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MORALITY BEFORE KNOWLEDGE

Development strategy toward renewable energy society: Integrating energy potential, efficiency, and community awareness

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ABSTRACT

Background: Energy demand continues to rise in line with global population and industrial growth. In Indonesia, approximately 87.3% of total energy supply is still generated from fossil-fuel-based power plants, leading to high CO_2 emissions and environmental degradation. Despite its abundant renewable resources, such as hydropower, solar, and wind, the national transition toward clean energy remains slow. This study aims to examine strategic pathways to accelerate renewable energy development and establish a renewable energy–based society in Indonesia. **Methods:** This research employs a quantitative approach using secondary data derived from previous studies and official national statistics to evaluate Indonesia's greenhouse gas (GHG) emission profile and renewable energy potential. Analytical techniques include the driver pressure state impact response (DPSIR) framework to assess causal relationships between human activities and environmental impacts, complemented by logical framework analysis (LFA) to identify the root causes hindering the adoption of renewable energy technologies. **Findings:** The study reveals that Indonesia possesses sufficient renewable energy resources to substitute existing coal-fired power plants entirely through the optimization of hydropower, solar, and wind energy systems. However, the transition process is hindered by multiple challenges, including technical limitations, financial constraints, and inconsistent policy implementation. The findings also emphasize the importance of community awareness, sustainable urban planning, and electrification of transportation systems to support nationwide decarbonization efforts. **Conclusion**: The development of a renewable energy society integrating energy efficiency, environmental awareness, and policy reform constitutes a critical step toward achieving a sustainable and climate-resilient future for Indonesia. **Novelty/Originality of this article**: This study introduces a holistic framework for establishing a renewable energy society in Indonesia by combining the DPSIR and LFA analytical methods. The proposed framework not only identifies systemic barriers but also outlines practical and policy-based strategies to accelerate the national energy transition while maintaining social, economic, and environmental sustainability.

KEYWORDS: CO_2 emission; fossil and renewable energy; power plant; renewable energy society; sustainable world.

1. Introduction

Industrial revolution began in year 1760 to 1830, in this era the use of fossil energy and pollution increase dramatically. Huge amount of CO_2 is produced and release to atmosphere. Population growth increase the problem, more population demand more house hold product, require more transportation, and more energy. The awareness on the

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sustainable environment is low until significant sign of nature degradation arise, global warming and climate change occur. Conflict of economic and environmental sustainability become more and more obvious. Since the beginning of 21st century, global greenhouse gas (GHG) emissions had followed is increasing. As a result, the atmospheric concentrations of greenhouse gases substantially increased enhancing the natural greenhouse effect, which may negatively affect the life on the Earth (Clark & Jacks, 2007).

Japan has been developing nuclear power plant since 1966, and nuclear energy has been a national strategic priority since 1973. Until 2011, Japan produced approximately 30% of its electricity from nuclear reactors, with projections aiming to raise this share to at least 40% by 2017. However, the current target has been adjusted to a minimum of 20% by 2030. Despite being the only nation to have experienced the catastrophic impact of nuclear weapons during wartime—resulting in over 100,000 fatalities—Japan adopted nuclear technology for peaceful purposes to supply a significant portion of its electricity. Initially, nuclear energy was anticipated to assume an even more prominent role in the country's future energy mix. In the context of the government's 'Cool Earth 50' energy innovative technology plan in 2008, the Japan Atomic Energy Agency (JAEA) modelled a 54% reduction in CO_2 emissions by 2050 leading onto a 90% reduction by 2100 (Shiraki et al., 2021).

Within the United Nations Framework Convention on Climate Change (UNFCCC), Indonesia has demonstrated a strong commitment to reducing greenhouse gas (GHG) emissions. Targeting 544 Million Tons reduction in year 2030, then targeting 540 Million Tons in year 2050, then achieve net-zero GHG emissions before year 2060. These targets are written in government regulatory frameworks, such Undang Undang No. 16/2016 Presidential Regulation/*Peraturan Presiden* (PERPRES) No. 18/2020 on the 2020–2024 National Medium-Term Development Plan (Rum et al., 2024).

On the contrary, until end of year 2022 total capacity of power plant in Indonesia is 83,813 MW. Industrial usage reach 62.5%, household 23.5%, commercial 10.2%, and pubic facility 3.8%. If look at the source of energy coal fired power plant 31.6%, oil 24.1%, gas 28.7%, hydropower 10.9%, and geothermal 1.8% Looking at this figure, the renewable energy source is only 12.7% and the rest is obtained by burning hydrocarbon that of course lead to CO_2 emission. This condition is now understandable because Indonesia still has huge reserve of coal for the next 62 years (ESDM, 2022).

The objective of this research is creating insight as preliminary step to make society development plan in integration with low energy usage development plan, conversion of fossil fuel engine vehicle to electric driven vehicles, and developing the use of renewable power plant, micro hydro power plant at individual and community level, individual wind turbines, and individual solar panels, and to be successful the development plan should be economically profitable to community, Socially acceptable, environmentally sustainable, and technologically manageable.

Europeans played a large role in the global oil and gas industry development. Since 1850s the use of oil was obtained almost exclusively from mining exploration. The use of oil increased in the 1860s with the introduction of new exploration and refining technology. Coal and oil technology continue to develop until today, however the excessive use of coal and oil have serious downside to climate change. Assimilation capacity of the earth on CO_2 emission has gone beyond limit (Craig et al., 2018).

Indonesia is an archipelago at the equator, this geographical position makes the country has luxurious access to unlimited renewable energy, sunlight, wind, and water (Silalahi et al., 2021). On the other side Indonesia is also blessed with oil and coal. This condition provides Indonesia with option in using the source of energy. In line with Indonesia commitment on GHG emission reduction the development of renewable energy utilization should have continuously increasing, the number of hydropower, wind power, and solar power should have been continuously constructed, but in actual until today only 12.7% of the national power need comes from renewable energy.

Indonesia is the 8th largest CO_2-emitting country in the world and the largest in Southeast Asia, with a total emission of 1.3 gigatons of CO_2 per day. Until the end of 2022, the total installed capacity of power plants in Indonesia reached 83,813 MW. This electricity capacity is distributed across various sectors, with industrial use accounting for 62.5%, household use 23.5%, commercial use 10.2%, and public facilities 3.8% (ESDM, 2022). In terms of energy sources, the composition consists of coal-fired power plants at 31.6%, crude oil-fired power plants at 24.1%, gas-fired power plants at 28.7%, hydropower at 10.9%, and geothermal energy at 1.8% (PLN, 2023).

The proportion of renewable energy sources in Indonesia is only 12.7%, while a massive amount of CO_2 continues to be released into the atmosphere. PLN (2023) presents the results of a study on the emission factor of Indonesia's Coal-Fired Power Plants/*Pembangkit Listrik Tenaga Uap* (PLTU), which is approximately 1.057 kg CO_2/kWh. This means that every day, coal-fired power plants throughout Indonesia emit around 1.057 kg CO_2/kWh × 83,813 × 1,000 kWh, equivalent to 88,590,341 kg CO_2 released into the atmosphere (Budi & Suparman, 2013). The main problems that must be addressed are how to meet energy demands without increasing national greenhouse gas emissions, and how to develop a renewable energy-based society to anticipate climate change while maintaining the earth's carrying and assimilation capacity. Every society requires a continuous supply of energy to meet basic human needs such as lighting, communication, cooking, mobility, air conditioning, and other daily activities (Frigo et al., 2021; Willand et al., 2024). However, most of today's electricity is still produced through carbon combustion, which generates CO_2 emissions. As a result, the atmospheric CO_2 concentration continues to increase and had reached 390 ppm by the end of 2010, about 39% higher than pre-industrial levels indicating a trend of global warming. Consequently, the global mean temperature is projected to rise within a range of 1.1°C to 6.4°C between 1980–2000 (Moomaw et al., 2011).

Society of renewable energy or SRE is a society that strive for energy transition from non-renewable energy to renewable energy use. Going to the root grass level there are Renewable Energy Community or REC that consist of various citizens, local business, companies, and government agencies that join together to produce electricity from renewable sources and able to meet their needs with their own clean energy source. Society and community movement is bottom up effort and this movement is hardly made their goal without government support. Willingness of the government is realized in the way of making policy, regulation and also providing incentives. Development plan shall be integrated with strategy to lower energy consumption and renewable source of energy.

2. Methods

The methodology employed in this study adopts a quantitative research approach utilizing secondary data obtained from previous studies. This approach is designed to address two primary objectives first, to quantify Indonesia's contribution to global greenhouse gas (GHG) emissions despite its abundant renewable energy potential, and second, to develop strategies for optimizing electricity generation through available renewable energy sources. The observation period spans four years, from 2020 to 2024, to ensure that the analysis captures recent trends and policy developments related to energy transition and emission mitigation.

To identify relevant indicators and evaluate the feedback effects arising from energy-related decisions, the Driver Pressure State Impact Response (DPSIR) framework is applied. The DPSIR framework establishes a causal chain that begins with driving forces, such as economic sectors and human activities, which exert pressures in the form of emissions and waste. These pressures subsequently influence environmental conditions, physical, chemical, and biological, and ultimately affect ecosystems, human health, and societal functions. The final stage of the framework involves defining appropriate responses that can mitigate adverse effects and restore balance. To complement this analysis, a logical framework analysis is utilized to identify the underlying root causes contributing to Indonesia's persistent dependence on fossil fuels and its limited adoption of renewable energy.

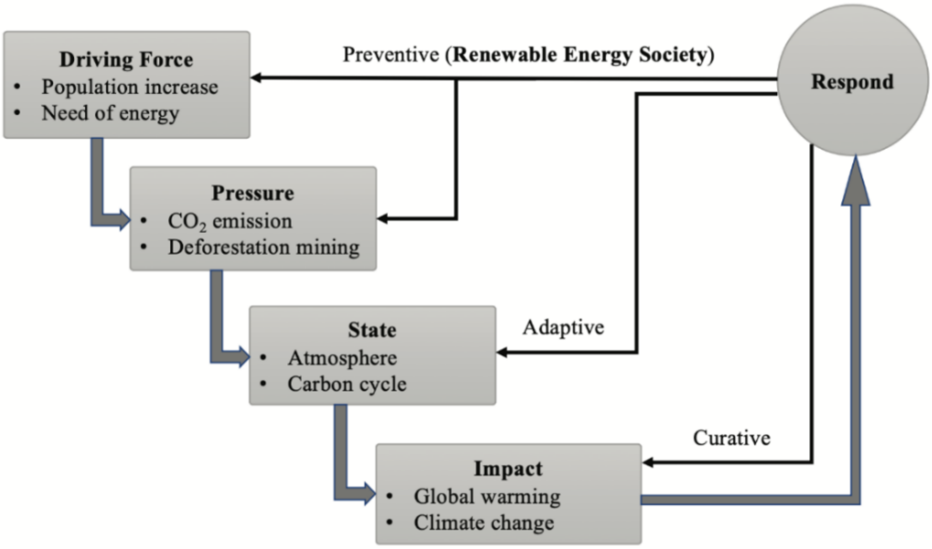


Fig. 1. DPSIR analysis

The logical framework approach provides a systematic and structured method that integrates analytical and planning tools in the design of interventions. It serves as a reference framework that can be applied throughout all stages of the intervention cycle. The process begins with an analytical phase, during which all potential causes are identified and mapped. These analyses are generally carried out during the identification phase and are gradually refined in an iterative process throughout the design phase until the main causal pathways are clearly established, as illustrated in Figure 2. At root cause level 3, three main drivers are recognized; (1) the continuing abundance of coal reserves, (2) the lack of stakeholder interest in renewable energy initiatives, and (3) the geographic dispersion of communities, which intensifies the demand for mobility and transportation energy. Progressing to root cause level 4, two deeper systemic issues emerge, (1) persistent economic dependence of stakeholders on the profitability of coal and oil industries, and (2) the low level of environmental awareness across both public and institutional domains. At the most fundamental level, the analysis concludes that the combination of economic motivations and limited environmental consciousness represents the core impediment to achieving sustainable development and maintaining the ecological balance of the earth.

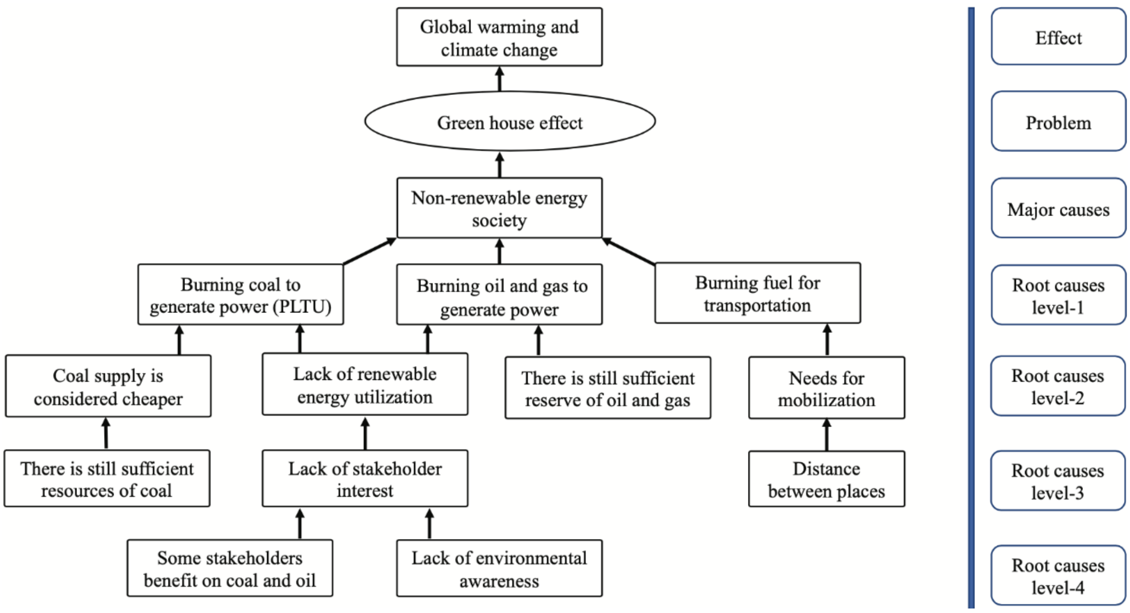


Fig. 2. Logical framework analysis

3. Results and Discussion

Based on the logical framework analysis we can have a big picture on the fact that composition of power generation type, fossil and renewable energy resources remains stagnant over the past years. Nowadays to fulfil demand on electricity government has built tremendous amount of coal fired power plant along coast of Indonesia. This policy is supported by the availability of coal resources and modular power plant that has been available from manufacturing country. Economic calculation on coal fired power plant is obvious and can be managed by government. State-own PLN will pay for every Watt of electricity generated by PLTU therefore the sustainability of this business is somehow secure (PLN, 2023). Business driver and lack of environmental awareness are keys factors against sustainable environment goal.

Renewable energy society is not scoping on the daily human activity and consumed energy only, but should also scope the industry sector because indirectly industry serve human need. Car industry exist because human demand for private transportation, plastic industry exists because human demand on plastic material. Electric power usage increases due to population growth and electric power usage per capita. CO_2 emission released to atmosphere every day is huge that might lead to global warming despite that renewable energy resources are unlimited.

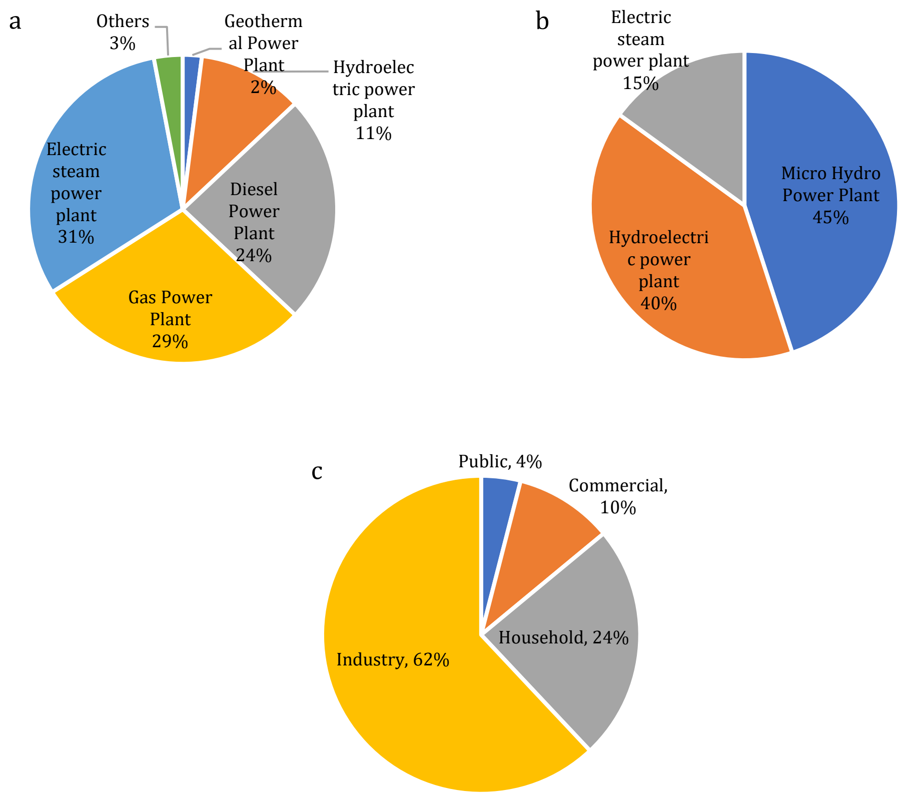


Fig 3. (a) power generation type and precentage; (b) potential of Indonesia renewable power genertaion vs current non- renewable energy power generation; (c) power utilization percentage

Topographically, Indonesia possesses significant hydro-power potential due to its mountainous landscape and abundant river systems. When the potential of large-scale hydro-power and micro-hydro installations is combined, the total capacity surpasses the current generation capability of coal-fired power plants/*Pembangkit Listrik Tenaga Uap* (PLTU), indicating that large-scale substitution of fossil-based energy is technically feasible. Although the development of hydro-power plants requires substantial infrastructure investment, particularly in dam construction, the long-term benefits are multifold. Besides providing a stable and renewable electricity supply, hydro-power development creates new aquatic ecosystems, enhances irrigation networks that boost agricultural productivity, and offers the advantage of very low operational costs once established. Most importantly, hydro-power generation emits no CO_2, making it one of the cleanest and most sustainable sources of electricity available.

It has been widely described that Indonesia possesses substantial potential for renewable energy development; however, the country continues to import approximately 600,000 barrels of crude oil per day to meet a domestic demand of around 1,200,000 barrels per day. In addition, Indonesia remains heavily dependent on coal-fired power plants as the primary source of electricity generation. This persistent reliance on fossil energy is not a single, isolated problem but rather a complex issue influenced by interrelated stakeholder interests, economic dependencies, and political considerations. According to the World Future Council, based in Hamburg, Germany, the primary obstacle preventing a global transition away from fossil fuels lies in the lack of political will. The Council emphasizes that world leaders, particularly those participating in the United Nations summits, must establish ambitious targets and clear timelines to accelerate the transition toward renewable energy systems.

Indonesia's commitment to renewable energy is, in fact, embedded within its constitutional mandates, government regulations, and ministerial decrees, reflecting strong policy support from both the central government and the legislative body. However, despite these formal commitments, new coal-fired power plants continue to be constructed, and restrictions remain in place regarding the synchronization of solar energy with the national electricity grid. The adoption of a 100% renewable energy target would send an unequivocal signal to investors that clean technology development is a secure and viable long-term commitment. The World Future Council report emphasizes that such a transition offers extensive benefits, including reduced dependency on fossil fuel imports, strengthened energy and economic security, and lower energy costs for governments, industries, and local communities.

Encouragingly, several regions around the world have already demonstrated that complete reliance on renewable energy is achievable. For instance, the Rhein-Hunsrück district west of Frankfurt, Germany, successfully met 100% of its electricity demand from renewable sources as early as 2012. By the end of that year, it had achieved an energy surplus equivalent to 230% of its local needs, exporting excess electricity to neighboring regions through the national grid. The district also plans to utilize this surplus for local transportation, as well as for hydrogen and methane production, further closing the loop toward a sustainable energy ecosystem. This success story illustrates a global shift away from fossil fuel dependence toward clean, renewable energy solutions. Renewable energy technologies are not merely an environmental necessity but also a catalyst for economic and social transformation, signaling the end of the fossil fuel era and the beginning of an energy renaissance (Caineng et al., 2023; Hassan et al., 2024; Rajput & Pathak, 2025). Indonesia, therefore, must embrace this transition proactively, capitalizing on its abundant natural resources to ensure that the move toward renewables maximizes benefits both for the present society and for future generations.

The development strategy toward a renewable energy society must be implemented comprehensively across all sectors, ensuring that every aspect of development consistently integrates energy efficiency and environmental considerations (Ahmed et al., 2024; Chou et al., 2023). At the community level, the primary strategy focuses on continuously enhancing public awareness of global warming and climate change through behavioral change, including minimizing household energy use, reducing plastic consumption, and lowering electricity demand to decrease greenhouse gas emissions. In the transportation sector, development should prioritize the widespread adoption of electric vehicles, including electric cars, buses, and trains, over conventional combustion engine vehicles to reduce dependence on fossil fuels.

Urban development strategies should emphasize the creation of green and compact cities, featuring pedestrian-friendly areas within a ten-minute walking distance, well-designed sidewalks, and adequate green spaces that support biodiversity conservation and tree protection. In the education sector, environmental awareness should be introduced early through formal curricula starting from the kindergarten level, instilling sustainability values from an early age (Petkou et al., 2025; Veselinovska et al., 2025). For building design and construction, the integration of environmentally responsive architectural concepts is essential. Such designs should aim to minimize electricity use for lighting, air conditioning, and water systems while enhancing natural air circulation, incorporating green walls and roofs, and optimizing sunlight penetration into the interior. The energy supply system in development areas should rely primarily on renewable energy sources, such as solar panels, hydro-power, and wind turbines. The installation of individual building-based solar systems can substantially reduce the overall energy demand of urban centers.

Moreover, effective law enforcement mechanisms are necessary to limit the expansion of non-renewable energy utilization and to impose mandatory renewable energy adoption for corporations. To reinforce these efforts, the government should introduce incentive policies for corporations and local authorities that demonstrate leadership and commitment to pioneering renewable energy applications. Nevertheless, it is important to recognize that political motivations also play a significant role in influencing decision-making processes related to renewable energy development. In a renewable energy–oriented society, environmental issues may become a powerful instrument for shaping public opinion and policy direction. Fossil fuel consist of carbon and its oxidation reaction will produce CO_2 and heat. The amount of CO_2 released is equal with number of carbons in the fuel that oxidized, therefore, CO_2 emission can be calculated using chemical reaction Equation 1.

$$C + O_2 \rightarrow CO_2 + \text{heat} \qquad \text{(Eq. 1)}$$

One carbon molecule will produce one molecule of CO_2, then to convert to Kg unit it is multiplied with the molecular weight. Molecular weight of Carbon is 12 gram/mol and molecular weight of CO_2, is 44 gram/mol, so 1 Kg of Carbon will produce 3.67 Kg of CO_2. Other type of fossil fuel having CO_2 emission is coal. Coal is burned inside boiler chamber to heat up and convert water to become superheated steam and due to it's expansion the steam pressure increase dramatically enough to rotate electric generator turbine. To generate 1 MW of electricity needs to burn 12 tons of coal. This number vary among power plants depends on their efficiency. A study has been carried out using several coal-fired power plant PLTU Banten CO_2 emission factor is 1.033 Kg/kWh, PLTU Indramayu CO_2 emission factor is 1,002 Kg/kWh, and Rembang electric steam power plant CO_2 emission factor is 1,136 Kg/kWh. The average result of electric steam power plant CO_2 emission factor is 1,057 Kg/kWh (Budi & Suparman, 2013). The fuel combustion engine operates by converting the chemical energy stored in the fuel into mechanical energy through the process of burning or oxidizing the hydrocarbon content of the fuel, which produces heat and carbon dioxide (CO_2). The simplified equilibrium equation for the combustion of a hydrocarbon fuel can be represented by Equation (2).

$$CnH_2n+_2 + nO_2 \rightarrow \text{Heat} + H_2O + nCO_2 \qquad \text{(Eq. 2)}$$

Emission factor can be calculated using the same Carbon oxidation reaction where 1 Kg of Carbon will produce 3.67 Kg CO_2. Gasoline contain 63% Carbon, therefore 1 Kg of gasoline, which contains about 0.63 kg of carbon, produce approximately 0.63 x 3.67 Kg = 2.3 kg of CO_2. Tailpipe CO_2 emission vary by fuel type and engine efficiency. Diesel fuel is denser than gasoline therefore it will produce more CO_2 for the same amount of fuel burned. Electric-driven vehicles have been developed long ago, and with the improvement of battery performance, electric vehicles have become increasingly feasible, allowing longer ranges to be achieved on a single charge. Charging infrastructure has also been initiated by PLN through the installation of electric vehicle charging units at rest areas. In this paper, the focus is on the electricity generated by coal-fired power plants, as they contribute the most to current power generation.

Table 1. Tailpipe CO_2 emission

Fuel type	Tailpipe CO_2 (kg/l fuel)
Gasoline	2.29
Ethanol E85	1.61
Biodiesel B5	2.65
Biodiesel B20	2.62

(Natural Resource Canada, 2014)

The CO_2 emission of electric vehicles is calculated by converting the electrical power used into the equivalent amount of coal burned in electric steam power plant. Studies on electric vehicles show that every 1 kW of electricity enables a travel distance of 7–8 km. The electric motors used in electric vehicles are designed to have a dual function as both motors and generators. When the car accelerates, power is supplied from the battery to the motor; when it decelerates or moves downhill, the motor acts as a generator, supplying power back to the battery, thereby minimizing energy loss. The comparison between electric vehicles and gasoline vehicles in terms of fuel consumption, cost, and CO_2 emission is presented in Table 2. The basic calculation uses a gasoline-engine light vehicle as the reference, with a gasoline CO_2 emission factor of 2.41 kg CO_2/kg, a coal CO_2 emission factor of 1.057 kg CO_2/kW, electric vehicle power consumption of 1 kW per 8 km, gasoline vehicle fuel consumption of 0.8 kg per 8 km, gasoline price of IDR 10,000 per kg, and electricity price of IDR 2,500 per kW, as shown in Table 2.

Table 2. Comparison study between fossil fuel vehicle against electric vehicle

Parameter	Fossil Fuel Vehicle	Electric Vehicle
Fuel type	Gasoline	Coal convert to electricity
Power consumption / 8 Km	0.8 Kg of gasoline	1 kW of electricity
Cost per 8 Km distance	IDR 8,000	IDR 2,500
CO_2 emission	1,928 Kg	1,057 Kg

At global level, CO_2 emission growth was still relatively slow until the mid 20th century. In 1950 the world emitted 6 billion tonnes of CO_2. By 1990 this had almost quadrupled, reaching more than 20 billion tonnes. Emissions have continued to grow rapidly we now emit over 35 billion tonnes each year. Nature has given ecosystem service in CO_2 cycles where trees on its chlorophyll can absorb and convert to glucose and releasing oxygen, however concentration of CO_2 in atmosphere is continuously growing due imbalance of this cycle. The amount of CO_2 produced is way above the capacity of trees in sequestering the CO_2, leave the excess goes to atmosphere. At standard Temperature and Pressure bulk density of CO_2 is 1.98 Kg/m^3 while bulk density of air is 1,225 Kg/m^3 therefore CO_2 will remain floating on earth surface. Despite the increasing of CO_2 emission forest clearing make multiple the green-house gas effect. Green-house gases like CO_2, CH_4, N_2O, and certain synthetic aerosol substances is responsible for global warning since these gases keep the energy trapped in the atmosphere. Green-house gases emissions associated with energy services are a major cause of climate change. Most of the observed increase in global average temperature since the mid 20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations (Moomaw et al., 2011).

The most recent assessment, finalized in March 2023 by the Intergovernmental Panel on Climate Change, reported that carbon dioxide contributes the largest share—approximately 75%—of total greenhouse gas (GHG) emissions in the atmosphere, followed by methane at 18% and nitrous oxide at 4%. Since the early 21st century, global greenhouse gas (GHG) emissions have shown a continuous upward trend, largely driven by rising emissions from China and other emerging economies. Consequently, atmospheric concentrations of greenhouse gases have increased significantly, intensifying the natural greenhouse effect and potentially threatening life on Earth. Recent data indicate that global

GHG emissions reached 53.0 Gt CO_2eq in 2023 (excluding emissions from land use, land-use change, and forestry). This marks the highest level on record, reflecting an increase of 1.9%, or 994 Mt CO_2eq, compared to 2022 levels.

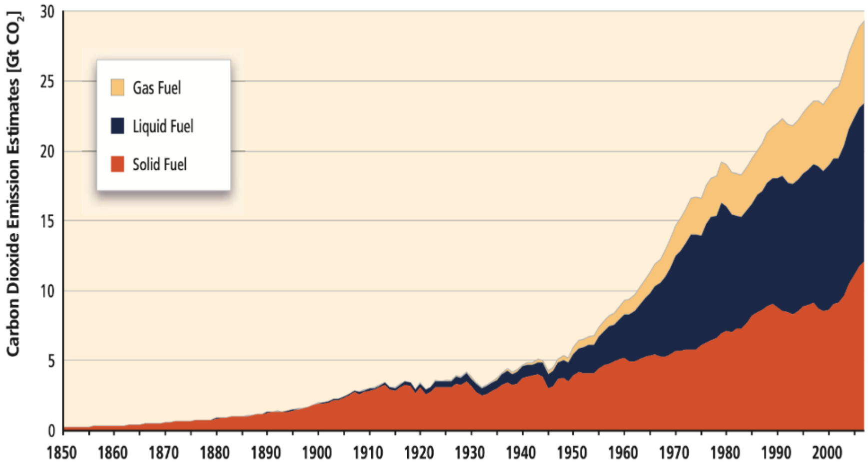


Fig. 4. Global CO_2 emissions from fossil fuel burning, 1850 to 2007 (Moomaw et al., 2011)

Climate change according to IPCC (Intergovermental Panel on Climate Change) is defined as every change of climate over the time caused by natural variability and human activity (NEC, 2011). Main cause of climate change is still under debate among scientist. Geological evidence indicates that, over timescales of thousands of years, the Earth's climate undergoes continuous fluctuations, with major ice ages occurring roughly every 100,000 years. These recurring glacial periods are largely driven by astronomical factors, particularly subtle variations in the distance and orientation between the Earth and the Sun. As the Earth revolves around the Sun, three regular orbital changes take place. One of these is that the Earth's orbit is slightly elliptical, and its eccentricity—meaning the extent to which it deviates from a perfect circle—varies over time. Second, the Earth's rotational axis is inclined relative to its orbital plane, with this tilt varying between 21.6° and 24.5° over a cycle of about 41,000 years; at present, it is approximately 23.5°. Third, the timing of when the Earth reaches perihelion—its closest position to the Sun—shifts over a cycle of roughly 23,000 years. These three cyclical variations lead to differences in solar radiation across latitudes and seasons, with fluctuations of up to 10% in polar regions during summer. This phenomenon acts as an astronomical driver of climate, contributing to the occurrence of ice ages, during which global average temperatures are estimated to be about 5–10°C lower than current levels. At present, the Earth is in an interglacial period between two ice ages, and without additional influencing factors, another ice age is expected to occur over thousands of years. The rate of global temperature change driven by these astronomical factors is relatively slow, typically amounting to only a few tenths of a degree Celsius per thousand years.

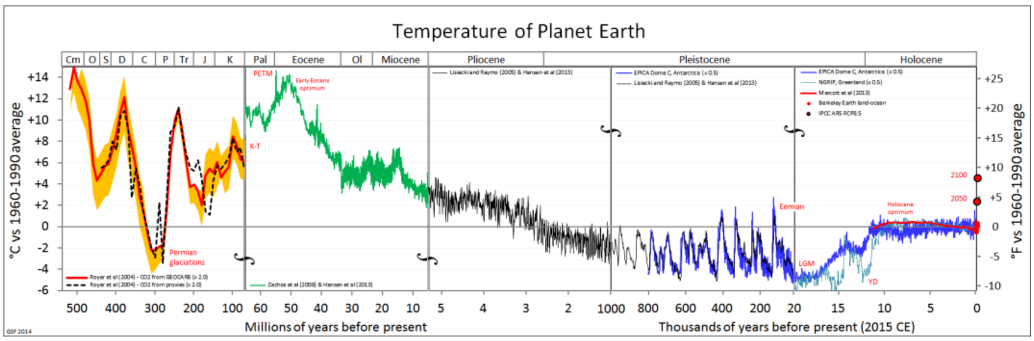
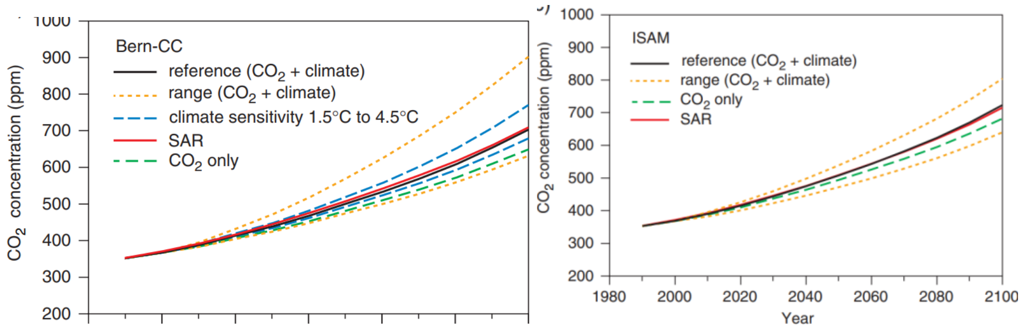


Fig. 5. Planet earth temperature dinamic (Farquhar et al., 2001)

Global surface temperature (GST) refers to the average temperature of the Earth's surface, encompassing both land and ocean areas. It is a key indicator used to understand changes in the Earth's climate system. Historical estimates of Earth's temperature have been derived from various natural proxies, including tree rings, corals, and ice cores, which provide indirect but reliable records of past climate conditions. In the modern era, temperature data are obtained from weather stations and satellite observations, offering more precise and continuous measurements.

The consistent increase in GST over time is widely recognized as strong evidence of ongoing climate change. Various estimates of global temperature have been developed, particularly since the end of the Pleistocene glaciation and throughout the current Holocene epoch. Geological evidence allows scientists to reconstruct temperature conditions extending back millions of years, while ice core data provide detailed records covering approximately the last 800,000 years. Additionally, tree rings and ice core measurements offer valuable insights into temperature variations over the past 1,000 to 2,000 years, contributing to a more comprehensive understanding of long-term climate trends.



(a) (b)

Fig. 6. (a) Projected CO_2 concentration were made with two fast carbon cycle models by Bern-CC; (b) Projected CO_2 concentration were made with two fast carbon cycle models by ISAM (Farquhar et al., 2001)

Carbon offset is a positive action that is undertaken to compensate excess of carbon produced by society and companies by creating certain green area. The chemical reaction so called photosynthesis CO_2 will be captured and converted to glucose and release oxygen at the chlorophyll with the help of sun light.

$$6CO_2 + 6H_2O + Light \rightarrow C_6H_{12}O_6 + 6O_2 \quad \text{(Eq. 3)}$$

Tropical forest is lung of the world, this true because it need sunlight to convert CO_2 become glucose and releasing O_2. High intensity of sunlight is available through all the year at the tropical area (Farquhar et al., 2001). The problem is that production of CO_2 gas is increasing continuously that there will be a time of over capacity on the CO_2 absorption. This problem obviously will add more CO_2 emission in the atmosphere. Area in the middle east where most of the world oil is produced the land is dry and has very little green area. Transition to renewable energy is a pathway to sustainable growth. Renewable energy sources, such as solar, wind, hydro, geothermal, and biomass. Renewable energy offers a means to decarbonize energy systems. It has economic, social, and environmental benefits. Renewable energy is is a cornerstone of sustainable development, it is more than a technological solution. By addressing environmental challenges, driving economic growth, and promoting social equity, renewable energy aligns with global aspirations for a sustainable future (Andish & Debo, 2024).

Indonesia has signed Paris Agreement to the United Nations Framework Convention on Climate Change on April 22nd 2016 in New York the United State. This is commitment of Indonesia Government to develop renewable energy and reduce CO_2 emission that is obligatory to be fulfilled. With mountains, lake, and rivers make Indonesia has hydro power potential of 75,091 MW spread across the nation, however currently 7.2% only is utilized.

On the other hands Presidential Regulation of the Republic of Indonesia Number 22 of 2017 about national energy development plan targeting the use of renewable energy at least 23% by the year 2025. Indonesia received a lot of rain in mountainous area that create stable flow of river water that deliver potential of hydropower. Despite this nationwide potential of hydro power plant, the achievement of hydro power plant is very low. A study by Taufiqurrahman & Windarta (2020) uncover total potentials of hydropower in Indonesia is 94,449 MW consist of Hydroelectric Power Plant/*Pembangkit Listrik Tenaga Air* (PLTA) 75,091 MW, PLT Medium and Micro Hydro 19,358 MW, as shown in Tables 3.

Table 3. Hydro power plant and micro-hydro power potential nationwide

Location	MW	Potential
West Papua	22,371	Hydro power plant
South, Central and East Kalimantan	16,884	
South and Shoutheast Sulawesi	6,340	
Aceh	5,062	
West Kalimantan	4,737	
North and Central Sulawesi	3,967	
North Sumatra	3,808	
West Sumatra, Riau	3,607	
South Sumatra, Bengkulu, Jambi, Lampung	3,102	
West Java	2,861	
Central Java	813	
East Java	525	
Bali, West Nusa Tenggara, East Nusa Tenggara	624	
Maluku	430	
Total	75,091	
East Kalimantan	3,562	Micro-hydro power
Central Kalimantan	3,313	
Aceh	1,538	
West Sumatra	1,353	
North Sumatra	1,204	
East Java	1,142	
Central Java	1,044	
North Kalimantan	943	
South Sulawesi	762	
West Java	647	
Papua	615	
South Sumatra	448	
Jambi	447	
Central Sulawesi	370	
Lampung	352	
Southeast Sulawesi	301	
Riau	284	
Maluku	190	
South Kalimantan	158	
West Kalimantan	124	
Gorontalo	117	
North Sulawesi	111	
Bengkulu	108	
East Nusa Tenggara	95	
Banten	72	
West Nusa Tenggara	31	
North Maluku	24	
Bali	15	
West Sulawesi	7	
Yogayakarta	5	
West Papua	3	
Total	19,385	

(Taufiqurrahman & Windarta, 2020)

Norway is a heavy producer of renewable energy because of hydropower. Over 99% of the electricity production from 31 GW hydropower plants, 86 tons per hour reservoir capacity, storing water from summer to winter. Norway is the largest producer of hydropower in Europe and ranks sixth globally. Around 90% of its hydropower capacity is publicly owned, with the largest share controlled by the Norwegian government through the state-owned Statkraft. This company owns nine of the largest hydroelectric plants and is also a significant participant in international energy markets. In addition to Statkraft, electricity generation is carried out by various other state-owned and private companies. Hydropower capacity was approximately 31 GW in 2014, and by 2019, total electricity production had reached 132 TWh, with about 95% derived from hydropower.

Laid in the equator, Indonesia received a lot of sun with high intensity. Solar panel technology development offers more efficient conversion of sunlight energy to become electricity. Synchronizing technology enable automatic combination of current from solar panel and electricity lines, this will greatly replace non-renewable power usage of industrial and commercial use during day operation. According to the traditional solar cell, electrical power cannot generate after the sunset, however solar panel technology continuously developing. A new concept of anti-solar considered the earth as a heat source, this model enables solar panel to generate energy when sunlight is not available during night time. Thermal equilibrium to the surroundings in the dark, the random absorption of photons by the cell equals the random emission from the cell.

Numerous studies have explored the application of nanomaterials in solar technology. Conventional silicon-based solar panels are limited in that they can only harness a portion of the solar spectrum. In contrast, multi-junction solar cells are capable of capturing a broader range of the solar spectrum, thereby significantly enhancing overall efficiency. Furthermore, hybrid solar power systems—such as solar–wind and solar–biomass technologies—enable continuous electricity generation even during cloudy conditions and at night.

First-generation solar cells are manufactured using silicon wafers and represent the oldest as well as the most widely used technology, primarily due to their high power efficiency. This silicon-based technology is further divided into two main types: single (monocrystalline) silicon solar cells and poly (multicrystalline) silicon solar cells. Second-generation solar cells consist of thin-film technologies, which are generally more cost-effective than silicon wafer-based cells. These include amorphous silicon thin films, cadmium telluride (CdTe), and copper indium gallium diselenide (CIGS) solar cells. The third generation of solar cells encompasses emerging and promising technologies that have not yet been extensively commercialized. These include nanocrystal-based solar cells, polymer-based solar cells, dye-sensitized solar cells, and concentrated solar cells.

The latest solar panel technology is the transparent solar panel technology. Approximately nine different technologies are currently being applied in the development of transparent solar cells, making them a key focus of ongoing research driven by growing market demand. The centre of research in Japan, Germany, and India have reported success on transparent solar cell. These technologies typically employ an FTO or ITO conductive layer deposited on glass, with a sheet resistance of approximately 10 Ω/sq and a thin-film thickness of less than 20 nm. Along with the inherent optical losses of the glass substrate, the photovoltaic (PV) layers reduce transparency by around 15–20% even before additional materials are applied. As a result, the maximum transparency currently achieved remains below 80%. The technologies that achieved more than 20% transmittance with at least 1% efficiency elaborated in chronological order below (Durganjali et al., 2020).

Hydrogen is a versatile energy carrier, when it is reacted with oxygen will generate huge amount of energy with water as reaction product. Obviously, hydrogen is green energy and makes it necessary to address sustainable challenges. Hydrogen production through water electrolysis is considered a promising approach, particularly because it can harness renewable energy sources such as solar and wind power. In general, hydrogen (H_2) production methods are categorized into four main groups: thermal, biological, photonic, and electrical processes.

In general, biological methods are limited by the activity and efficiency of microorganisms, while thermal methods require extreme conditions, including pressures around 22 MPa and temperatures near 300°C. In contrast, photocatalytic and electrochemical approaches show strong potential for sustainable hydrogen (H_2) production, achieving purity levels above 95% when using brine solutions. These technologies have demonstrated energy conversion efficiencies ranging from 45% to 85% in hydrogen generation. A recent Technoeconomic analysis (TEA) for a photo-electrochemical reactor for brines mention that the technology could drive prices as low as USD 0.78/kg H2 gas through the utilization of a hybrid system with real brines (Sanchez et al., 2025). Electrolysis is a well-established technology for hydrogen (H_2) production using renewable energy sources. This process relies on chemical reactions driven by electron transfer within an electrical circuit, which includes an anode, a cathode, and a conductive electrolyte. In this context, brines are particularly advantageous due to their high conductivity and ionic strength, as these properties enhance energy transfer efficiency within the electrochemical system. Reduction of the electrical resistance means a lower energy consumption. The electrolysis reactions are as shown in Equation 4.

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad \text{(Eq. 4)}$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad \text{(Eq. 5)}$$

Hydrogen gas is collected, compressed, and may be liquified to produce hydrogen fuel (Aziz, 2021). Nowadays this type of fuel has been applied for rockets and hydrogen cell electric vehicles in some countries in North Europe. On the automotive technology, hydrogen fuel can be used in two ways, first is internal combustion (HICEV) and the second is hydrogen cell vehicle (FCEV). A hydrogen internal combustion engine (H_2 ICE) vehicle is a type of hydrogen-powered vehicle that utilizes an internal combustion engine designed to burn hydrogen as fuel. Essentially, it is a modified version of a conventional gasoline-powered engine. Because hydrogen contains no carbon, its combustion does not produce CO_2, thereby eliminating the primary greenhouse gas emissions typically associated with petroleum-based engines.

A fuel cell vehicle (FCV), or fuel cell electric vehicle (FCEV), is an electric vehicle that uses a fuel cell to generate electricity for powering its onboard motor. In these systems, the fuel cell produces electricity through a reaction between compressed hydrogen and oxygen from the air. As a result, fuel cell vehicles are classified as zero-emission vehicles. Fuel cell technology is currently being developed and tested across a wide range of transportation modes, including trucks, buses, boats, ships, motorcycles, and bicycles. The most crucial part is how to produce the hydrogen, it remains green when the energy to produce it is coming from renewable energy source.

The industrial sector consumes 62.5% of the national electric power, posing a significant challenge since this sector also contributes greatly to the national economy. At the production site, energy consumption largely depends on process efficiency, and as part of continuous improvement programs, engineers should consistently strive to enhance efficiency and promote energy saving. In addition to production facilities, office buildings also play a crucial role in reducing electricity consumption. Energy-efficient buildings are designed to minimize energy usage for illumination and air conditioning. Such architecture promotes socioeconomic and environmental sustainability, enhances livability, and simultaneously improves energy performance. Energy efficiency in buildings can be achieved through several strategies, including thermal insulation of roofs to maintain indoor temperature, the use of solar panels for water heating, dual flush toilets to reduce water consumption, energy-efficient heating and cooling systems, energy star appliances, and energy-efficient lighting. Additional measures include the installation of solar panel and micro wind turbine generators, high-visibility window designs, adjustable air ventilation, and the application of light-colored walls and interior designs (Donev, 2024).

Households consume 23.5% of the nationally generated electricity, ranking second after industrial use. The National Energy Efficiency and Fuel Poverty Charity (NEA), an independent organization registered in England and Wales (No. 1853927), reviewed household electricity consumption and provided recommendations to reduce energy use. These include turning off lights when leaving a room, switching to low-energy LED lamps that can save up to 90% electricity, using energy-efficient appliances, drying clothes naturally, maximizing microwave use, and setting off-timers for air conditioners.

In terms of law and regulation, the Indonesian government has established comprehensive frameworks to support renewable energy development. These include various legislative and regulatory instruments such as *Undang-Undang* (UU), *Peraturan Pemerintah* (PP), *Peraturan Presiden* (Perpres), and *Peraturan Menteri* (Permen). Key policies include UU No. 30/2007 on Energy, UU No. 30/2009 on Electricity, UU No. 7/2007 on Water Resources, UU No. 16/2016 on Climate Change Commitment, PP No. 79/2014 on National Energy Policy, PP No. 14/2002 *jo* PP 23/2014 on Electrical Energy Business, Perpres No. 47/2017 on Solar Energy for Rural Citizens, Permen ESDM No. 33/2017 on Solar Energy for Rural Citizens, and Permen ESDM No. 50/2017 on Utilizing Renewable Energy for Power Generation. Although sufficient policies, laws, and regulations are already in place, consistent implementation remains the key challenge. Conflicts of interest often arise between pro-environmental groups and corporations that benefit from coal and oil exploitation.

Indeed, there are many evident of green-house-gases or GHG impact to global warming. Concentration of GHG which consist of CO_2, CH_4, and N2O are increasing, global means temperature has risen approximately 0.76 ^oC every decade, numerous climate models predict the increase of global means temperature approximately 0.64 ^oC every decade, extreme weather condition like super rain, cyclone, heavy waves, heavy precipitation, and sea level increase. The impact GHG to global warming and climate change is scary and endanger human life, however awareness is the multiplier in this equation. Additional knowledge remains to be delivered related to renewable energy and its role in GHG emission reduction. Through continuous campaign, seminars, and education we can increase people knowledge and awareness. Government may take role by introducing incentives on electric vehicles and trading privilege (Milfont, 2010).

Urban development strategy should be integrated with urban ecosystem planning (Blanco et al., 2021; Cai et al., 2024; Lourdes et al., 2024). It is very crucial to maintain primary vegetation and create secondary vegetation as well as maintaining cycle of water, carbon, and nitrogen. Green urbanism and sustainable urbanism both emphasize the relationship between cities and the natural environment, aiming to create healthier communities and improved lifestyles. Green urbanism is grounded in the "triple-zero" framework, which promotes zero fossil fuel energy use, zero waste, and zero emissions. In contrast, sustainable urbanism places greater emphasis on designing communities that are walkable and well-served by public transportation, encouraging people to meet their daily needs primarily on foot. Interdependence and harmony are mandatory requirement to have sustainable ecosystem. When harmony is imbalance then nature will balance itself (Farquhar et al., 2001).

4. Conclusions

This study highlights the multifaceted dimensions of climate change, its continuous progression, underlying causes, and far-reaching impacts on human life, ecosystems, forests, wildlife, agriculture, and water resources. Human activities remain the dominant source of greenhouse gas (GHG) emissions, primarily driven by unsustainable lifestyles that include transportation habits, domestic energy consumption, waste management practices, and the extensive use of plastics. Although the adverse consequences of global warming can be mitigated, significant challenges persist due to economic interests and limited environmental awareness among both individuals and institutions. The establishment of a renewable energy–based society represents a critical foundation for achieving a sustainable and resilient ecosystem. Development in key sectors, such as building design, infrastructure, public transportation, and household energy systems, must prioritize energy efficiency and low-emission technologies. The large-scale adoption of hydro-power, wind turbines, and solar power plants should progressively replace coal- and oil-fired generation systems to reduce dependency on fossil fuels and mitigate carbon emissions. Ultimately, the transition toward renewable energy requires collective commitment, technological innovation, and global cooperation. Through coordinated international action and sustained policy implementation, the renewable energy society can serve as a viable pathway toward long-term environmental sustainability and climate resilience.

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Author Contribution

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