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Sustainability and Renewable Energy

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Abstract: *To address the current environmental issues, sustained development initiatives over the long term are required. One of the most economical and effective energy sources is renewable energy. Because of this, sustainable development and renewable energy are closely related. This study thoroughly examines projected future energy consumption trends and related environmental effects (with an emphasis on acid precipitation, stratospheric ozone depletion, and the greenhouse effect). Technology related to renewable energy is also identified, as are prospective solutions to current environmental issues. A practical example and an illustrative one are provided to demonstrate the relationships between renewable energy and sustainable development. Numerous issues pertaining to sustainable development, the environment, and renewable energy are examined from both the present and the future throughout the essay.*

Keywords: environmental issues

I. INTRODUCTION

Sources of renewable energy include geothermal energy, biomass, wind, solar, and hydropower. These sources used to be known as "alternative energy sources." In the early years of the twenty-first century, the world is running out of useable energy from fossil fuels (oil, gas, coal, natural gas, and nuclear power), while renewable energies (wind and solar) are still too immature to offer a comprehensive and flexible substitute. Society is currently shifting toward a reliance on renewable energy sources since fossil fuels are finite resources and most estimates show that proven oil reserves won't be sufficient to meet global demand by at least the middle of the twenty-first century. All of this leads to a paradox of sorts because, two centuries ago, energy was renewable and sustainable in and of itself. For instance, people propelled ships across oceans and powered water mills using wind or water. The extensive use of fossil fuels, which resulted in considerable pollution, set the stage for the energy industry's eventual digitization as well as the shift to renewable energy and sustainable development. All of these advancements were impacted by the initial Industrial Revolution.

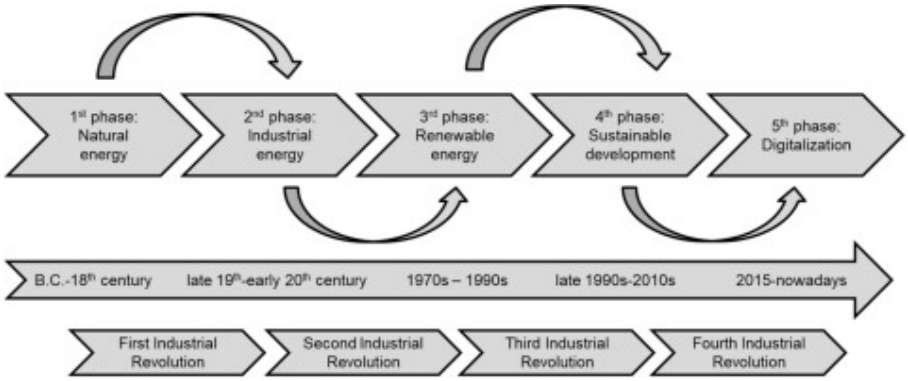

Figure 1. Development of the energy sector prior and beyond the first to the fourth Industrial Revolutions.

In 2021, the Energy Information Administration (EIA) projects that over 70% of new electricity generation capacity in the United States will come from renewable sources. Solar energy is expected to lead this shift, representing 39% of the new capacity, with wind energy following at 31%. Hydroelectric power also plays a significant role, contributing around 6% to the total electricity generation. Some experts categorize nuclear energy as a renewable resource due to its minimal environmental impact; it accounts for approximately 10% of global electricity generation according to the

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International Atomic Energy Agency. Additionally, the largest hydropower plant generated roughly 16.3% of the world's electricity in 2015, making it the second largest source of global electricity behind nuclear power. The transition from fossil fuels to renewable energy sources is a key strategy for decarbonizing the energy sector. Renewable energy is derived from resources that naturally replenish over time, and according to the World Bank, it helps mitigate greenhouse gas emissions, which are the primary contributors to global warming and climate change. In the European Union, renewable sources make up about 20% of gross final energy consumption, with hydropower accounting for 18% of this. Wind energy, harnessed through turbines, provides over 1.3 million MW of capacity across 41 states and 2 territories, as reported by the National Renewable Energy Laboratory (NREL).

Energy is a crucial element of modern society, with even a short-term disruption in supply revealing our dependency on it. As global populations grow and lifestyles become more energy-intensive, the demand for energy continues to rise. Wealthier, industrialized nations, which represent 25% of the global population, consume 75% of the world's energy resources. The environmental impact of energy use extends beyond global warming to include issues such as air pollution, acid rain, ozone layer depletion, deforestation, and radioactive emissions. Addressing these environmental challenges requires a comprehensive approach that considers all aspects of energy use and its consequences. Recognizing the shared responsibility of consumers in pollution and its associated costs is increasingly important. This paper aims to explore various environmental issues such as acid rain, ozone depletion, and the greenhouse effect, while examining future energy use patterns and their potential environmental impacts. It also seeks to identify solutions to these problems, with a focus on renewable energy sources and technologies, and their role in promoting sustainable development.

II. ENVIRONMENTAL PROBLEMS

Over the past two decades, the threat and reality of environmental degradation have intensified, driven by several factors including rapid population growth, increased consumerism, and expanded industrial activity..

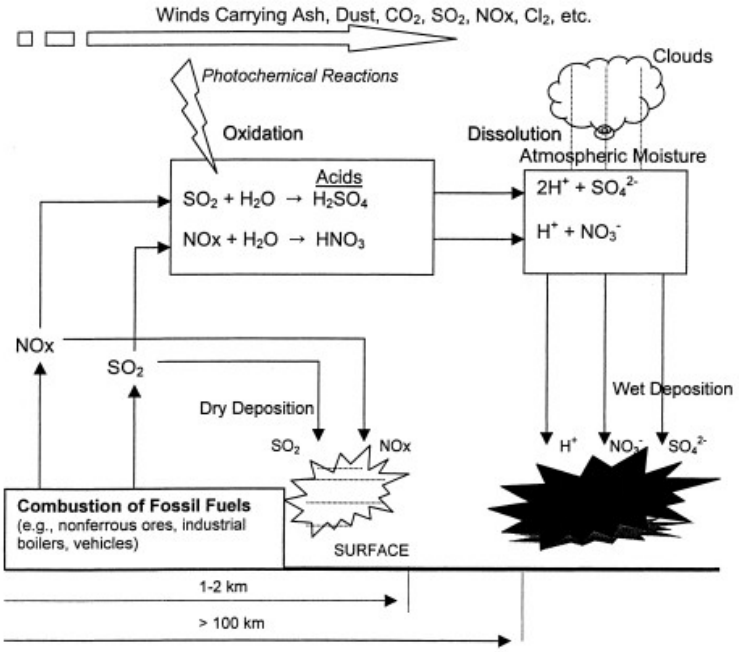

Fig. 2. A schematic representation of the formation, distribution, and impact of acid precipitation.

The impact of human activities on the environment has become more pronounced as these factors have surged. In the 1970s, environmental research and regulations predominantly addressed common pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulates, and carbon monoxide (CO). However, recent focus has shifted towards managing micro- or hazardous air pollutants—often toxic chemicals that are harmful even in small quantities—as well

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as globally significant pollutants like carbon dioxide (CO_2). Alongside advancements in environmental research, evolving industrial practices have introduced new environmental challenges. Notably, increased road traffic from the transportation of industrial goods and personal vehicles has shifted attention to the impacts of nitrogen oxides (NO_x) and volatile organic compounds (VOCs) on air quality and overall environmental health

Environmental problems span a continuously growing range of pollutants, hazards and ecosystemdegradation over ever wider areas. The major areas of environmental problems may be classified as follows:

- Major environmental accidents
- Water pollution
- Maritime pollution
- Land use and siting impact
- Radiation and radioactivity
- Solid waste disposal
- Hazardous air pollutants
- Ambient air quality
- Acid rain
- Stratospheric ozone depletion, and
- Global climate change (greenhouse effect).

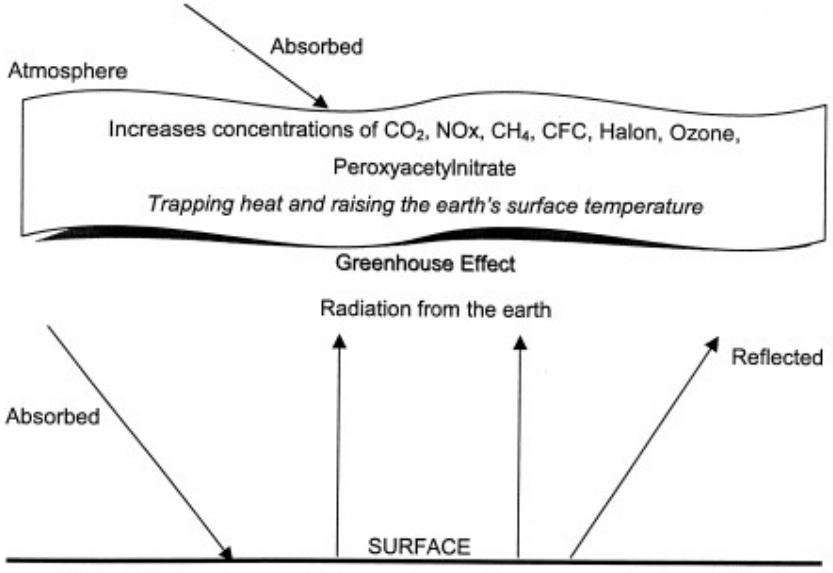

Fig. 3. A schematic representation of greenhouse effect.

III. SUSTAINABLE DEVELOPMENT

A secure and reliable supply of energy resources is widely recognized as essential for societal development, but it alone is not sufficient for achieving true progress. Sustainable development requires a continuous and reliable supply of energy resources that is available at a reasonable cost and can be used for all necessary purposes without causing detrimental societal impacts. Fossil fuels such as coal, oil, and natural gas, along with uranium, are finite and non-renewable, whereas energy sources like sunlight, wind, and flowing water are considered renewable and sustainable over the long term. Similarly, waste materials, which can be converted into useful energy through technologies like waste-to-energy incineration, and biomass fuels are typically regarded as sustainable

The concept of sustainability is deeply intertwined with environmental concerns, as activities that consistently degrade the environment are inherently unsustainable. The cumulative environmental impacts of such activities often lead to health, ecological, and other problems. A significant portion of these impacts is linked to energy resource utilization.

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While ideally, a society would use energy resources that have no environmental impact, all forms of energy production inevitably result in some degree of environmental effect. Therefore, improving energy efficiency can help mitigate some of these negative impacts, as it generally leads to reduced resource use and lower pollution levels for the same level of service or production.

Although not all renewable energy resources are inherently clean, the wide range of available options means that a transition to renewable energy within a sustainable development framework could result in a cleaner energy system compared to stricter controls on conventional energy sources. Renewable energy systems are often site-specific and lend themselves to decentralization, which allows for more localized solutions that are less dependent on national grids. This decentralization also helps individuals better understand and address the externalities of energy consumption. Furthermore, the relatively small scale of renewable energy projects often means that they can be designed and implemented more quickly, providing greater flexibility to adapt to changing energy demands and growth.

3.1 Sustainable Development and Electric Power

In order to meet future energy challenges, the most important types of renewable energy sources with great potential are solar, wind, hydro, and biomass. Renewable energy sources should ensure sustainable development of a country due to the exhaustive share of fossil fuels, rising fossil fuel prices worldwide, and reduced environmental impacts. The use of nuclear energy for electricity generation is a means of reducing resource requirements to a more sustainable level. The extent to which these technologies have been industrialized and commercialized is important. The number of materials used to produce electricity measured by the amount of fossil fuel-producing technology that consumes, and the extent to which the technology has been industrialized, is inevitable, because the industrial size and speed of development of that technology is larger in developed countries than developing countries. Figure 4 shows the total electricity generation trends in the selected OECD countries

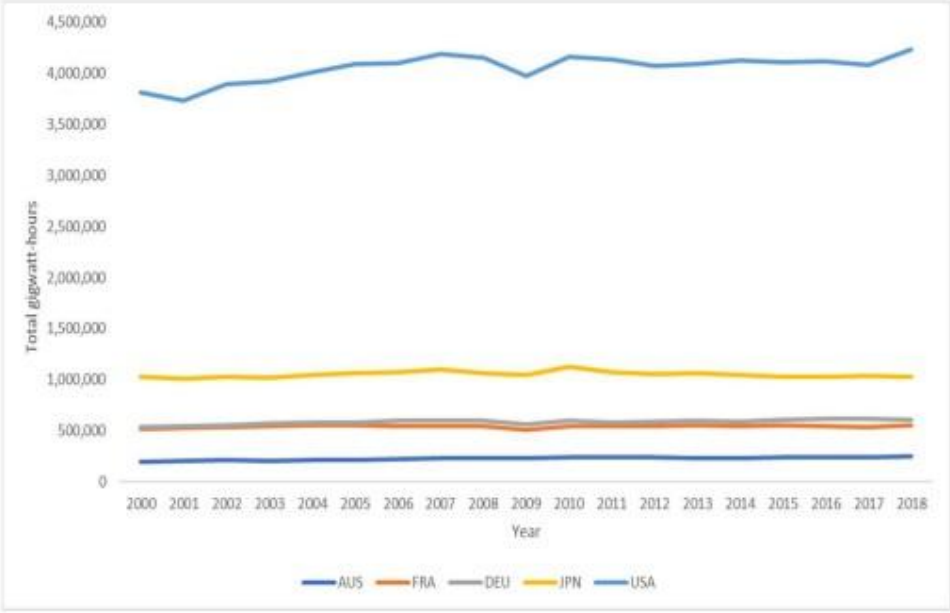

Figure 4. Total electricity generation in selected OECD countries (2000–2018).

Access to modern energy brings significant benefits, yet achieving this goal hinges on affordability. To evaluate energy sector decisions, one can compare different power generation technologies, such as geothermal and coal, alongside emerging technologies like wind and solar. The cost-effectiveness of these options is crucial, as it impacts the overall expenses borne by the system. With the global demand for electricity rising rapidly and the push towards sustainable development, energy policies must address their effects on energy security, efficiency, and environmental sustainability. This approach offers the potential for accelerated economic growth and the development of more reliable and affordable energy solutions.

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For instance, creating unified electricity markets, such as the common electricity market of the Eurasian Economic Union, which includes Russia and several post-Soviet states, can promote mutually beneficial economic growth. Enhancing and maintaining cross-border power lines and establishing clear market rules are essential for economic integration and energy security. In this context, balancing electricity generation capacity with demand is critical.

3.2 Importance of renewable energy resources and technologies for sustainable development

The exploitation of renewable energy resources and technologies is a key component of sustainable development. There are three significant reasons for it as follows.

- They have much less environmental impact compared to other sources of energy since there is no anyenergy sources with zero environmental impact. There are a variety of choices available in practice that a shift to renewables could provide a far cleaner energy system than would be feasible by tightening controls on conventional energy
- Renewable energy resources can not be depleted unlike fossil fuel and uranium resources. If used wisely in appropriate and ancient applications, they can provide a reliable and sustainable supply energy almost indefinitely. In contrast, fossil fuel and uranium resources are finite and can be diminished by extraction and consumption.

IV. CRITICAL FACTORS INFLUENCING RENEWABLE ENERGY GENERATION

In general, renewable energies can be generated locally with systems, devices, and locations using panels, government buildings, geothermal heat pumps, biomass, or combined heat and power. Using renewable energy, such as solar and wind, to generate electricity can produce electricity without emitting carbon dioxide, but electricity depends on cost-effective technologies that can improve or reduce the cost of peak sources of kilowatthours per kWh. In addition, other promising technologies for producing renewable energy tend to emerge—for example, the ones offering the prospects of harnessing energy from tides and waves. Solar thermal technologies, in particular heat storage, have great potential in sunny climates. Although government support for the use of wind and solar technologies are in the same league, their prices per kilowatt-hour are in the same league, increasing the cost of fossil-fuel technologies and the possible CO_2 emissions they generate. The cost of generating electricity from shore wind has dropped by 23% since 2010 and the cost of solar power (PV) has fallen by 73% over the same period. Another reason for the continuing fall in prices is renewable energy tariffs. The impact of falling tariffs affects two key players: electricity producers and plant builders. Along the value chain, equipment manufacturers face oversupply problems, as many countries recently withdrew support for solar photovoltaic generation.

4.1 Renewable Energy Resources and Technologies

Since the oil crises in the early 1970 s, there has been active worldwide research and development in the field of renewable energy resources and systems. During this time, energy conversion systems that were based on renewable energy technologies appeared to be most attractive because of facts such as the projected high costof oil and the cost e€ectiveness estimates and easy implementation of renewable energy systems. Furthermore, in more recent times, it has been realized that renewable energy sources and systems can have a beneficial impact on the following essential technical, environmental, economic, and political issues of the world.

- Major environmental problems (e.g., acid rain, stratospheric ozone depletion, greenhouse e€ect)
- Environmental degradation
- Depletion of the world's nonrenewable energy sources
- Increasing energy use in developing countries

As pointed out by Hartley, renewable energy technologies produce marketable energy by converting natural phenomena into useful energy forms. These technologies use the energy inherent in sunlight and its direct and indirect impacts on the Earth (photons, wind, falling water, heating e€ects, and plant growth), gravitational forces (the tides), and the heat of the Earth's core (geothermal) as the resources from which they produce energy. These resources represent a massive energy potential which dwarfs that of equivalent fossil resources. Therefore, the magnitude of these is not a

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key constraint on energy production. However, they are generally di€use and not fully accessible, some are intermittent, and all have distinct regional variabilities. Such aspects of their nature give rise to difficult, but solvable, technical, institutional, and economical challenges inherent in development and use of renewable energy resources. Despite having such difficulties and challenges, the research and development on renewable energy resources and technologies has been expanded during the past two decades because of the facts listed above. Nowadays, significant progress is made by:

- Improving the collection and conversion efficiencies
- Lowering the initial and maintenance costs
- Increasing the reliability and applicability
- Understanding the phenomena of renewable energy systems.

Table 1 gives the renewable energy technologies as a mix of several old concepts (e.g., hydropower, geothermal, biomass) and new technologies (e.g., solar, ocean thermal). Renewable energy technologies become important as environmental concerns increase, utility (hydro) costs climb and labor costs escalate. The uncertain global economy is an additional factor. The situation may be turned around with an increase in research and development in the Hi-Tech fields, some of which are closely associated with renewable energy technologies. This may lead to innovative products a nd job creation that are supported by the governments. The progress in other technologies, especially in Hi-Tech has induced some innovative ideas in renewable energy system designs. The ubiquitous computer has provided means for optimizing system performance, costs/benefits and environmental impacts even before the engineer was o€ the drawing board! The operating and financial attributes of renewable energy technologies, which include modularity and flexibility, low operating costs (suggesting relative cost certainty), are considerably di€erent than those for traditional, fossil based technologies, whose attributes include large capital investments, long implementation lead times, and operating cost uncertainties, regarding future fuel costs. The overall benefits of renewable energy technologies are often not well understood and consequently they are often evaluated to be not as cost e€ective as traditional technologies. In order to assess comprehensively renewable energy technologies, however, some of their benefits that are often not considered must be accounted for. Renewable energy technologies, in general, are sometimes seen as direct substitutes for existing technologies so that their benefits and costs are conceived in terms of assessment methods developed for the existing technologies. For example, solar and other renewable energy technologies can provide small incremental capacity additions to the existing energy systems with short lead times

Table:1 Maturity of renewable energy technologies

Proven capability Hydropower	Transition phase Wind	Future potential Advanced Turbines
Geothermal Hydrothermal	Geothermal Hydrothermal	Geothermal Hot dry rock Geopressure Magma
Biomass Direct combustion Gasification	Biofuels Ethanol from corn Municipal wastes	Biofuels Methane
Passive solar Buildings	Active solar Buildings Process heat	Solar thermal Advanced electricity High-temperature processes
	Solar Thermal Thermal/gas hybrid	
Photovoltaics Small remote Specialty products	Photovoltaics Remote power Diesel hybrids	Photovoltaics Utility power
		Ocean Thermal

4.2 Legal and Policy Boost Factors for Renewable Energy Project Development

There are many success stories that list the use of legal and policy factors for boosting renewable energy projects that justify continued state involvement in a dynamic energy market. For example, between 2001 and 2017, the cumulative

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wind capacity worldwide increased by more than 539,000 megawatts (23,900 MW), more than 22-fold. This fast-growing sector has created jobs, made power grids more resilient, expanded access to energy in developing countries, and helped reduce energy costs. The use of renewable energies, in particular solar and wind energy, needs the wide support of the population.

However, without government support for the use of wind and solar technologies, their costs will be in the same league as the increased cost of fossil-fuel technologies per kilowatthour, and it is more likely that CO_2 emissions will be added to electricity generation by these technologies. Wind turbines have developed rapidly in recent decades, and solar photovoltaic technologies are becoming increasingly efficient, improvingthe prospects of harnessing energy from tides and waves. Solar thermal technologies, in particular heat storage, have great potential in sunny climates. Some people are opposed to wind turbines, but they look to the horizon, where they are solid, and wind energy prices are falling, proving that a valuable resource can be denied. Currently, 29 U.S. states have set standards for renewable energy—policies that require a certain percentage of energy to come from renewable sources—and more than 100 cities have at least 70% renewable energy, whereas others have committed to reaching 100%.

In 2020, states, cities, utilities, and businesses started to announce and pursue decarbonization plans after the onset of the global pandemic and recession. Direct incentives for the development of green infrastructure andstimulus measures adopted in response to COVID-19 and the demand for clean energy in the United States have proven resilient, with renewable storage systems recording declining costs and increasing capacity and utilization factors. New policy initiatives have revised customs policy and made purchasing and production obligations mandatory. Expressions of interest invited the installation of photovoltaic production capacity and the associated guaranteed purchase of up to 20 GW. Tenders are set for solar, wind, and hybrid systems, and existing projects are invited. Facilitating research and development of renewable energy technologies in national laboratories for policy testing, standardization, and certification has been announced by the authorities.

Renewable Energy Impact at the Utility Side and the Benefits for the System In order to expand the paper's focus on renewables' interconnection as a benefit for customers and markets, the impact on the utility side and the benefits for the system should also be mentioned. Renewable energy technologies use resources in the environment to generate electricity. Unlike conventional fossil fuel power plants, renewable energy power plants are not "disposable" or "generative" (so called because they depend on variable resources such as solar and wind, which change over the course of a day). On a centralized supply scale, a renewable power plant is comparable to a fossil fuel power plant producing several hundred megawatts of electricity. Wind, geothermal, solar, water, and other renewable technologies are the most popular energy sources in the world today. Renewables will become an increasingly important source of energy in the near future, as we use these resources to generate useful energy.

In order to develop sound policies, policymakers need to understand the relative environmental impact of alternative energy sources, including the impact of these technologies compared to fossil fuel technologies and ways to improve energy efficiency. Energy storage improves the efficiency of the electricity grid by increasing the capacity of existing resources, thus offsetting the need to build new, polluting peak power plants. Through more flexibility in the grid, energy storage systems can help integrate solar, wind, and decentralized energy resources. Energy storage is a critical hub for our power grid, adding demand-side resources and system efficiency values to resources such as wind, solar, hydro, nuclear, and fossil fuels. Moreover, energy storage saves the energy grid cost of operation and money for electricity consumers who install energy storage in their homes and businesses. Since renewable energy sources are connected to the grid, capacity issues arise, but energy storage is the main problem with long-standing systems.

V. CONCLUSION

Renewable energy resources and their utilization are intimately related to sustainable development. For societies to attain or try to attain sustainable development, much e€ort should be devoted to discovering sustainable energy resources in terms of renewables.

All in all, it appears that the role of renewable energy in the sustainable development of the electrical power sector is far from underestimated. It includes the protection of the environment, the improvement of the sources used for the generation of electric power, and the creation of new business opportunities for companies and individuals (in the framework of the sharing economy and peer-to-peer (P2P) energy

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networks) who are becoming the prosumers (both producers and consumers of the electric energy). One can see that renewable energy sources offer many direct and indirect economic benefits at both the micro and macro level.

The term “renewable” is applied to energy resources and technologies that have the common feature of not being exhaustible and being refillable. Renewable resources include solar energy, wind, falling water, geothermal energy, plant materials, biomass, waves, ocean currents, temperature differences, ocean energy, and tides. Renewable energy technologies have an environmental impact because they are preferable to conventional sources, can replace fossil fuels, and have considerable potential for reducing greenhouse gas emissions. Replacing the burning of harmful fossil fuels with renewable energy can help mitigate problems such as air and water pollution, excessive water and land use, habitat loss for wildlife, harm to public health, and global warming. Moreover, most people realize that solar and wind energy are low-carbon energy sources, and bioenergy and carbon capture and storage play an indispensable role in scenarios in which countries reduce their carbon emissions. Renewable technologies are considered to constitute clean energy sources by the general public because optimal use of renewable technologies reduces environmental impact, produces minimal secondary waste, and is sustainable based on current and future economic and social needs. Countries around the world are promoting energy security and economic growth, and studying and using renewable energy sources to solve environmental challenges posed by climate change. Renewable energy technologies are increasingly being used in countries with a higher per capita GDP and higher energy security. However, risks associated with their generation, storage, and deployment should also be calculated and taken into account. The recent gas crisis in Europe happened largely due to the ill-executed decarbonization strategy, when seasonal changes and downfalls in the renewable energy generation, as well as the lack of the backup by traditional fossil fuel generation facilities, left many European countries unprepared.

In addition, environmental concerns should be addressed. The following concluding remarks can be drawn from this study:

- There are a number of environmental problems that we face today. These problems span a continuously growing range of pollutants, hazards and ecosystem degradation over ever wider areas. The most significant ones are acid precipitation, stratospheric ozone depletion, and global climate change.
- Potentially the most important environmental problem relating to energy utilization is the greenhouse e€ect. Increasing atmospheric concentrations of greenhouse gases are increasing the manner in which these gases trap heat radiated from the Earth's surface, thereby raising the surface temperature of the Earth and as a consequence risen sea levels.
- Recently, a variety of potential solutions to the current environmental problems associated with the harmful pollutant emissions has evolved. However, renewable energy appears to be one of the most important solutions.
- In order to attain the energy, economic and environmental bene®ts that renewable energy sources o€er, an integrated set of activities such as R&D, technology assessment, standards development and technology transfer should be conducted as required.

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