ammonia-driven ships with advanced technology [26]. This circular energy economy relies as much on technological innovation from major industries as a stable grid that can provide constant and reliable green power [27]. In northern Europe, this can best be achieved with wind power from offshore parks and with hydrogen power. If the countries bordering the North Sea can help balance one another's demand for green power, then this could become a model worldwide. The longest of the underwater links to date was constructed in 2021 to connect Norway with England's east coast [28]. At some hydroelectric power stations in Norway, water drops hundreds of meters to propel turbines that generate gigawatts of electricity [29]. Hydropower generated at the Kvilldal power station is converted for onward transmission to Blyth in England, where gigawatts of electricity are generated from offshore wind and where a converter station that physically converts direct current to alternating current (or vice versa) is being installed [30]. This converter has interconnectors which allow it to take in green energy from lakes in Norway and offshore winds, enabling a transition to green energy not just in the UK but in neighboring countries such as Norway, France, and Denmark. Britain has become a leader in Europe in developing offshore wind power in the North Sea and is now an exporter of green power via a super-fast green highway for the transfer of energy to connected countries, enabling security of supply. Blyth was once a prosperous mining town, but it suffered a sharp economic blow from the decline in coal mining [31]. Port of Blyth manager Martin Lawlor hopes that the power link will help return the town to its former glory. The port of Blyth is already a major offshore energy hub for the UK, and this is actually helping attract further investments, as companies want to be part of the cluster and feed off some of the specialty hydraulics and electrics, vessel operators, and cable factories, which will help to drive further investments all around the estuary.

The world's largest network for reliable generation of energy has been under construction in the North Sea since 2020. In order for a new energy economy to succeed, it is crucial to build large green power grids that are stable. By becoming partners in a new North Sea grid through direct coast-to-coast lines, border countries are inching closer to the goal of attaining energy security [32]. The North Sea grid will deploy the latest technology to move generated energy back and forth on demand. Large industrial centers will be built at the hubs, including a planned "energy island" about 80 km off the coast of Jutland, as part of an inner network on the high seas that can be expanded over time. This energy island, the first in a series, will actually power different countries around the North Sea at the same time [33]. According to the latest estimates, it will cost more than EUR 30 billion but one day should provide electricity for up to one million households. This will require large substations where alternating current can be converted to direct current and back again, which is vital for transmitting electricity over long distances. The energy island system started as a piece of technology to help integrate large bulk power and transmit it over long distances with much better efficiency thanks to much lower losses. The more

systems it integrates, the more complex the entire energy system becomes. To integrate the next 20–30% of electric vehicles into the electricity system, it will need to integrate up to 60 GW of offshore wind, which is roughly equivalent to the capacity of 40 nuclear power plants, and thus planning and investments must begin now in order to deploy the grid technology on time. Construction of a new power cable on the east coast of Britain was recently completed. It connects the grids of Britain and Denmark and will supply them with electricity from offshore wind parks in both countries. The new interconnector between the two countries is called the Viking Link and is 765 km long, making it the longest underwater power cable in the world. To meet the ever-growing need for energy in the future, large storage facilities will be required in addition to transmission infrastructure. Hydrogen has immense potential as a storage medium for green electricity [34].

At a Siemens energy site in Berlin, Germany, a simulator shows the total demand for energy in a complex industrial society. If hydrogen is to become the new optimal energy carrier, then technology to produce hydrogen holds great strategic significance, although the industrial infrastructure is only being built now. One way to create hydrogen is via electrolysis, a process which uses an electric current to split water into hydrogen and oxygen. The electricity used to carry out this process must come from renewable sources so that its production is sustainable. The advantage of electrolysis is that it can be integrated into existing economic cycles relatively easily. In the future, an industrial site could use electrolysis to secure its electricity supply with hydrogen storage. Hydrogen is available in virtually unlimited quantities and may become the key to future supplies [35]. There are three levers for overall energy transition: energy efficiency by reducing energy consumption and finding ways to recycle the energy that is produced; electrification where possible, because this is going to be the cheapest path to decarbonization; and hydrogen and green molecules where electrification is not enough in order to capture and store energy and reuse it elsewhere or in processes.

Hydrogen can be further refined with CO<sub>2</sub> into new fuels to replace fossil fuels in heavy industry. The hope is that hydrogen can be the basis for a whole range of fuels in the future. Hydrogen can be used as is, but much will be transformed into so-called e-fuels together with captured carbon to replace many of the fuels that we know today. In many poor parts of the world, wood and fossil fuel products such as propane are used for cooking and heating. Converting hydrogen and CO<sub>2</sub> into a clean fuel would be a sustainable alternative, and some projects are in the experimental stage but will hopefully become building blocks in an ever-expanding circular energy economy [36].

At sites around the world, researchers are working on green technologies. Singapore in particular is considered a laboratory for the future. The main problem for the new energy economy is that batteries are the most important storage medium but are made from costly materials which are becoming increasingly scarce as global demand grows. Research is needed on how to recycle lithium-ion batteries and other e-waste so that it can be reintegrated into the production cycle. There has to be a mindset shift toward a circular economy to prevent shortages of essential resources. Universities such as Nanyang Technological, Berkeley, and Stanford are among the world's most well-regarded research hubs and are focusing on developing technology that could be rapidly deployed in future industries [37].

There are many synergies between materials research and research on a circular economy of materials, but there is still some silo thinking. In Copenhagen, many practical experiments relevant to both areas are being logged in a database to highlight the most promising results.

It often takes two decades for basic research to reach industrial maturity, but for the climate crisis, time is of the essence, and solutions need to be employed faster. This is an incredibly complex challenge, and applied research will need to adapt. The main challenge and the potential solution both lie in inventing new materials for the green transition. This involves rethinking materials discovery, system development, and the process itself as well as integrating all parts of the discovery production and end use cycle. This is

especially critical because the next innovations are already on the horizon as researchers conduct research in the field of solar energy conversion, turning sunlight into electricity and heat. A relatively new branch of research is working to imitate nature's most fundamental energy-harvesting process (photosynthesis). Nature has the capacity for something almost miraculous in the leaf of every plant: harvesting CO<sub>2</sub> from the atmosphere together with water in the presence of sunlight and transforming those chemical reactants into complex sugars and starches that sustain life. These complex sugars and starches are essentially fuels. Researchers at Pasadena, Ilmenau, and the Fraunhofer Institute have drawn inspiration from nature to envision a process called artificial photosynthesis, which uses engineered materials to perform the same kind of reduction–oxidation reactions that enable the formation of fuels directly from sunlight. However, instead of sunlight shining on a leaf, as occurs in nature, researchers use structures made of intricately manufactured semiconductors (artificial leaves) in which solar energy can turn water into hydrogen and oxygen. The efficiency of artificial photosynthesis is currently at 19.3%. If this process could be scaled up for industrial use, then hydrogen would become cheaper than any other fuel. Semiconductors, which are small and inconspicuous, are of critical importance for artificial photosynthesis and are the basis of all advanced technologies. They can be made from many different types of materials. Of course, not every single component of new energy systems is ready for action, and rolling out innovations to communities and industries will be a key step. Many scientific breakthroughs and technological innovations have not yet been widely implemented for public use. Researchers have made tremendous strides in recent years, and technology has come a long way, but successfully transforming the energy supply to make it sustainable hinges on the ability to scale these solutions and integrate them into large sectors of society before it is too late.

#### *Working Principle of a Smart Meter*

On the demand side, the newest innovation in energy management is the smart meter. It can be used to cut energy waste, boost productivity, and lower costs by monitoring how much energy is consumed in homes and workplaces in real time (Figure 1). Since smart meters make it simple and quick for users to monitor their energy consumption, they are seen as an innovative approach to energy management. The energy source in a house or place of business communicates with smart meters to function. In order for the energy supplier to bill appropriately for the quantity of energy consumed, the meter measures the energy used and sends the data to them. Additionally, the meter records data on energy use over time, enabling users to keep an eye on their consumption and, if necessary, take action to cut back. Water, natural gas, and electricity usage may all be measured with smart meters. They are typically linked to a wireless network, enabling real-time data collection and transmission. Customers can more readily identify where energy is being consumed and take action to reduce it by using the meters to monitor energy usage in every section of a home or business. There are several advantages which smart meters offer their users [29]. They make it possible for consumers to monitor their energy consumption in real time and identify areas where they can cut costs by using less energy. Energy providers can also create comprehensive profiles of their customers' energy usage with smart meters, which helps them better understand demand and deliver more specialized services. The widespread adoption of smart meters in many nations is propelling advances in energy systems with greater efficiency. They are making it possible for energy suppliers to better serve their clients and for consumers to have more control and knowledge over how much energy they use.

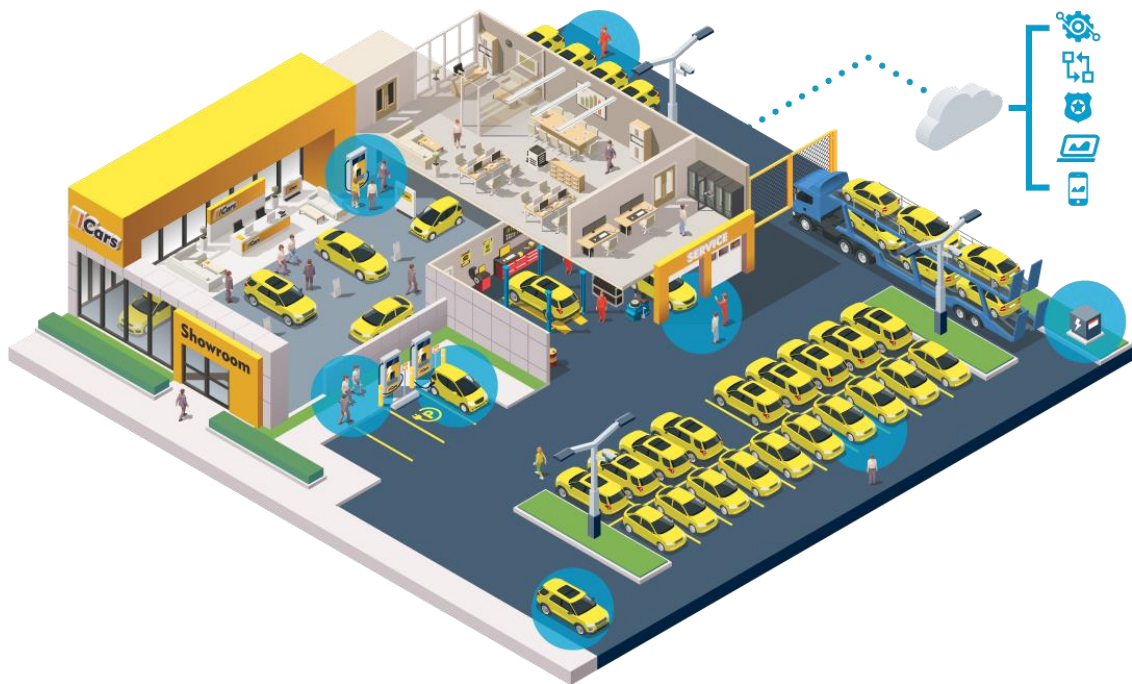


Figure 1. Components of a smart meter system [37].

### 3. Methods

A series of procedures (review of available techniques, data analysis, identification of relevant questions, and further analysis) were applied to the secondary data used in this paper (Figure 2). A literature review was used to gather general data. The review results were codified and consolidated using grounded theory. The data were then analyzed by concept group (tidal, hydrogen, or solar energy), taxonomy, and notes and used in a questionnaire-based survey on database security that yielded quantifiable and qualitative information. The survey responses were analyzed by statistical methods, followed by grouping or reducing the statements and producing a list of statements to validate and a question bank. Finally, research gaps were identified (output).

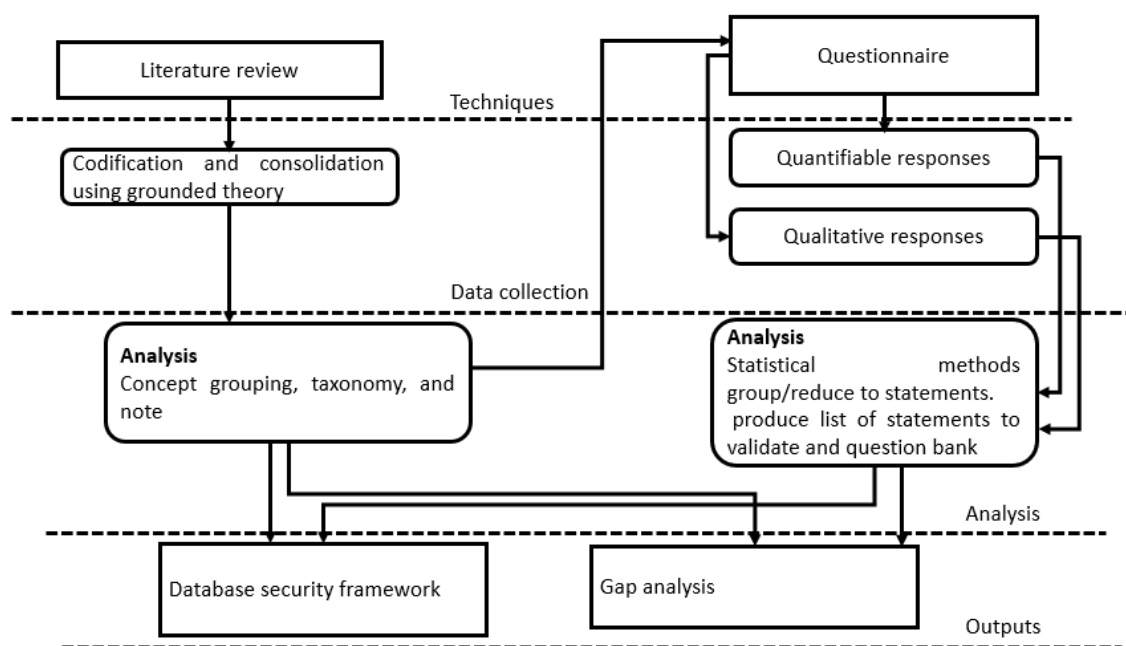


Figure 2. Mind map showing components included in the analysis in this study.

Using various search keywords and key words, relevant articles for the literature review were found in SCOPUS, Dimension, PubMed, Web of Science (WOS), Crossreff, and Google Scholar. After comparing the hits, duplicate papers were removed (Figure 3). A slicer filtering technique was used in Microsoft Excel to process the remaining documents. We started by downloading many articles and saving them as CSV files. Then, we arranged the various pieces according to the year of publication. We also considered journal titles. The information was arranged into cell arrays according to a “published since 2000” criterion. Older publications were excluded.

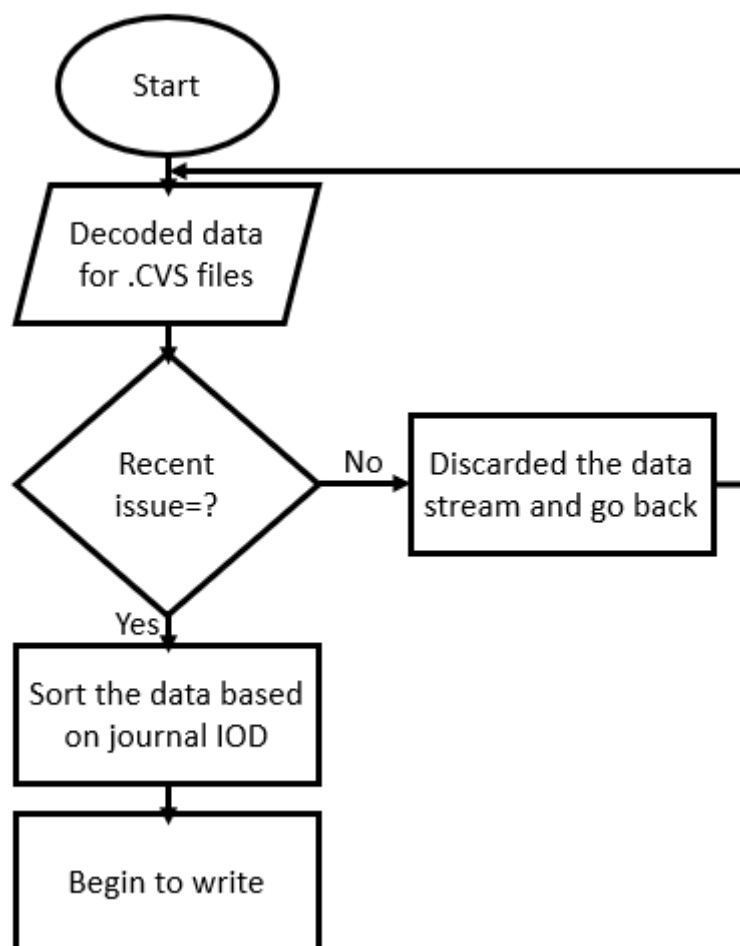


Figure 3. Flowchart of data processing.

## 4. Results and Discussion

### 4.1. Tidal Energy

Tidal energy generation is summarized in Figure 4. A tide refers to the rise and fall of the ocean’s surface caused by the centrifugal force created by the Earth’s rotation and attraction mainly from the gravitational field of the moon, which is twice that of the sun. Ocean tides on Earth, the source of tidal energy, are caused by periodic changes in this gravitational pull. Owing to the ocean’s high inertia, a bulge in the water level is produced, momentarily raising the sea level. Similar to wind turbines, which use wind energy to power turbines, tidal stream generators employ the kinetic energy of moving water to power turbines. In order to allay worries about their effects on the surrounding environment, certain tidal generators can be completely submerged or integrated into existing bridges. Tidal barrages exploit the potential energy in the difference in height (or hydraulic head) between high and low tides and use it to create electricity in carefully positioned specialized dams. The transient increase in tidal power is directed into a sizable



basin behind the dam, which contains a significant quantity of potential energy when the sea level rises and the tide starts to come in.

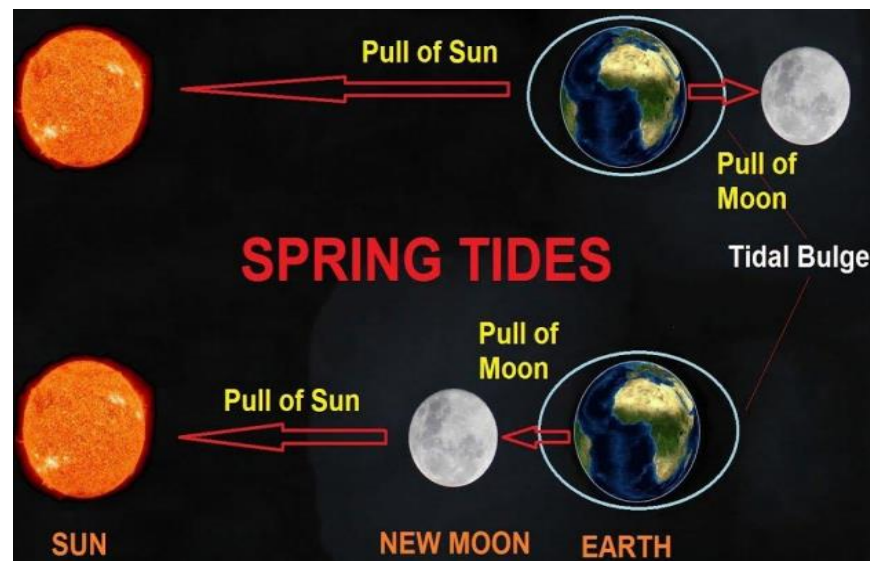


Figure 4. Causes of tide [37].

An emerging and intriguing technique called dynamic tidal power (DTP) seeks to exploit the interaction between kinetic and potential energy in tidal flows. When tidal phase discrepancies are introduced across a dam, shallow coastal seas with strong oscillating tidal currents parallel to the coast, such as those off of the UK, China, and Korea, experience a notable water level discrepancy. Circular retaining walls with integral turbines can be built to harness the potential energy of tides in a novel approach (Figure 5). The artificially produced reservoirs created by these walls bear some resemblance to tidal barrages, with the exception that the former lack an innate ecosystem. Lagoons can also be doubled (or tripled) in format, either with no pumping at all or with pumping that flattens the output of electricity.



Figure 5. Tidal power plant [37].

Figure 6 shows the global tidal energy potential, where the USA has the greatest potential (57 GW), followed by Canada (29 GW), Russia (16 GW), Argentina (6 GW), and Europe (around 2 GW). However, the tidal energy potentials for some coasts of west Africa, China, and Australia are not known [38–40].

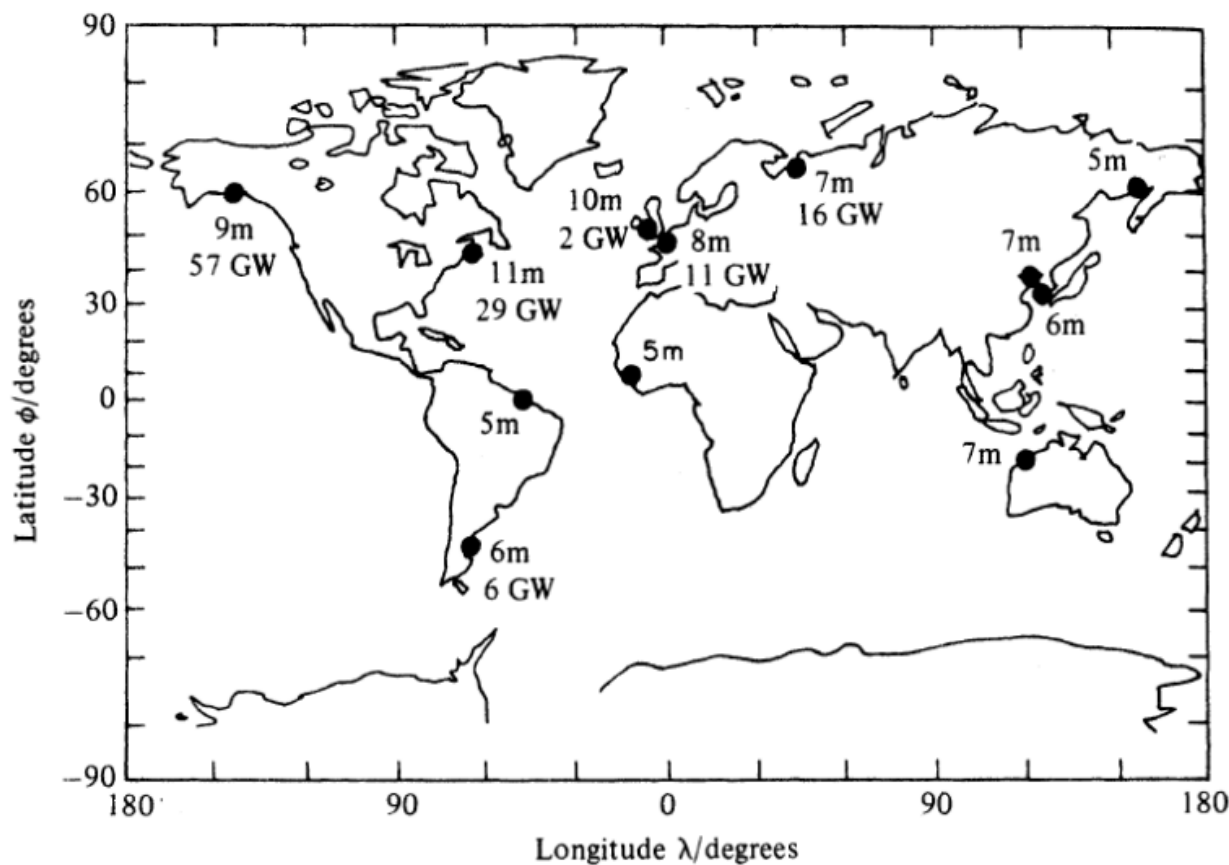


Figure 6. Map showing global tidal energy potential [40].

Table 1 shows the capability for energy generation per unit mass of different types of renewable energy sources. The mean power capacities of solar, wind, biogas, geothermal, and hydrogen energy are 325 kWh, 900 W, 300 W, 434 W, 150 W, and 2.75 MWh, while their capabilities for generating electricity are 1.5 kWh, 1182.5 kWh, 1.7 kWh, 1.5 kWh, 1.55 kWh, and 3.6 MWh, respectively. In terms of ranking, ocean (offshore) energy is the renewable energy capable of generating by far the most electricity, followed by wind and geothermal energy. Solar and biogas energy generate equivalent amounts of electricity.

Table 1. Comparison of the capabilities of renewable energy sources [41].

Renewable Energy Specification	Min. Power Generation Capability	Max. Power Generation Capability	Mean Power Generation Capability	Mean Electricity Generation Capability
Solar (watts)	250 kWh	400 kWh	325 kWh	1.5 kWh
Wind (watts)	900	900	900	1182.5 kWh
Biogas	220	380	300	1.7 kWh
Geothermal	368	500	434	1.5 kWh
Hydrogen	150	150	150	1.55 kWh
Ocean	2.5	3.00	2.75	1.6 MWh

#### 4.2. Hydrogen Energy

Table 2 shows the different technologies used for generation of hydrogen energy. Alkaline electrolysis, PEM electrolysis, anion exchange membrane, steam reformation, partial oxidation, and biomass gasification are available in commercial form, with efficiencies of 50–78%, 50–83%, 57–59%, 70–85%, 60–75%, and 35–50%, respectively. Seawater electrolysis is available at the R&D level with an efficiency of 72%, while autothermal reformation and pyrolysis will become available in the near term, with efficiencies of 60–75% and 35–50%, respectively. Solid oxide electrolysis cells will become available in the medium term, with an efficiency of 89%. Photolysis, dark fermentation, photo fermentation, and microbial electrolysis cells are likely to emerge in the long term, with efficiencies of 10–11%, 60–80%, 10%, and 78%, respectively.

**Table 2.** Comparison of available technologies for hydrogen generation.

Reference	Technology	Maturity	Efficiency (%)
[42]	Alkaline electrolysis	Commercial	50–78
[42]	PEM electrolysis	Commercial	50–83
[43]	Solid oxide electrolysis cells	Medium term	89 labs
[44]	Anion exchange membrane	Commercial	57–59
[45]	Seawater electrolysis	R&D	72
[46]	Photolysis	Long term	10–11
[47]	Dark fermentation	Long term	60–80
[48]	Photo fermentation	Long term	10
[49]	Microbial electrolysis cells	Long term	78
[50]	Steam reformation	Commercial	70–85
[51]	Partial oxidation	Commercial	60–75
[52]	Autothermal reformation	Near term	60–75
[53]	Plasma reformation	Long term	9–85
[54]	Biomass gasification	Commercial	35–50
[55]	Pyrolysis	Near term	35–50

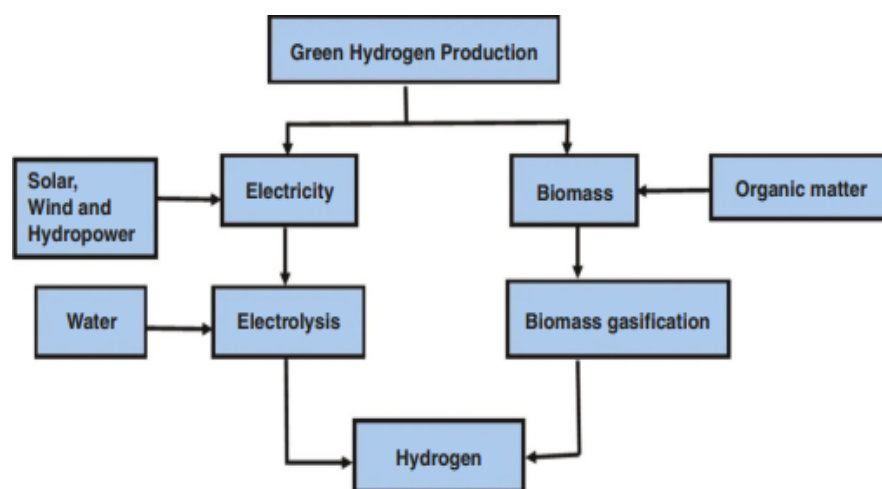
Table 3 shows the capital costs of hydrogen and battery storage. The battery charging cost is currently USD 196/kW, the discharging cost is USD 60/kW, and the storage cost is USD 218/kW. The underground hydrogen charging, discharging, and storage costs are USD 942/kW, USD 574/kW, and USD 0.08/kW, respectively, while the aboveground hydrogen charging, discharging, and storage costs are USD 942/kW, USD 574/kW, and USD 0.08/kW, respectively.

**Table 3.** Capital cost of hydrogen and battery storage [56].

Technology	Charging Cost (USD/kW)	Discharging Cost (USD/kW)	Storage Cost (USD/kW)
Battery	196	60	218
Hydrogen underground	942	574	0.08
Hydrogen above ground	942	574	35

Green hydrogen has the potential to be extremely important in the transition to a more sustainable and clean energy future when costs decrease, technology advances, and policies that support it are implemented. A possible method for creating hydrogen from renewable energy sources is shown in Figure 7. Upon decomposition of organic matter,

such as food scraps and animal manure, biogas, an environmentally benign renewable energy source, is created. Organic materials or agricultural waste can be gasified in a regulated setting to extract a mixture of hydrogen and methane (biogas) that can be used to power vehicles, heat homes, and produce electricity. Electrolysis is a process that turns water into hydrogen and oxygen using energy generated by renewable sources, like solar technology (photovoltaics (PVs) or concentrated solar power (CSP)), wind, or hydropower. The hydrogen produced can be stored or used for a variety of applications, including industrial processes and fuel cells.



**Figure 7.** A possible route for generating hydrogen using renewable energy.

Green hydrogen is a clean energy source that requires cooperation from businesses, governments, communities, and academic organizations. Its generation presents an opportunity to boost sustainable growth, diversify energy sources, and lower CO<sub>2</sub> emissions (Table 4). Sub-Saharan Africa, the Middle East and North Africa, North America, Oceania (Australia), South America, the rest of Asia, Northeast Asia, Europe, and Southeast Asia have estimated energy capacities of around 2715, 2023, 1314, 1272, 1114, 684, 212, 88, and 68 exajoules (EJs), contributing 28.6, 21.3, 13.3, 13.4, 11.7, 7.2, 2.23, 0.92, and 0.67% of the total, respectively.

**Table 4.** Potential for producing green hydrogen worldwide, broken down by region [57].

Region	Estimated Energy Capacity, Exajoules (EJs)	Percentage Contribution
Sub-Saharan Africa	2715	28.6
Middle East and North Africa	2023	21.3
North America	1314	13.8
Oceania (Australia)	1272	13.4
South America	1114	11.7
Rest of Asia	684	7.2
Northeast Asia	212	2.23
Europe	88	0.92
Southeast Asia	68	0.67

#### 4.3. Solar Energy

Table 5 shows the global solar energy potential by continent without an EROI threshold. Africa has the highest amount of solar energy, with a total of 444 J/year (40% of the global total), PVs of 444 J/year (37% of the total), and CSP of 112 J/year (38% of the total). Asia has

the second-highest potential, with a total of 315 J/year (29% of the total), PVs of 361 J/year (30% of the total), and CSP of 72 J/year (25% of the total). Oceania is third, with a total of 125 J/year (11% of the total), PVs of 129 J/year (11% of the total), and CSP of 55 J/year (19% of the total), and South America is fourth, with a total of 114 J/year (10% of the total), PVs of 120 J/year (10% of the total), and CSP of 23 J/year (8% of the total). North America and Europe have the lowest solar energy potentials (Table 5).

**Table 5.** Global solar potential (total, photovoltaics (PVs), and concentrated solar power (CSP)) split by continent without an EROI threshold. All values in J/year [58,59].

Continent (EJ/Year)	Total	% of Global Total	PV	% of PV	CSP	% of CSP
Africa	444	40	444	37	112	38
Asia	315	29	361	30	72	25
Oceania	125	11	129	11	55	19
South America	114	10	120	10	23	8
North America	68	6	106	9	25	8
Europe	24	2	27	2	4	1

When setting the EROI value at  $\geq 9$  and splitting the global potential energy per year by continent (Table 6), Africa again is in first place, with a total of (PV only) 124 J/year (67% of the global total), followed by Asia (35 J/year, 19% of the total), South America (14 J/year, 8% of the total), and Oceania (11 J/year, 6% of the total). North America and Europe made no contribution.

**Table 6.** Global potential at EROI  $\geq 9$  split by continent. All values in J/year [60–63].

Continent	Total (PV Only)	% of Total
Africa	124	67
Asia	35	19
Oceania	11	6
South America	14	8
North America	0	0
Europe	0	0

## 5. Conclusions

This paper assessed renewable energy potential from a global perspective, based on a review of the literature. By 2050, the global population will be 9 billion, and the demand for energy will have increased accordingly. However, the goal for 2050 is to achieve zero net carbon emissions, and this can only be achieved if all countries contribute as much as possible. To this end, developed countries are focusing on green energy policies, whereas underdeveloped countries, particularly in Africa, are currently not involved in such efforts. Future energy sources, such as offshore energy, solar energy, and wind and geothermal power, are hot research areas at present.

Offshore energy can be obtained in three main forms: ocean thermal energy, wave energy, and tidal energy. The USA has the highest tidal energy potential (57 GW), followed by Canada (29 GW) and Russia (16 GW). Europe has the lowest known tidal energy potential (2 GW). The mean global capabilities for solar, wind, biogas, geothermal, hydrogen, and ocean energy are 325 W, 900 W, 300 W, 434 W, 150 W, and 2.75 MWh, and their mean capacities for generating electricity are 1.5 KWh, 1182.5 KWh, 1.7 KWh, 1.5 KWh, 1.55 KWh, and 3.6 MWh, respectively. Thus, the ocean is the renewable source that can produce by far the most electricity (offshore).

The various technologies for producing hydrogen energy include steam reformation, partial oxidation, alkaline electrolysis, PEM electrolysis, an anion exchange membrane, plasma electrolysis, steam reformation, and biomass gasification, with efficiencies of around 60–85%. All of these processes are available in commercial form. Autothermal reformation and pyrolysis will become available in the near future (efficiencies of 60–75% and 35–50%, respectively), while seawater electrolysis is only available at the R&D level with 72% efficiency.

The solar energy global potential split by continent without an EROI threshold is the highest for Africa (40% of the global total), followed by Asia (29%), Oceania (11%), and then South America (10%).

Thus, the availability of renewable energy differs between continents, as well as the utilization of said energy. Real-time monitoring of energy consumption is now possible by using intelligent electrical gadgets and sensors in smart energy meters. In order to adopt more effective energy-saving techniques, it is important to reveal consumption patterns through real-time monitoring of energy usage. Smart energy meters enable electrical utility companies to remotely gather meter readings without having to visit a customer's location, saving money, time, and effort. They provide accurate real-time data on energy consumption, and time-of-use pricing is applied, which improves billing accuracy. They also enable real-time electrical supply system monitoring and can identify service problems more quickly, giving a more dependable electrical supply. Customers can use information on their patterns of energy consumption to make decisions that maximize energy efficiency and reduce energy costs. This lowers energy use, which in turn reduces greenhouse gas emissions and the carbon footprint. Integrating renewable energy sources such as solar, wind, and geothermal power with the conventional grid is made easier through the use of smart energy meters, reducing the need for energy generation using conventional techniques. However, smart energy meters have some drawbacks, including poorer customer adoption, greater installation costs, and cybersecurity vulnerabilities.

## 6. Recommendations

In efforts to achieve net zero carbon emissions by 2050, we make the following recommendations, especially for African leaders, since that continent has not yet set any green energy targets:

- Securing the energy sector brought about a great revolution to SDG achievement. Therefore, all nations should pay attention to energy security first.
- Resources are limited, and thus global attention must focus on renewable energy. Tidal (offshore) energy is the most suitable renewable energy source.
- Africa has many renewable energy sources, but tidal energy is available only off the west coast of Africa. ECOWAS countries must collaborate on the utilization of available tidal energy for the prosperity of all.
- African countries should focus on renewable energy sources such as hydrogen production and wind, geothermal, biogas, and solar power. To contribute to net zero carbon emissions and overcome poverty, all leaders of African countries must turn to renewable energy and take action immediately.
- Achieving net zero carbon emissions by 2050 and green energy generation will be difficult for individual African countries, and thus we recommend that groups of countries unite within regions to invest in renewable energy.
- Developed countries cannot achieve net zero carbon emissions by 2050 on their own. This must be a common goal for all countries worldwide.
- The East Africa region has a massive amount of resources, and continued growth in hydro, coal, oil, gas, bioenergy, and solar PV power is predicted up until 2040. However, the region faces challenges in providing affordable and reliable electricity for its population. For instance, high electricity prices in Kenya limit household use and discourage energy-intensive industries, while in Ethiopia and other countries, almost 85% of the population does not have access to electricity. Leaders in East

- African countries should concentrate on renewable energy to improve the prosperity of the region.
- According to the Ministry of Water, Irrigation, and Energy (MoWIE), Ethiopia had generation capacity of 2310 MW in 2015, and there were plans to expand the nation's power output capacity to 15,000 MW by 2020. However, the population is increasing, as is energy demand. To fulfill the energy demands of the growing population, the Ethiopian government should focus on hydrogen production from water and biogas, wind, solar, and geothermal sources.
  - Geothermal energy (heat) from the inner core of the Earth is one of the most sustainable forms of energy. The technology works by pushing hot water from reservoirs in volcanoes and geysers toward the surface, where it turns into steam due to the reduced pressure. Active volcanoes are proving important in the global race to transition to renewable energy, with regions containing these natural wonders working to harness their heat. Erta Ale, a continuously active basaltic shield volcano in the Afar Region of northeastern Ethiopia, which is part of the wider Afar Triangle, has not been used for energy generation in the country to date, but it could solve domestic energy problems and reduce the carbon footprint for the country and the continent.

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