

10. The Benefits and Limitations of Diverse Renewable Energy Technologies

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Abstract:

Renewable energy sources are crucial for a sustainable and eco-friendly future, offering abundant, clean, and naturally replenishing energy from sources like solar, wind, hydroelectric, geothermal, and ocean energy. Each type of renewable energy has its own set of advantages and disadvantages. Solar energy is abundant, versatile, and environmentally friendly, but it requires high initial costs and space for installation. Wind energy is renewable, pure, and scalable, but it can be variable and disrupt habitats. Hydroelectric energy provides reliable and low-cost electricity but can have social, environmental, and technological limitations. Geothermal energy is renewable, emits minimal emissions, and has versatile applications, but it requires suitable locations and high initial costs. Ocean energy is abundant, predictable, and low impact, but it faces challenges such as infrastructure complexity, high initial costs, technological immaturity, resource variability, and environmental impact. Despite these challenges, renewable energy sources hold immense potential for mitigating climate change, improving energy security, stimulating economic growth, and creating a cleaner environment for future generations. Continued research, innovation, and investment are essential to overcome barriers and maximize the benefits of renewable energy technologies.

10.1 Introduction:

The foundation of a sustainable and ecologically friendly future is renewable energy. In contrast to fossil fuels, which have a limited supply and are linked to pollution and global warming, renewable energy originates from abundant, clean, naturally replenishing sources.

These energy sources consist of biomass, geothermal heat, wind, water, and sunshine. Using renewable energy has many advantages, including lowering greenhouse gas emissions and preventing climate change, improving energy security, and stimulating economic growth by generating jobs and advancing technology. Renewable energy is a ray of hope for the future, providing a more resilient, brighter, and cleaner environment for future generations as the world works to shift to a more sustainable energy system.

The 5 Major Types of Renewable Energy:

- Solar energy
- Wind energy
- Hydroelectric energy

- Geothermal energy
- Ocean energy

10.2 Solar Energy:

One of the renewable energies, solar energy is defined as the transformation of energy found in the sun.

Most of the sunlight is converted to visible light and infrared radiation once it enters the earth's atmosphere. Photosynthesis is the process by which plants use it to convert into starches and sugars. These energy sources are transformed into electricity using solar cell panels.

A. Advantages of Solar Energy:

- **Renewable:** One source of energy that can be used forever is solar power. We can use the sun's energy to generate power for as long as it is around.
- **Abundant:** Every day, the sun gives Earth an enormous amount of energy. The sun produces enough energy in an hour to cover the world's energy needs for a full year.
- **Environmentally Friendly:** When compared to the use of fossil fuels, solar power generation generates fewer greenhouse gases and pollutants, contributing to the reduction of air pollution and climate change.
- **Versatility:** There are several sizes at which solar energy can be used, ranging from modest rooftop systems for homes to massive solar farms for utilities. Additionally, it can be incorporated into already-existing infrastructure, such as streets, buildings, and cars.
- **Low operating cost:** Operating costs for solar panels are comparatively low once they are installed. Compared to traditional energy sources, which frequently involve fuel costs, maintenance, and infrastructure upgrades, there are less ongoing expenses.
- **Energy Independence:** By lowering reliance on fossil fuels, solar energy promotes energy independence for people, communities, and countries. Energy stability and security may be improved in this way.
- **Longevity:** Solar panels usually have long lifespans; they can function for up to 25 years or longer with little to no performance deterioration. This guarantees a consistent and trustworthy energy source over time.

B. Disadvantages of Solar Energy:

- **High Initial Cost:** Solar energy has low operating costs, but installing and buying solar panels can be a substantial upfront cost. Even though solar energy has many advantages in the long run, this financial barrier may prevent some people or companies from using it.
- **Space Requirement:** Large surfaces are usually needed for the installation of solar panels in solar power generation, especially in utility-scale projects. Locating appropriate sites for solar installations can be difficult in crowded areas or places with little space.

- **Intermittency and Variability:** The availability of sunlight, which varies throughout the day, season, and geographic location, is a prerequisite for the generation of solar power. Maintaining a steady energy supply may be hampered by this intermittency, particularly in the absence of sufficient energy storage or backup systems.
- **Impact on Environment:** Substantial land use may be necessary for large-scale solar installations, potentially competing with natural habitats or agriculture. Furthermore, poor solar project siting or construction can have an adverse effect on nearby ecosystems and communities by causing habitat disruption, degrading the soil, or producing unsightly effects.

10.3 Wind Energy:

Utilizing wind energy allows for the production of electricity. Through the use of wind turbines, which transform wind energy from kinetic energy into mechanical power, wind energy has become a prominent renewable energy source.

The potential of this abundant and clean energy source to lower greenhouse gas emissions and lessen reliance on fossil fuels has drawn attention. We will examine the fundamentals of wind energy production, its advantages, and its part in the worldwide shift to a more sustainable energy future in this introduction.

A. Advantages of Wind Energy:

- **Renewable and Abundant:** Since the sun will always be able to heat the Earth and produce wind, wind energy is a renewable resource. It's also plentiful, as wind constantly blows across the surface of the Earth, offering a nearly infinite supply of energy.
- **Pure and Ecologically Consistent:** In contrast to fossil fuel-based power generation, wind energy production emits no greenhouse gases or air pollutants. This enhances public health, improves air quality, and lessens carbon footprint while assisting in the fight against climate change.
- **Minimal Running Cost:** Compared to conventional power plants, wind turbines have comparatively low operating costs after installation. Over the course of the wind farm's lifetime, electricity prices will remain steady and predictable since there is no need for ongoing fuel expenses or purchases.
- **Scalability and Versatility:** There are several sizes at which wind energy systems can be installed, ranging from tiny turbines for homes to massive wind farms for utilities. They can be positioned either onshore or offshore, giving deployment flexibility based on regional conditions and energy requirements. Furthermore, wind energy can be used to balance out other renewable energy sources, like solar energy, to create a stable and varied energy mix.
- **Economic Development and Employment Creation:** Jobs are generated by the wind energy sector in a number of industries, including manufacturing, installation, maintenance, and research. Because they give landowners revenue and generate tax revenue for the communities where they are located, wind farms also boost local economies.

B. Disadvantages of Wind Energy:

- **Infrastructure and Initial Expenses:** Although the initial investment required to develop wind energy projects can be substantial, the costs of operation are relatively low. This covers costs for site preparation, grid connection, infrastructure development, and turbine manufacturing, all of which may discourage investment in wind energy in favor of other energy sources.
- **Disruption of Habitat by Land use:** The installation of large-scale wind farms requires a large amount of land, which could compete with natural areas or agricultural fields. Wind turbine installation and maintenance have the potential to upset regional ecosystems, compromising vegetation, soil quality, and wildlife habitats.
- **Variability and Intermittency:** The production of wind energy is reliant on wind availability, which can change dramatically with time and place. Maintaining a steady and dependable energy supply is made more difficult by this intermittency, particularly in the absence of sufficient energy storage or backup systems.
- **Impact on Vision and Noise:** Particularly in residential or picturesque settings, wind turbines can be aesthetically bothersome, which may cause locals to object. Furthermore, some people find wind turbine noise to be annoying, which can lower the quality of life for those who live nearby.
- **Bird and Bat collisions:** Birds and bats may be at risk from wind turbines, particularly during migratory or feeding seasons. Turbine blade collisions have the potential to kill people and harm local wildlife populations, raising ecological and legal issues.

10.4 Hydroelectric Energy:

Often called hydroelectric power or hydro-electric energy, hydro-electric energy uses the energy of falling or flowing water to create electricity. The history of this renewable energy source dates back thousands of years, making it one of the most established and popular ones. The fundamentals of hydro-electric energy generation, its advantages, and its contribution to the global supply of sustainable and clean electricity will all be covered in this introduction.

A. Advantages of Hydroelectric Energy:

- **Renewable and Reliable:** Because hydroelectric power is dependent on the water cycle, which is constantly refilled by precipitation and snowmelt, it is considered renewable energy. Hydroelectric power plants are a consistent source of energy because they can produce electricity with high reliability as long as water flows.
- **Low Operating Cost:** Compared to power plants based on fossil fuels, hydroelectric power plants have comparatively low operating and maintenance costs once they are built. Fuel purchases are not necessary, which results in steady electricity prices and long-term financial savings.
- **Multifunctional Storage Tanks:** Reservoirs are used by many hydroelectric power plants to store water, which has uses other than producing electricity. These reservoirs benefit communities and ecosystems in addition to being useful for irrigation, recreation, flood control, and water supply.

- **Flexibility and Grid Stability:** The ability of hydroelectric power plants to swiftly modify their electricity output in response to variations in demand helps to stabilize the grid and balance sporadic renewable energy sources like solar and wind. Because of its adaptability, hydroelectric power is a crucial part of a stable and diverse energy mix.
- **Zero-emission Electricity:** When hydroelectric power plants are used instead of fossil fuel-based power plants, fewer greenhouse gas emissions and air pollutants are produced. This contributes to environmental sustainability by lowering carbon dioxide emissions, slowing down climate change, and improving air quality.

B. Disadvantages on Hydroelectric Energy:

- **Effect on Society and Culture:** Hydroelectric project development has the potential to cause social and cultural upheavals, such as the uprooting of indigenous communities, the destruction of culturally significant locations, and modifications to customary ways of life. Insufficient attention to the requirements and worries of impacted communities during the resettlement process could result in societal injustices and disputes.
- **Environmental Impact:** Significant environmental effects from large-scale hydroelectric projects can include habitat destruction, ecosystem changes in rivers, and disturbance of fish migration patterns. Large tracts of land may submerge as a result of dam construction, uprooting human settlements and wildlife.
- **Limited Access to the Site:** There are few suitable locations for hydroelectric power plants, and they are frequently found in isolated or environmentally delicate areas. It can be difficult to find acceptable sites for new projects, and building dams may necessitate extensive land clearing and landscape modification.
- **Hazard of Sedimentation in Reservoirs:** Sediment buildup in reservoirs behind hydroelectric dams can lower the reservoirs' efficiency and storage capacity over time. In addition to causing long-term maintenance issues and environmental concerns, sedimentation can damage water quality and upset ecosystems downstream.
- **Potential for Seismic Activity:** In certain situations, particularly in seismically active areas, large dams and reservoirs can cause seismic activity. Near hydroelectric infrastructure, earthquakes or seismic events present a risk to dam safety because they have the potential to cause catastrophic failure, which could result in downstream flooding and damage.

10.5 Geothermal Energy:

An environmentally friendly and renewable energy source, geothermal energy comes from the inherent heat of the Earth's interior.

The residual heat from the formation of the Earth and the radioactive decay of minerals are the sources of this heat. Geothermal heat pumps and power plants are just two examples of the technologies that can be used to capture geothermal energy.

Hot water or steam from subterranean reservoirs powers turbines in geothermal power plants, producing electricity. Tectonic plate borders and volcanic regions are examples of places where this process usually takes place due to high levels of geothermal activity.

A. Advantages of Geo-thermal Energy:

- **Renewable and Sustainable:** Geological processes continuously replenish the Earth's natural heat, which is the source of geothermal energy. It can therefore be used as a sustainable and renewable energy source for many generations to come without running out.
- **Low emissions:** In comparison to power plants that rely on fossil fuels, geothermal power plants produce extremely low amounts of greenhouse gases and air pollutants. Geothermal energy contributes to improved air quality and lessens the effects of climate change by producing power without using fossil fuels.
- **Base-load Power and Reliability:** In contrast to certain other renewable energy sources like solar and wind, geothermal energy is always available, offering a steady and dependable supply of electricity. Because geothermal power plants have a high-capacity factor, they can be used to generate base-load power to meet steady demand for electricity.
- **Minimal Impact on the Environment:** In comparison to conventional power plants, geothermal power plants have a comparatively smaller environmental impact. When operating, they take up very little land and have negligible effects on the environment in terms of noise and appearance, particularly when compared to large-scale hydro-power or fossil fuel extraction projects.
- **Versatility:** Beyond producing electricity, geothermal energy has many other uses, such as heating and cooling. Buildings can be effectively heated and cooled by geothermal heat pumps, which offer an environmentally responsible and energy-efficient replacement for conventional heating and cooling systems.

B. Disadvantages of Geo-thermal energy:

- **Location dependency:** Geographically limited, geothermal resources are mostly found in areas experiencing tectonic activity, such as volcanic regions or hot spots. This restricts the general application of geothermal energy and may lead to increased expenses for the transmission infrastructure needed to transport energy to remote areas.
- **High initial cost:** Creating geothermal energy projects can be expensive up front, especially if deep drilling and reservoir exploration are involved. Geothermal projects can be economically challenging due to the substantial initial capital costs associated with drilling wells and building power plants, particularly when compared to other renewable energy sources.
- **Depletion of Resources and Performance Decline:** Long-term resource depletion or a decline in reservoir performance can result from prolonged heat extraction from geothermal reservoirs. Over-exploitation can lead to decreased power output, decreased efficiency, or even the reservoir's total depletion if it is not managed sustainably, which would make the project unfeasible.
- **Impact on Environment:** Geothermal energy still affects the environment even though its emissions are lower than those of fossil fuels. Land disturbance, habitat modification, and the release of chemicals and trace gases during drilling and fluid extraction are a few examples of these. Geothermal fluid disposal that contains dissolved minerals and trace elements can also be problematic for environmental protection and water management.

- **Restricted advancement in Technology:** Compared to other renewable energy sources like solar and wind, geothermal energy has received less research and development funding despite its potential. Its widespread adoption and cost competitiveness have been hampered by the slower technological advancements and innovations in geothermal exploration, drilling, and power plant design brought about by this limited investment.

10.6 Ocean Energy:

Ocean energy is the renewable energy produced by the world's oceans and seas from their abundant resources. It includes a variety of unique technologies that capture the energy found in thermal gradients, tides, currents, and ocean waves.

- **Wave Energy:** Ocean waves are created when wind blows over the water's surface, and this motion produces wave energy. The kinetic energy of waves is captured by wave energy converters (WECs), which transform it into electrical energy using a variety of mechanisms like attenuator, point absorbent, or oscillating water columns.
- **Tidal Energy:** Ocean tides rise and fall due to the gravitational pull of the sun and moon, which can be harnessed for tidal energy. When water flows into and out of coastal areas, tidal energy systems usually use barrage systems or tidal turbines to harness the energy of the tidal currents and produce electricity.
- **Ocean Current Energy:** Ocean currents with enormous amounts of kinetic energy, like the Gulf Stream and the Kuroshio Current, can be used to generate electricity. Technologies like underwater turbines and underwater kites are being developed to harness the energy of ocean currents and turn them into electrical power.
- **Ocean Thermal Energy Conversion:** OTEC produces electricity by taking advantage of the temperature differential between warm surface waters and cold deep waters. In order to condense a working fluid with a low boiling point, like ammonia, OTEC systems pump cold water from the ocean's depths. This process creates steam, which powers a turbine and generates energy.

A. Advantages of Ocean Energy:

- **Abundance:** Ocean energy is a plentiful and almost limitless resource. Over 70% of the Earth is made up of oceans, which presents a huge potential source of renewable energy. Diverse opportunities exist for utilizing the energy of the ocean, including tides, waves, currents, and temperature differences.
- **Predictability:** Ocean energy sources are very predictable, in contrast to some other renewable energy sources like solar and wind, which can be erratic and intermittent. Reliable sources of energy generation are made possible by the accurate forecasting of tides, currents, and wave patterns months or even years in advance.
- **High Energy Density:** Ocean resources, especially waves and tides, have a much higher energy density than solar or wind energy. This indicates that even small-scale ocean energy installations have the capacity to produce significant amounts of electricity, which makes them appropriate for both distributed and centralized power generation.

- **Steady Power Generation:** Similar to conventional power plants, ocean energy sources like tidal streams and ocean currents generate power continuously and consistently. Because of its base-load quality, ocean energy improves grid stability and reliability and is a valuable supplement to intermittent renewable energy sources like solar and wind.
- **Low Environmental Impact:** Comparing ocean energy technologies to more conventional energy sources like fossil fuels, the environmental impact is usually negligible. Especially when deployed offshore, they have relatively low visual and noise impacts and emit no greenhouse gases while in operation. Ocean energy projects can live in harmony with coastal communities and marine ecosystems with proper planning and site selection.

B. Disadvantages on Ocean Energy:

- **Infrastructure Challenges:** Complex infrastructure, including grid connections, mooring systems, and offshore platforms, is frequently needed for the deployment of ocean energy technologies. It can be expensive and technically difficult to operate and maintain these structures in harsh marine environments, especially in deep water or isolated areas with limited access and logistics.
- **High Initial Cost:** Ocean energy technologies, like tidal turbines and wave energy converters, often need large upfront investments for development and implementation. When compared to other renewable energy sources, ocean energy projects are prohibitively expensive due to the associated costs of infrastructure, engineering, permitting, and research and development.
- **Technological Immaturity:** Many ocean energy technologies are still in the early phases of development and face efficiency, durability, and design-related technical obstacles. Investors and project developers face uncertainty and risk due to a lack of standard industry practices and limited operational experience.
- **Resource Variability:** Ocean energy sources, like tides, currents, and waves, can change in strength and accessibility over time. The variability of resource potential due to factors like weather patterns, seasonal variations, and geographic location makes it difficult to forecast and maximize energy production from ocean sources.
- **Environmental Impact:** Marine ecosystems and habitats may be impacted by ocean energy technologies, even though they typically have less of an environmental impact than fossil fuel-based power generation. Underwater turbines have the potential to endanger marine life due to various reasons such as collisions, entanglement, or alterations in water flow patterns. To reduce these effects, thorough environmental assessments and mitigation strategies are required.

10.7 Summary:

In summary, renewable energy sources offer promising solutions for a sustainable and eco-friendly future. They derive from abundant, clean, and naturally replenishing sources like biomass, solar energy, wind energy, hydroelectric energy, geothermal energy, and ocean energy. Each type of renewable energy has its own set of advantages and disadvantages. Solar energy, derived from the sun's radiation, is abundant, versatile, and environmentally friendly. However, it requires high initial costs and space for installation. Wind energy,

generated by wind turbines, is renewable, pure, and scalable, but it can be variable and disrupt habitats. Hydroelectric energy, harnessed from flowing or falling water, provides reliable and low-cost electricity but can have social, environmental, and technological limitations. Geothermal energy, utilizing the Earth's heat, is renewable, emits minimal emissions, and has versatile applications, but it requires suitable locations and high initial costs.

Ocean energy, extracted from thermal gradients, tides, currents, and waves, is abundant, predictable, and low-impact. However, it faces challenges such as infrastructure complexity, high initial costs, technological immaturity, resource variability, and environmental impact.

Despite these challenges, renewable energy sources hold immense potential for mitigating climate change, improving energy security, stimulating economic growth, and creating a cleaner environment for future generations. Continued research, innovation, and investment are essential to overcome barriers and maximize the benefits of renewable energy technologies.

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