INTRODUCTION

1.1 What do we mean by Energy?

Energy is the basic capacity to produce motion, heat, or change. It can exist in a variety of forms (kinetic, potential, electrical, chemical, electromagnetic etc.) and is conserved by the principle that it can't be created or destroyed, only transformed. The Joule (J) is the standard unit of measurement.

1.2 What is the relevance of energy?

Energy is vital because of its following usefulness:

Human Life & Health

Biological Functions**:** Powers your heart, breathing, thinking, and cell repair.

Daily Activities**:** Enables movement, cooking, heating, and using appliances.

Health Services**:** Essential for hospitals, clinical services, and keeping medical equipment running.

Society & Economy

Infrastructure: Lights homes, runs offices, powers water and sanitation systems.

Economic Growth**:** Fuels industries, agriculture, trade, and creates jobs.

Technology & Communication**:** Powers computers, the internet, and modern communication.

Development**:** Raises living standards and reduces poverty, especially in developing nations.

Environment & Future

Sustainability**:** Shifting to green/clean/ renewable energy sources that reduce pollution and greenhouse gases, fighting climate change.

Resource Management**:** Sustainable energy access protects ecosystems and improves local environments.

1.3 Common Forms of Energy

Diversity of energy forms can be reduced to four: Mechanical energy, Thermal energy, Electrical energy, and Nuclear energy.

Mechanical Energy

Kinetic Energy: It is the energy of a body possessed by virtue of its motion. It is equal to the half the mass of the object times the square of its speed $\left(KE = \frac{1}{2}mv^2\right)$. KE within a material determines its temperature.

Gravitational/Potential Energy: It is the energy possessed by a body by virtue of its position. The PE stored in raising an object of mass m to a height h is

$$PE = \text{force} \times \text{distance} = \text{weight} \times \text{height} = \text{m} \times \text{g} \times \text{h}$$

The kinetic energy and potential energy are attributed to mechanical energy. It is required in industrial processes for motion of objects and changing the shape of the objects in agriculture, transportation, handling, processing, rolling etc..

Thermal energy or Heat Energy

It is the energy associated with the random motion of the atoms or molecules within the material. It is used to enhance the temperature of a body in industrial processes. Types of thermal energy include: high grade $\left(>500^oC\right)$, medium grade $\left(150-500^oC\right)$, and low grade $\left(70-150^oC\right)$. Low grade thermal energy cannot be converted into mechanical energy and is mostly used in heating the devices.

Electrical energy

It is the energy at microscopic level holds together the atoms and molecules of all materials. It is used in lighting, heating, and cooling homes; running household appliances; charging devices, operating industrial machinery, enabling computers and communication, and powering transportation thereby boosting industries, healthcare, and commerce.

Electromagnetic energy is a form of electrical energy carried by electromagnetic radiation. EM energy is radiated in lesser or greater amount by every object. It travels as a wave that carries energy through empty space. They include: X-rays, gamma rays, UV rays, infrared radiation, visible light, radio waves, and microwaves.

Chemical energy

It is the energy which is involved in fuels and organic matters. Heat energy is usually released in exothermic chemical reaction. In technologies like fuel cells, chemical energy is directly converted to both electrical and thermal energy. While batteries generate electricity through chemical processes that occasionally result in waste heat, your house furnace likewise transforms chemical energy (gas or oil) into heat

Nuclear energy

It is the energy bounded up in the central nuclei of the atom. Nuclear energy is released in the processes such as nuclear fission (a heavy atomic nucleus like Uranium-235 is split into smaller nuclei, releasing neutrons and a large amount of energy, used in current reactors); nuclear fusion **(**light atomic nuclei like hydrogen isotopes combine to form a heavier nucleus, releasing even more energy, the process that powers stars); radioactive decay (energy released as unstable nuclei spontaneously break down). It doesn't produce greenhouse gases during operation, making it a significant source of carbon-free power.

1.4 Common Energy Resources

The common energy resources are (i) conventional/ non-renewable energy sources and (II) non-conventional/ renewable energy sources.

1.4.1 Conventional/ non-renewable energy sources

It is known as primary sources of energy. These are resources that were present in nature before being converted or transformed by humans. These are finite and do not get replenished after their consumption. Examples: **coal, oil, natural gas, nuclear energy, and hydro sources** etc.. These are located, explored, extracted, processed and are converted to a form as required by the consumer. The energy yield ratio of an energy extraction process = Energy received from raw energy source/ Energy spent to obtain raw energy source. Only resources for which the energy yield ratio is fairly high are considered worthy of exploration.

Importance

- ***Economic Driver:*** They serve as the backbone of national economies and development by fostering trade, agricultural, and industrial growth.
- ***Reliability & Scale:*** In contrast to renewable energy sources, they offer reliable baseload power (minimum power need) that can be readily scaled up to meet large needs, which is essential for continuous operations.

- ***Established Infrastructure:*** They are easily accessible because there are already vast networks of power plants, pipelines, and transportation systems in place.
- ***High Energy Density:*** Fossil fuels are effective for transportation and large-scale generation because they provide a lot of energy from a little volume.
- ***Versatility:*** Utilized to power everything from houses to cars, including electricity, heating, cooking, and as feedstock for industry.

Advantages

- Cheaper than non-conventional sources
- As storage is easy and convenient, the energy availability can be ensured for certain period.
- Very convenient to use as technology for their conversion and use is universally available.

Disadvantages

- Fossil fuels produce heat, particulate matters (mixture of airborne solids and water droplets), and other pollutants that are harmful to human health and contribute to global warming.
- The food, paint, chemical, and pharmaceutical industries use coal as a raw material. For future demands, coal conservation is therefore desirable.
- Nuclear plant trash has ***radiation quotients*** (average annual nuclear radiation dose from a normal nuclear power plant operation-0.01 millirem) that are hazardous to human health. It is difficult to dispose of it safely, which is crucial to preventing radioactive pollution. Unintentional ***radioactive material leakage*** from the reactor is a potential. The technology currently in use for ***uranium resources is scarce***

Challenges

- Due to increased industrialization and population development, the need for energy is rising exponentially, and traditional energy sources will not be able to keep up.

- With the exception of hydro, conventional sources are non-renewable and will eventually run out.
- The usage of conventional sources, such as nuclear and fossil fuels, deteriorates the environment because they also produce pollutants such as CO, CO_2, SO_2, particulate matter (fly ash).
- Large hydro resources have an impact on animals, contribute to deforestation, ecological disturbances such as earthquakes, submerge of large land area, affects wildlife, dislocation of a large population and their rehabilitating, and present a number of socioeconomic issues.

Fossil Fuels

Approximately 80% of the world's energy comes from fossil fuels, which include coal, oil, and natural gas.

Fossil Fuels are in fact the fossils of old biological life that once existed on the surface of the earth. It is formed in several parts of the earth at varying depths, during several million years by slow decomposition and chemical actions of buried organic matter under favorable pressure, heat and bacterial marine environment. The fossil fuels include **coal, oil and gas**.

Fossil fuels (coal, oil and gas) are essential to modern life, providing much of the world's energy for power generation, transportation (cars, planes, ships) and heating, and also serving as essential raw materials for the production of plastics, chemicals and fertilizers, supporting economic growth and industrialization due to their high energy density and existing infrastructure. However, its importance is offset by significant environmental disadvantages such as air pollution and climate change, which are driving a global transition to renewable energy sources.

As the amount available depletes, the commodity becomes costlier, and its use gradually declines. Also, new reserves are continuously being discovered and new technologies are being invented for those resources.

Relevance

- **Energy Generation:**

  Burned in power plants to generate vast amounts of electricity for homes, industries, and businesses.

- **Transportation:**

  Refined into gasoline, diesel, and jet fuel for cars, trucks, airplanes, and ships, powering global logistics.

- **Industrial Processes:**

  Fuel heavy machinery, power factories, and provide heat for manufacturing.

- **Product Manufacturing:**

  Essential for creating plastics, synthetic fibers, medicines, cosmetics, lubricants, and asphalt.

- **Economic Growth:**

  Historically fuelled the Industrial Revolution, enabling mass production, technological advancement, and job creation.

Advantages

- **High Energy Density:** Release a significant amount of energy, making them efficient.
- **Abundant & Accessible:** Widely available globally, with established extraction and transport networks (pipelines, tankers).
- **Reliable:** Provide consistent energy supply, unlike intermittent renewables.
- **Cost-Effective:** Relatively cheap to produce and process into usable energy.

Drawbacks

- **Environmental Damage:** Extraction, processing, and burning release greenhouse gases (CO_2, methane), causing global warming.
- **Pollution:** Contribute to air and water pollution, impacting public health and ecosystems.

- **Finite Resources:** Non-renewable, meaning they will eventually run out.

Key Challenges

Climate Change & Global Warming**:** Massive CO2 emissions from combustion result in extreme weather, a ~1°C increase in global temperatures, and the devastation of ecosystems.

Air Pollution & Health Risks**:** Burning fossil fuels emits harmful pollutants like sulfur dioxide and nitrogen oxides, which contribute to acid rain, smog, and health problems, resulting in early deaths worldwide.

EnvironmentalDegradation**:**Extraction techniques like drilling, fracking, and strip mining ca use habitat fragmentation, deforestation, and biodiversity loss..

Water Contamination**:**

Fracking fluids, oil spills, and leaks contaminate water sources, endangering drinking water a nd ecosystems.

Resource Depletion**:**

Fossil fuels are nonrenewable and unsustainable since they are limited resources; oil and gas are expected to run out in as short as 50 years.

Geopolitical Conflicts**:**

International tensions and conflicts are brought on by reliance on finite, geographically conce ntrated reserves.

Safety Hazards**:**

With the potential for explosions, fires, and industrial disasters, production is intrinsically ris ky.

Current Status

Due to environmental concerns, there is a global trend to move away from fossil fuels and towards renewable energy sources, balancing current economic benefits with long-term sustainability goals.

Hydropower Sources

Hydropower is the world's largest, most reliable renewable energy source, generating over 14% of global electricity and over 50% of renewable electricity. Numerous large and medium-sized hydro schemes have been created. Only around one-third of the true potential has been realized thus far due to the need for significant capital investment and serious environmental problems with major facilities. With a turbine life of roughly 50 years, hydro installations and plants are long-lasting. This is brought on by constant, high-temperature operation or other stresses. As a result, it frequently generates electricity at low cost, which has positive economic effects. Its primary importance lies in providing clean, low-carbon baseload power, grid flexibility, and energy storage, while offering critical, multipurpose benefits like flood control, irrigation, and water supply management.

Relevance and Benefits

- **Clean & Sustainable Power:** Hydropower generates electricity without directly emitting greenhouse gases and provides a sustainable alternative to fossil fuels.
- **Grid Stability & Flexibility:** Unlike solar and wind power, hydropower can (arguably) quickly adjust energy production based on demand, playing a key role in balancing grid fluctuations and providing backup power.
- **Energy Storage (Pumped Storage):** Pumped storage hydropower (PSH) acts as a giant battery, storing energy for later use, which is critical for balancing intermittent renewable sources.
- **Multipurpose Infrastructure:** Reservoirs provide essential benefits beyond power, including flood control, water supply for agriculture (irrigation), clean drinking water, and recreational activities.
- **Economic & Reliable:** Hydropower facilities have low operating costs and long lifespans, offering a reliable, cost-effective, and long-term energy source.
- **Energy Security:** Hydropower provides domestic, locally-produced energy, reducing reliance on imported fuels.

Key Trends and Challenges

Pumped Storage Hydropower (PSH): Expanding support from wind and solar, capacity expected to grow significantly, especially in China.

***Climate Change & Drought*:** Reduced rainfall has heavily affected production due to droughts (China, Europe, and the US).

***Aging Infrastructure*:** Significant modernization resolves it.

***Growth Outlook*:** To meet net-zero scenarios by 2050, global capacity needs annual additions of over 40 GW.

Current Status

As of 2020, hydropower supplied 17% of global electricity, making it the third-largest source behind coal and natural gas. It is the main source of power in 28 emerging/developing economies.

Nuclear Energy

U^{235} and U^{233} (isotopes of uranium) and Pu^{239} (plutonium) are used as nuclear fuels in nuclear reactors (thermal reactors) and are known as **fissile (or fissionable) materials**. Out of these, only U^{235} occurs in nature. U^{233} and Pu^{239} are produced from $Th^{212}$and U^{238} respectively in Fast Breeder Reactors. $Th^{212}$and U^{238} are called **fertile materials**. Natural uranium contains 0.71% of $U^{235}$and 99.29% of U^{238}.

Uranium reserves in the world are small. The content of natural uranium in uranium ore is about 0.1-0.5%, Major available sources of uranium are in Australia, Canada, and Kazakhstan and USA. Nuclear power is a least-cost, low-emission technology that can provide base-load power.

Nuclear fusion reaction has a lot more potential and vast resources are available. However, controlled fusion reaction has not been achieved yet. Once this happens, nuclear fusion reaction will be the main source of energy on the earth.

Nuclear energy is a highly relevant, low-carbon, and reliable baseload power source, providing approximately 10% of global electricity. Its significance lies in its ability to operate 24/7, offering high energy density and assisting in climate change goals by avoiding over 470 million metric tons of CO_2 annually.

Relevance and Benefits

- **Clean Energy Transition**: Nuclear is crucial for reaching net-zero goals, as it produces almost no greenhouse gas emissions during operation.
- **Reliability and Baseload Power**: Unlike wind and solar, nuclear power is dispatchable and provides a consistent, 24/7, weather-independent energy supply.

- **High Energy Density**: Nuclear fuel is incredibly efficient; a single pellet can produce the same energy as one ton of coal, making it exceptionally space-efficient compared to renewables.
- **Energy Security**: Nuclear plants reduce reliance on imported fossil fuels, enhancing national energy independence.
- **Future Development**: Small Modular Reactors (SMRs) and advanced, next-generation reactors are enhancing safety and enabling potential expansion for electricity, heat, and hydrogen production.

Key challenges

***Immense Upfront Investment*:** Nuclear power plants have high upfront construction costs, although they are cost-effective over their long operational lives (40–60 years).

***Cost Overruns and Delays*:** Severe budget overruns and construction delays making projects less attractive to private investors.

***Competition with Renewables*:** Solar and wind energy are significantly cheaper compared to cost incurred in nuclear power production.

***Concentrated Supply Chain*:** geopolitical and supply risks to concentration of global uranium mining and enrichment in a few countries.

***Rising Demand vs. Declining Output*:** While demand for uranium is expected to rise by 30% by 2030, production from traditional suppliers like Canada and Kazakhstan may decrease.

***Long-Term Resource Scarcity*:** Long development times for new mines (10–20 years) develops a potential fuel gap.

***Lack of Long-Term Solutions*:** Establishment of permanent, deep geological repositories for high-level radioactive waste.

***Environmental and Health Risks*:** Temporary storage solutions yield long-term environmental and health risks.

***Ageing Reactor Fleet*:** Expensive life-extension programs for ageing nuclear reactor fleet.

***Regulatory Complexity*:** Significant costs and time are required for implementation of stringent safety regulations for new designs and aging plants.

***Water Scarcity and Climate Change*:** Nuclear plants require significant water for cooling. Because of rising temperatures, droughts, and lower water levels in rivers, plants reduce output or shut down-expected to increase.

***Cybersecurity Threats*:** Digital attacks to nuclear infrastructure is critical.

Waste Management: A major, long-term challenge is the safe disposal of spent fuel.

Public Perception: Safety concerns, often stemming from historical accidents, continue to impact public acceptance.

***Weapons Proliferation*:** The growth of nuclear energy initiatives heightens the threat of nuclear weapons spread, since technology and fuel may be misappropriated for military use.

Current Status

Over 30 countries operate nuclear power plants, with around 60 new reactors under construction as of 2023. Many nations are including nuclear in there, with some aiming to triple capacity by 2050 to meet, or exceed, Paris Agreement goals.

1.4.2 Non-conventional/ Renewable energy sources

Because of the growing usage of fossil fuels and the quick depletion of natural resources, environmental concerns have prompted the development of renewable and eco-friendly alternative energy sources. In order to lessen an excessive reliance on conventional resources, it is now crucial to investigate and develop non-conventional energy sources.

These are the resources which are renewed by nature again and again and their supply is not affected by the rate of their consumption. These are considered for large-scale use. Examples: **solar, wind, biomass, ocean (thermal, tidal and wave), geothermal, hydro power**, etc.

Importance

Mitigates Climate Change: Global warming is immediately addressed by renewable energy sources, which emit little to no greenhouse gases.

Reduces Air Pollution: By replacing fossil fuels, dangerous pollutants are reduced, avoiding asthma, respiratory ailments, and the millions of premature deaths caused by poor air quality.

Protects Waterways: Water sources are kept cleaner by using less water and producing less harmful waste than fossil fuel facilities.

Energy Independence: Local renewable energy production enhances national security and reduces reliance on the unstable international fossil fuel markets.

Job Creation: The growing renewable energy industry boosts local economies by generating a large number of employments in manufacture, installation, and maintenance.

Stable Costs: Although an initial investment is required, long-term cost reductions and stable energy prices result from declining technology costs and free fuel (wind, sun).

Inexhaustible Supply: Unlike finite fossil fuels, renewable resources like the sun, wind, and water guarantee a sustainable energy future.

Resilient Infrastructure: Energy grids may be more resilient to interruptions with decentralized renewable energy systems.

Universal Access: Renewable energy sources provide isolated and underprivileged populations with a dependable, clean energy source.

Advantages

- ***Inexhaustible & Sustainable:*** Sources like sun, wind, and water never run out.
- ***Environmental Benefits:*** Minimizes the effects of climate change and air pollution by producing minimal or no greenhouse emissions.
- ***Lower Operating Costs:*** Fuel (sun, wind) is free after installation, resulting in reduced long-term energy costs and price resilience.
- ***Energy Independence:*** Improves national energy security by lowering dependency on imported fossil fuels.

- ***Job Creation:*** Increases employment in the maintenance, installation, and manufacturing industries.
- ***Reduced Waste & Water Use:*** utilizes less water and produces less waste than fossil fuels.

Disadvantages

Intermittency: Weather (wind, sun) affects generation, necessitating storage or backup power.

High Upfront Costs: Infrastructure (turbines, solar farms) requires a large initial investment.

Geographic Limitations: Location (windy, sunny, water sources) determines suitability.

Land Use: Large-scale projects may need a substantial amount of land.

Storage Challenges: Energy storage at times when the sun isn't shining or the wind isn't blowing is still a challenge.

Not Always 100% Carbon-Free: Certain biomass is not emission-free, and manufacturing and installation may have a carbon footprint.

Solar Energy

The sustainable future of the planet depends on solar energy, which provides a clean, renewable, and more affordable substitute for fossil fuels. Using thermal and photovoltaic conversion technologies, solar energy can be used as a significant power source. It accounts for around 31% of all installed renewable capacity as of 2022, and it is essential to lowering greenhouse gas emissions and enhancing energy independence. In both developed and emerging economies, it is quickly transforming access to energy.

On a bright, sunny day at midday, the earth's surface receives about 1kW of solar ener gy per square meter.78 billion MW of solar power, or almost 10,000 times the global consum ption, is continuously intercepted by the earth.One estimate states that the world's electrical p ower needs could be met if all buildings were covered in solar PV panels.Solar photovoltaic power is regarded as a costly energy source.A solar PV system currently costs Rs 200.00 per W (Rs 20 crore/MW compared to Rs 4 crore/MW for a coal-fired thermal plant).

Relevance

***Environmental Sustainability*:**

As a clean, renewable energy source with no emissions, solar power immediately addresses the environmental harm and global warming caused by fossil fuels.

***Economic Impact*:**

Since solar panels are now so inexpensive, they are a very competitive energy source.It offers energy independence and reduces electricity costs for commercial, industrial, and domestic customers.

***Energy Security and Independence*:**

Countries can increase energy security and, in certain situations, reduce the strain on centralized, outdated, or inefficient power infrastructures by lowering their reliance on imported, unstable fossil fuels.

***Versatility in Applications*:**

Solar energy is used for electricity generation (photovoltaics), heating/cooling buildings, water heating, and powering agricultural irrigation systems.

***Global Accessibility*:**

Solar energy provides a dependable source of electricity for industrial, agricultural, and household purposes in remote locations without grid connectivity.

***Second Largest Renewable*:**

With 1053 GW of installed capacity as of 2022, it is the second largest installed renewable technology behind hydropower.

***Rapid Adoption*:**

Because of its tremendous scalability and decreasing cost, it is expected to dominate future energy supplies.

Challenges

Despite the high growth, challenges of solar power include high initial installation costs, storage, and intermittency (sunlight is not always available).

Wind Energy

Providing more than 12% of the world's electricity and contributing significantly to decarbonization, wind power is an essential, quickly expanding, and reasonably priced renewable energy source. As a clean, limitless resource, it lowers greenhouse gas emissions, preventing more than 1.1 billion tonnes of CO_2 per year, while also generating jobs, lowering energy imports, and providing stable, affordable energy prices.

Wind power installation costs Rs 4crore/MW, which is similar to the cost of traditional thermal facilities. The number of wind power installations worldwide has increased remarkably. Further, 2024 saw a record increase in wind power capacity worldwide, with an additional 117–120 GW added, putting the total capacity to over 1,136 GW. Germany leads the world in wind power, with 22,247 MW of installed capacity.

Relevance

Climate & Sustainability

Reducing dependency on fossil fuels, lowering CO_2, CO, and PM emissions, and reducing harmful pollutants that affect ecosystems and human health all depend on wind energy.

Economic Impact

One of the cheapest and most economical energy sources is onshore wind, which is frequently less expensive than coal or gas.

Growth Potential

It is the second-largest source of renewable energy and is expected to nearly double in capacity to over 2,000 gigawatts (GW) by 2030.

Technology Advancements

The capacity of modern, higher turbines with bigger rotors is growing, improving the effectiveness and efficiency of energy production.

Integration

Both onshore and offshore wind energy are widely used to serve energy needs, from powerin g large, interconnected electric networks to rural, distant places.

Challenges

- **Grid Bottlenecks:** Lack of grid infrastructure to connect new wind farms.
- **Supply Chain:** Equipment shortages, high interest rates, and inflation.
- **Permitting:** Delays in approving new projects.
- **Intermittency:** Wind doesn't always blow
- **Endangerment:** Land-use impacts on wildlife and landscapes.

Global Impact

Despite this, it remains a cornerstone of future global energy strategies, particularly as offshore wind expands.

Biomass Energy

Energy resources available from animal and vegetation art called biomass energy resources. This is an important resource for developing countries, especially in rural areas. The principal biomass resources are:

- Trees (wood, leaves and forest) waste
- Cultivated plants grown for energy
- Algae and other vegetation from oceans and lakes
- Urban waste (municipal and industrial waste)
- Rural waste (agricultural and animal waste, crop residue, etc.)

Examples of intermediate biofuels that can be produced from biomass material by chemical or biological transformation include charcoal, ethanol, and biogas (methane). At the moment, China is home to the vast majority of the millions of biogas plants worldwide.

Relevance

Produced from organic resources like wood and agricultural waste, biomass energy is a renewable, carbon-neutral alternative to fossil fuels that encourages waste reduction and energy independence. It currently contributes more than 55% of the world's output of renewable energy and is essential to the decarbonization of industries including electricity generating, heating, and transportation.

- **Sustainability and Carbon Neutrality**: Biomass is renewable because it can be replenished quickly. It is considered carbon-neutral because the CO_2 released during combustion is similar to the amount absorbed by plants during growth, helping to mitigate climate change.
- **Waste Management**: It converts organic waste (agriculture, municipal, animal manure) into valuable energy, reducing landfill use by 60 to 90 percent.

- **Energy Security and Versatility**: In contrast to intermittent solar or wind, biomass offers a stable, consistent, and regulated "baseload" power source, that is why it is crucial for grid stability. It can be transformed into fuels that are solid, liquid, or gaseous (biogas, biofuels).

- **Economic Benefits**: It provides a lower-cost energy source that can create revenue from waste products.
- **Decarbonization Role**: It is crucial for hard-to-abate sectors like aviation, shipping, and heavy manufacturing.

Challenges

Environmental and Sustainability Challenges

- **Deforestation and Land Use:** Significant land is needed for large-scale biomass production, which can cause deforestation, biodiversity loss, and competition with food crops.
- **Air Pollution:** Similar to fossil fuels, burning biomass releases particulate matter, carbon monoxide, and nitrogen oxides.

- **Greenhouse Gas (GHG) Emissions:** While theoretically carbon-neutral, improper management, methane leaks, and transportation can result in a net increase in GHGs.
- **Water Intensity:** The cultivation of energy crops can strain water supplies, particularly in arid regions.

Operational and Economic Challenges

- **Low Energy Density & Transportation:** Transferring biomass from source to plant is costly and inefficient due to its weight and frequent moisture content.

- **High Initial Costs:** It costs a lot of money to build and run biomass power plants since they need specialized infrastructure and equipment.

- **Seasonal Availability:** Feedstock supply varies with seasons, creating storage problems and price fluctuations.

Technical Challenges

- **Efficiency:** Because it needs more feedstock to generate the same amount of energy, biomass is frequently less efficient than fossil fuels.

- **Pre-treatment Needs:** Raw biomass often needs pre-processing (e.g., drying, densification) to increase its energy value and prevent biodegrade

Geothermal energy

It originates from the vast reserves of thermal energy located within the Earth's interior, although its economic extraction at the surface isn't practical in all locations. While its overall impact on total energy needs is minimal, it remains a crucial resource in specific areas.

Geothermal energy represents a significant, renewable, and dependable energy source, delivering uninterrupted (24/7) electricity and direct heating while producing minimal carbon emissions. It ensures energy security, boasts high capacity, and has a low environmental impact, functioning autonomously from weather fluctuations. This energy source is essential for stabilizing intermittent renewable energy and for the decarbonization of heating and industrial sectors.

Relevance

- **Continuous and Reliable Source:** Unlike solar or wind, geothermal energy provides base-load power (24 hours a day, 365 days a year), offering high-capacity factors (often 90% or more).
- **Decarbonization and Environmental Benefits:** Because it produces relatively fewer greenhouse gases than fossil fuels, it is essential to the energy transition to carbon neutrality.
- **Versatile Applications:** Beyond electricity generation, it is used for direct heating of buildings (district heating), industrial processes (e.g., food processing), and aquaculture.
- **Energy Security and Independence:** Because it is an indigenous resource, it reduces dependency on foreign fuels, improving energy security.
- **High Potential and Efficiency:** It has massive untapped potential, with new, advanced, and enhanced geothermal systems (EGS) expanding the ability to access deep, high-temperature resources.
- **Economic Value:** Geothermal plants are generally safe, long-lasting, and, once installed, offer low-cost energy.

Challenges

- **High Initial Capital Costs:** Drilling and building power plants are extremely expensive, with drilling alone accounting for 30% to 57% of total costs. There is also a high risk of investing in a site that turns out to be non-viable.
- **Location Constraints:** Widespread adoption is limited because suitable, high-temperature geothermal resources are typically found close to tectonic plate borders or volcanoes.
- **Environmental Concerns & Hazards:**

✓ **Seismicity:** Drilling and fluid injection can trigger small earthquakes.

✓ **Subsidence:** The ground surface may sink due to the removal of underground fluids.

- ✓ **Emissions:** While low-emission, plants can release greenhouse gases like hydrogen sulphide.
- **Resource Management & Sustainability:** The resource may run out and the site may cool if geothermal fluids are not injected back into the reservoir at the same rate that they are removed.

- **Technical and Operational Hurdles:**

- ✓ **Corrosion and Scaling:** Highly mineralized, hot, and acidic fluids can damage pipes and turbines.
- **Deep Drilling:**
  Drilling hundreds of feet to reach the required, extremely high temperatures is a techn ologically hard process.
- **Infrastructure and Location:** High-potential areas are often located in remote areas, necessitating expensive transmission infrastructure to transport energy.

Ocean (tidal, thermal and wave) Energy

A large, renewable, and extremely reliable substitute for fossil fuels, ocean energy (tidal, thermal, and wave) can power coastal settlements with very little carbon emissions. With yearly potentials surpassing 10,000 TWh, these technologies provide dependable, sustainable electricity by utilizing the enormous power density of temperature gradients and ocean movements.

Types

- **Tidal Energy:** Derived from the gravitational pull of the moon, this uses tidal barrages or stream turbines to convert the rise and fall of water into electricity.

- **Wave Energy:** Captures power from surface waves using devices like oscillating water columns or converters, which are highly effective in coastal areas.

- **Ocean Thermal Energy Conversion (OTEC):** Uses the temperature difference between warm surface water and cold deep water to generate electricity.

Relevance and Benefits

- **Predictability and Reliability:** Reliable, almost continuous power generation is made possible by the high predictability of tidal energy and the tendency of wave energy to be more consistent than solar or wind energy.
- **High Energy Density:** Tidal currents and waves can produce significant amounts of electricity because water is denser than air, and wave energy has a higher density than solar power.
- **Significant Resource Potential:** The potential of tides, waves, and thermal sources greatly outstrips the world's need for electricity, making ocean energy the largest untapped renewable resource.
- **Environmental Benefits:** These technologies contribute to the decrease of greenhouse gas emissions by offering clean, renewable power with low carbon footprints.
- **Coastal Support:** Major coastal population areas can benefit from the development of ocean energy, which lowers transmission costs and ensures energy security.
- **Diverse Applications:** In addition to electricity, desalination can be accomplished using ocean thermal energy, and aquaculture can be powered by various technologies.

Challenges

High development costs, the requirement for innovations to survive severe marine settings, and environmental impact assessments are the main obstacles. The goal of ongoing research is to advance technologies like wave energy converters and tidal stream generators.

1.5 World Energy Status

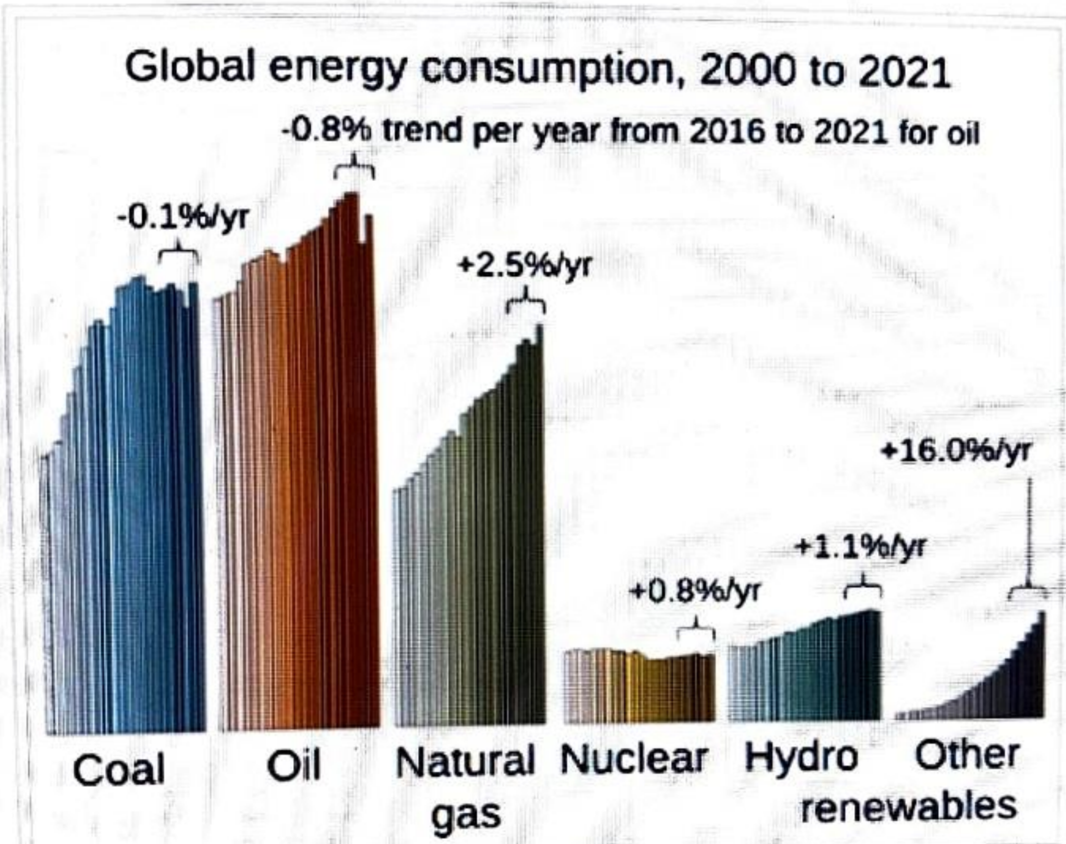
1.5.1 Global Energy Consumption

Global primary energy consumption reached a record high of approximately 620 exajoules (or roughly 15,000–16,000 million tonnes of oil equivalent) (1 EJ=10^{18}J) in 2023, driven by a 2% increase in demand. In 2024, energy consumption increased by 2.2%, with notable increases in the BRICS countries, especially China and India. As of late 2024–2025 data, conventional energy sources (fossil fuels and nuclear) still dominate the global primary energy consumption, accounting for approximately **80% to 85%** of the total, though their relative share is slowly contracting due to the growth of renewables.

Based on data from the Energy Institute and IEA in 2024–2025, the percentage contributions are estimated as follows:

- ***Total Consumption* (2023):** ~620 exajoules (EJ).
- ***Primary Energy Mix*:** Oil (33% – 34%), Coal (27% – 28%), Natural Gas (24% – 25%), Nuclear **(**4% – 5%),
- ***Renewables Share*:** While growing, renewable energy (including hydro) makes up a smaller portion of the overall mix, with other renewables at 5.7% and hydro at 6.9%.
- **Total Conventional: ~87% - 90%** (when traditional biomass is included in some metrics, but usually cited ~80-85% for modern fossil + nuclear)
- **Renewables (Hydro, Solar, Wind, Bioenergy):** ~10% – 15% (growing rapidly)
- ***Growth Drivers (2024):*** The growth was driven by a 4% increase in China's energy consumption.
- ***Top Consumers:*** China leads with 176.35 exajoules, followed by the United States (95.5 exajoules) and India (40.81 exajoules).

The world’s energy consumption from non-renewable and renewable sources are mentioned in figures 1.1, 1.2, and 1.3.



Global energy consumption, measured in exajoules per year: Coal, oil, and natural gas remain the primary global energy sources even as renewables have begun rapidly increasing.[1]

Figure 1.1

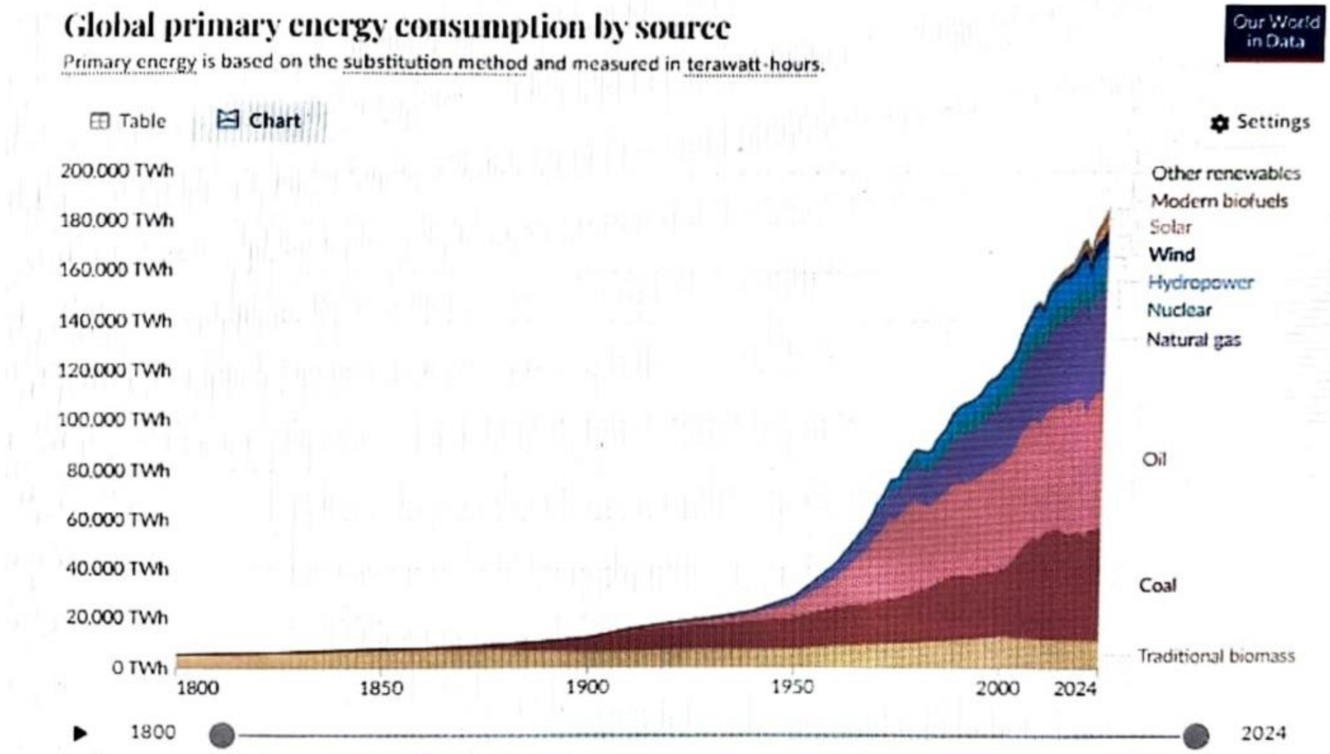

Global primary energy consumption by source
Primary energy is based on the substitution method and measured in terawatt-hours.
Our World in Data
Table
Chart
Settings
200,000 TWh
180,000 TWh
160,000 TWh
140,000 TWh
120,000 TWh
100,000 TWh
80,000 TWh
60,000 TWh
40,000 TWh
20,000 TWh
0 TWh
1800
1850
1900
1950
2000
2024
Other renewables
Modern biofuels
Solar
Wind
Hydropower
Nuclear
Natural gas
Oil
Coal
Traditional biomass
1800
2024

Figure 1.2

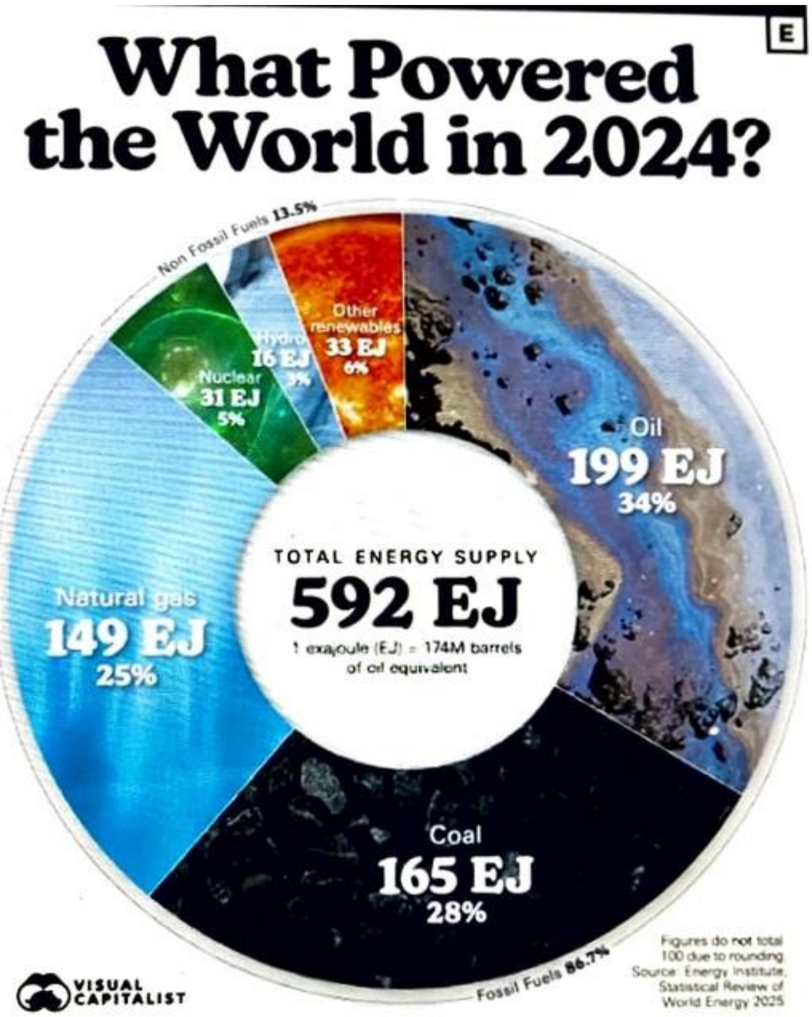

What Powered
the World in 2024?
Non Fossil Fuels 13.5%
Other renewables
33 EJ
6%
Hydro
16 EJ
3%
Nuclear
31 EJ
5%
Oil
199 EJ
34%
Natural gas
149 EJ
25%
TOTAL ENERGY SUPPLY
592 EJ
1 exajoule (EJ) = 174M barrels of oil equivalent
Coal
165 EJ
28%
Fossil Fuels 86.7%
Figures do not total 100 due to rounding
Source: Energy Institute, Statistical Review of World Energy 2025
VISUAL CAPITALIST

Figure 1.3

1.5.2 Availability of Conventional Sources

Fossil Fuels

The **locations and estimates (2024-2025 Estimates)** of the world's main fossil fuel reserves are as follows:

Global fossil fuel reserves are heavily concentrated, with Venezuela leading in oil (303 billion barrels) and Russia leading in natural gas [1,320+ Tcf (trillion cubic feet)]. Proven oil reserves are mainly in the Middle East, Venezuela, and Canada, while natural gas is concentrated in Russia, Iran, and Qatar. Total estimated global oil reserves are approximately 1.73 trillion barrels, with organization of the petroleum exporting countries (OPEC) countries controlling 80%.

Main OIL Reserves

Venezuela**:** Holds the largest proven reserves (approx. 303 billion barrels), mostly in the Orinoco Belt.

Saudi Arabia**:** Holds roughly 267 billion barrels, featuring the Ghawar Field.

Iran**:** Holds around 208-209 billion barrels.

Canada**:** Contains approximately 163 billion barrels, primarily from oil sands.

Iraq**:** Holds around 145 billion barrels.

Main Natural Gas Reserves

Russia**:** Holds the largest reserves, exceeding 1,300 trillion cubic feet (Tcf).

Iran**:** Holds over 1,100 Tcf.

Qatar**:** Holds roughly 870 Tcf.

United States**:** Holds significant reserves, estimated around 445 Tcf.

Main Coal Reserves

United States**:** Possesses the largest estimated recoverable coal reserves.

Russia, China, Australia, and India: Also hold major global coal deposits.

Key Locations & Regional Concentration

Middle East**:** Contains about 50% of the world's proven oil reserves and a dominant share of natural gas.

Orinoco Belt (Venezuela)**:** Contains massive extra-heavy crude reserves.

Western & Eastern Offshore (India)**:** Significant natural gas potential, roughly 29% and 23% respectively.

Deepwater**:** A significant portion of future reserves (91%) is located in the "Golden Triangle" (Gulf of Mexico, Brazil, West Africa).

Hydro Power Sources

The **locations and estimates (2023-2024 Estimates)** of the world's main hydro power reserves are as follows:

Hydropower is the world's largest source of renewable electricity, with a global installed capacity of approximately **1,253 GW to 1,400 GW**. It generates over 15% of the world's electricity, with production often exceeding 4,200 TWh annually.

Top Global Locations for Hydropower (Installed Capacity)

The majority of the world's hydropower capacity is concentrated in a few key nations with significant water resources:

China**:** The undisputed global leader, with over **370 GW** to 400 GW of capacity (roughly 30% of global capacity).

Brazil**:** Ranked second, heavily reliant on the Amazon and Paraná rivers for over 70% of its electricity, with over 109 GW installed.

Canada**:** A major producer with over 83 GW, using hydropower for about 60% of its electricity.

United States**:** With over 80 GW, particularly in the Pacific Northwest.

Russia**:** Possesses 50–60 GW, with massive plants on the Yenisei and Angara rivers.

Other significant countries include India (approx. 47 GW), Norway (34 GW), Turkey (31 GW), Japan, and Vietnam.

Largest Hydropower Stations

Three Gorges Dam (China): 22.5 GW (World's largest, Yangtze River).

Baihetan Dam (China): 16 GW (Jinsha River).

Itaipu Dam (Brazil/Paraguay): 14 GW (Paraná River).

Xiluodu Dam (China): 13.86 GW (Jinsha River).

Belo Monte Dam (Brazil): 11.2 GW (Xingu River).

Guri Dam (Venezuela): 10.2 GW (Caroní River).

Regional and Future Potential Estimates (Massive untapped potential)

Africa**:** Only about 10% of potential has been tapped, with a potential capacity of 474 GW.

Asia: Besides China, significant growth is occurring in Nepal and Laos (targeting 13 GW by 2030).

Latin America**:** In addition to Brazil, Colombia and Argentina are leading future growth.

Untapped Potential**:** Russia, China, Canada, and Brazil hold the highest remaining technical potential.

Nuclear Resources

The **locations and estimates (2024-2025 Estimates)** of the world's main nuclear power reserves are as follows:

The world's main nuclear power reserves, referring to identified, economically recoverable uranium resources, are concentrated in a few key nations, with **Australia** holding the largest share. Global uranium production is heavily dominated by **Kazakhstan**, followed by **Canada** and **Namibia**.

Top 10 Countries by Uranium Reserves (2024-2025 Estimates)

The following estimates represent known recoverable resources:

Australia**:** ~1.68 million tonnes (approx. 28–30% of global reserves)

Kazakhstan**:** ~815,200 tonnes (approx. 13–14% of global reserves)

Canada**:** ~588,500 tonnes (approx. 10% of global reserves)

Russia**:** ~480,900 tonnes (approx. 8% of global reserves)

Namibia**:** ~470,100 tonnes (approx. 8% of global reserves)

Niger**:** ~311,100 tonnes (approx. 5% of global reserves)

Brazil**:** ~303,900 tonnes (approx. 5% of global reserves)

China**:** ~243,120 tonnes (approx. 4% of global reserves)

Mongolia**:** ~121,560 tonnes (approx. 2% of global reserves)

Uzbekistan**:** ~121,560 tonnes (approx. 2% of global reserves)

Key Locations of Deposits

Australia**:** Olympic Dam deposit (largest single uranium deposit in the world).

Kazakhstan**:** Inkady, Mynkuduk, Budenovskoye.

Canada**:** Athabasca Basin in Saskatchewan

Namibia**:** Major open-pit mines in the Namib Desert.

Russia**:** Streltsovsky caldera

Production Trends

Kazakhstan**:** World's largest producer, accounting for 39% of global supply in 2024 (approx. 23,270 tonnes U).

Canada**:** Second largest producer (approx. 14,309 tonnes U in 2024)

Namibia**:** Ranks third in production, supplying roughly 12% of the world's uranium in 2024 (approx. 7,333 tonnes U).

1.5.3 Availability of Non-conventional Sources

Solar Energy

Global Solar Energy Estimates (2024–2025)

Global solar power capacity experienced unprecedented growth in 2024, with total installed capacity surpassing 2 Terawatts (TW) and 2024 annual installations reaching an estimated 597 GW. For 2025, global solar PV installations are projected to grow by another 10%, potentially reaching 655 GW of new capacity.

Top Solar Power Countries (2024-2025 Estimates)

China: By mid-2025, China's total capacity surpassed 1,100 GW (1.1 TW).

United States: Ranked second, with 50 GW installed in 2024. Total operational capacity is expected to exceed 300 GW in the coming years.

India: Reclaimed third place in 2024 with 30.7 GW added. India's solar capacity exceeded 100 GW in January 2025, reaching 132.85 GW by November 2025.

Brazil: Ranked fourth in 2024, with 18.9 GW added, and continued growth in 2025.

Germany: Ranked fifth, with total capacity exceeding 100 GW in 2024, aiming for 215 GW by 2030.

Key Global Locations of Major Solar Power Parks (2024-2025)

Bhadla Solar Park (India): Located in Rajasthan, this is the world's largest solar park with a capacity of 2,245 MW.

Urumqi Solar Facility (China): In June 2024, China activated a 3.5 GW facility in Xinjiang.

Pavagada Solar Park (India): Located in Karnataka, with a 2,050 MW capacity.

Benban Solar Park (Egypt): A major facility located in the Western Desert, Egypt.

Mohammed Bin Rashid Al Maktoum Solar Park (UAE): A large-scale project in Dubai.

Solar Power Trends & Forecasts (2024-2025)

Growth Drivers: Low module prices, intense competition, and policy support are driving this growth.

***Manufacturing Dominance*:** China continues to produce over 80% of the world's solar panel materials.

***Forecasting*:** The global solar market is expected to grow by 20% in 2026, reaching 750 GW under a medium scenario.

Wind Energy

Global Wind Energy Estimates (2024–2025)

Based on 2024–2025 estimates and reports, the global wind energy sector is experiencing significant, record-breaking growth, with total global capacity surpassing 1,100 GW in 2024 and projected to exceed 1,300 GW by the end of 2025. Asia, particularly China, continues to dominate, while India has emerged as a top-four global player with substantial capacity additions.

- **Total Capacity:** Global wind capacity reached approximately 1,136 GW by the end of 2024.
- **2024 Growth:** Roughly 117 GW to 127 GW of new wind capacity was installed in 2024.
- **2025 Outlook:** New installations are expected to exceed 150 GW in 2025.
- **Key Trends:** The average size of new onshore turbines has passed 5 MW, while offshore turbines average over 9.8 MW.

Top Locations for Wind Energy (2024–2025)

1. **China:** Remains the unrivalled leader, accounting for 70% of new capacity in 2024 (approx. 79.8 GW). Total capacity in China exceeded 520 GW in 2024.
2. **United States:** Ranked second in cumulative capacity (154.8 GW) in 2024, despite a fourth consecutive year of lower-than-expected installations (approx. 4.1 GW) due to supply chain and grid issues.
3. **Germany:** Leading European market with over 72 GW total capacity at the end of 2024, focusing heavily on repowering.
4. **India:** Ranked 4th globally in total capacity, reaching over 50 GW by March 2025.

5. **Brazil:** A major, yet volatile market, which faced a 31% drop in 2024 to 33.7 GW total capacity due to infrastructure, regulatory, and financial challenges.

Regional Breakdown & Developments

- **Asia-Pacific:** Continued to lead, with over 75% of new capacity in 2024. Emerging markets like Vietnam, Australia, and the Philippines are scaling up.
- **Europe:** Added 16.4 GW in 2024, with 84% being onshore. The UK, France, and Finland are top performers behind Germany.
- **Africa & Middle East:** Onshore wind capacity doubled in 2024, with Egypt and Saudi Arabia leading in new installations.

Offshore Wind Sector (2024–2025)

- **2024 Performance:** 8 GW of new offshore wind capacity was installed globally in 2024, a 26% decrease from 2023, largely due to grid connection delays in China and Europe.
- **Top Offshore Markets:** China (41.8 GW total), UK (15.9 GW), Germany (9.1 GW), Netherlands (4.7 GW), and Taiwan (3 GW).
- **Outlook:** Annual offshore installations are expected to double in 2025 and triple by 2027.

Biomass Energy

Biomass is the world's largest renewable energy source, providing approximately 12.6% of total global energy consumption in 2020, with a major focus on heating. It accounts for over 6% of the global energy supply (55% of renewable energy). As of 2022, bio-power capacity reached 149 GW, with 672 TWh generated. The sector is transitioning from traditional, inefficient biomass to modern, sustainable applications.

Global Biomass Energy Estimates (2024-2025)

Based on 2024–2025 estimates, the global biomass energy market is expanding, with significant growth in bio-power generation and biofuels, particularly in Asia-Pacific and South America. The global market was valued at approximately **USD 99 billion in 2024** and is projected to grow with increased investments, including a 13% rise in bioenergy investment expected for 2025, reaching a record high of USD 16 billion.

- **Market Growth & Value:** The global biomass energy market is expected to grow at a CAGR of 4.46% between 2025 and 2035, with a forecasted market size of USD 160 billion by 2035.

- **Installed Capacity:** Global biopower generation capacity expanded by 4.6 GW in 2024 to reach a total of 150.8 GW.

Regional Trends:

- ✓ **Asia-Pacific:** Expected to generate the highest demand, with China's biopower capacity accounting for over half of Asia's total in 2024.
- ✓ **Brazil:** A key biofuels leader, having raised ethanol blending to 30% (potential for 35%) and biodiesel to 14% (B14) in 2024, with targets to reach 20% (B20) by 2030.
- ✓ **Europe:** Focused on biogas and sustainable aviation fuel (SAF), with 2024 seeing a 50.9% surge in advanced biofuel consumption.

- **Key Growth Drivers:** Investment in SAF is growing rapidly, with production reaching 1.8 billion litres in 2024 and expected to increase another 40% in 2025.

- **Future Outlook (Net Zero):** Modern bioenergy is expected to nearly double from roughly 21 EJ in 2023 to 39 EJ by 2030, requiring a 9.3% annual growth rate.

- **Key Producers (2026 Projections):** Major producers include India, Germany, Thailand, and the Netherlands.

Key Locations and Regional Focus

- **India:**

  - ➢ **Capacity:** As of March 31, 2025, India's cumulative installed capacity for biomass power and cogeneration is **10.74 GW** (9.82 GW bagasse/IPP and 0.92 GW non-bagasse).
  - ➢ **Waste-to-Energy:** The capacity reached 840.21 MW as of March 2025.

- **Potential:** India produces over 600 MW of biomass annually, with ~285 MW of surplus, particularly in states like Punjab, Uttar Pradesh, Maharashtra, Gujarat, and Madhya Pradesh.
- **Biofuels:** India is the third-largest ethanol producer (6.35 billion liters in 2024), driven by E20 blending goals for 2025.

- **United States:**
  - ✓ **Biofuels:** Ethanol production reached a record 61.4 billion liters in 2024.
  - ✓ **Capacity:** Biomass power capacity is expected to remain largely steady in 2024 and 2025,
- **Indonesia:**
  - ✓ **Biodiesel:** 2024 marked the first full year of B35 (35% biodiesel blending) implementation, with consumption reaching 12.6 billion litres.
- **Brazil:**
  - ✓ **Bioenergy:** Reached 17.8 GW of biopower capacity in 2024.

2024-2025 Market Trends

- **Investments:** Bioenergy investments are shifting towards liquid biofuels and biogas, with a 60% increase in biogas investment, primarily in Europe.
- **Policy Support:** Increased regulatory mandates (e.g., Brazil's "Fuel of the Future" law, India's National Bioenergy Programme) are crucial to market growth.
- **Industry Shift:** Oil refineries are increasingly diversifying, with global biojet and renewable diesel capacity expected to increase 40% in 2025.

Geothermal Energy

Global geothermal Energy Estimates (2024-2025)

The global geothermal electricity market is experiencing strong growth, with market size increasing from approximately $7.91 billion in 2024 to an estimated $8.59 billion in 2025, driven by a CAGR of 8.6%. Total installed capacity reached 15.1 GW in 2024 with over 400 MW of new capacity added. Globally, use of geothermal power is growing annually at a rate of about 3% electrical and 7.5% thermal. The market is expected to expand further due to technological advancements in Enhanced Geothermal Systems (EGS) and rising demand for clean baseload power.

- **Market Growth:** The geothermal electricity market is projected to grow to over $12 billion by 2029, with a CAGR of 9.7%.
- **Capacity Expansion:** At least 400 MW of new capacity was added in 2024, pushing the global total to 15.1 GW.
- **2024 Status:** Approximately 99 TWh of electricity was generated from geothermal, with direct-use heat increasing by 20% to 245 TWh.
- **Investment Trends:** While 2024 saw significant momentum, 2025 is expected to see a slight contraction in funding due to investor caution, even as long-term investment projections remain strong (potentially $1 trillion cumulatively by 2035).

Key Regional and Sector Trends

- **Top Regions:** North America leads in market share, while the Asia-Pacific (APAC) region is expected to see the highest growth rate (27.8%) from 2025–2030.
- **Major Trends:** Increasing deployment of Enhanced Geothermal Systems (EGS), hybridization with other renewable sources, and the rise of geothermal heat pumps are key trends.
- **Future Potential:** The IEA estimates that at a depth of 5 km, U.S. technical potential exceeds 7 TW, while China accounts for nearly 8% (50 TW) of the global total, highlighting massive, long-term EGS potential.
- **New Policies:** India is emerging as a significant player, introducing its first National Policy on Geothermal Energy in 2025 to tap into an estimated 10.6 GW of potential.

Ocean (tidal, thermal and wave) Energy

Global Ocean Energy Market Estimates (2024-2025)

Based on reports for 2024–2025, the global ocean energy sector (tidal, wave, and ocean thermal energy conversion - OTEC) is experiencing significant growth, driven by a surge in renewable energy demand and technological advancements, with the market expected to grow from roughly **$0.83 billion in 2024 to over $1 billion in 2025**. While still in early stages compared to wind and solar, the sector is moving from pilot tests to larger-scale commercial deployments.

- **2024 Market Value:** Estimated around USD 0.83 billion to USD 1.18 billion.
- **2025 Market Forecast:** Projected to reach USD 1.01 billion to USD 1.61 billion, growing at a Compound Annual Growth Rate (CAGR) exceeding 20%.
- **Operational Capacity (2024):** Approximately 513 MW of total ocean power capacity was operational, with 1.6 MW added in 2024.
- **Future Outlook:** The market is projected to reach USD 2.33 billion to USD 6.29 billion by 2030-2034.

Tidal Energy Estimates

- **Status:** The most mature of the ocean technologies.
- **Key Developments (2024-2025):** The 240 MW La Rance (France) and 254 MW Sihwa (South Korea) tidal range systems still account for most capacity. In 2025, Minesto's Dragon 12 kite achieved 1.2 MW operation.
- **Regional Hubs:** Europe (Scotland/UK) remains the lead, with a 165 MW pipeline of projects planned over the next five years.

Wave Energy Estimates

- **Status:** Rapidly advancing, with focus on improving energy capture and lowering maintenance costs.
- **Key Developments (2024-2025):** CorPower Ocean installed its C4 commercial-scale converter in Portugal. Wavepiston installed a device in Spain.

- **Market Position:** Wave energy is increasingly being coupled with desalination and offshore wind for hybrid power generation.

Ocean Thermal Energy Conversion (OTEC)

- **Potential:** Extremely high, particularly in tropical regions.
- **Estimates:** OTEC potential around India is estimated at 180,000 MW.
- **2025 Activity:** South Korea invested in a wave-powered hydrogen plant (Yongsoo OWC) and planned larger, multi-module facilities for 2025.

Key Drivers and Trends (2024-2025)

- **High Growth Rate:** The sector is expected to see a CAGR of over 20-30% in the coming years due to increased investment and supportive government policies.
- **Regional Leadership:** Europe holds the largest market share (approx. 62.7% by 2035), while Asia-Pacific is identified as the fastest-growing region.
- **Challenges:** High capital costs and harsh marine environments, though new technologies in AI monitoring and improved materials are mitigating these challenges.
- **Funding:** The U.S. committed USD 141 million in public support in 2024.

1.6 Energy Status of India

1.6.1 Energy Consumption of India

India's energy environment is defined by record-high demand, rapid increase of renewable energy capacity, and a persistent, albeit shifting, reliance on coal, according to data from 2025 and estimates for the fiscal year 2025–2026.

Energy Consumption & Generation Metrics (FY 2025-26 Data)

- **Total Electricity Demand:** India successfully met a record peak power demand of **242.49 GW** in June 2025.
- **Total Energy Requirement (FY25):** The total electrical energy requirement for FY 2024-25 was estimated at **1,694 billion Units (BU)**.

- **Per Capita Consumption:** Per capita electricity consumption surged to **1,460 kWh in 2024–25**, reflecting a 52.6% increase from 2013-14 levels.
- **Power Shortages:** Energy shortages at the national level dropped significantly to a mere **0.03%** in FY 2025-26.

Energy Mix and Production (2025-26)

- **Installed Capacity:** As of November 30, 2025, India's total installed power generation capacity reached **509.74 GW**.
- **Renewable Energy (RE) Milestone:** In June 2025, India achieved a significant milestone, with non-fossil fuel sources (including large hydro and nuclear) accounting for **50% of total installed capacity**.
- **Renewable Energy Capacity (Nov 2025):** The total renewable energy installed capacity reached **253.96 GW**.
- **Solar Expansion:** Solar energy capacity crossed 100 GW in January 2025 and reached **132.85 GW** by November 2025.
- **Thermal (Coal) Role:** Despite the green shift, coal remains critical, with the total installed capacity of coal and lignite-based plants standing at **226.23 GW** as of November 2025, and 13.32 GW of new coal capacity awarded in FY 2025-26.

Growth Drivers and Trends

- **Rapid Demand Growth:** Total power consumption in India is growing at a high rate, with a 5-year Compound Annual Growth Rates (CAGR) of 7.4% up to FY25.
- **Industrial Consumption:** The industrial sector is the largest energy consumer, accounting for roughly **40% of demand**, followed by the residential sector at 25%.
- **Biofuel Adoption:** Ethanol blending in petrol reached **18.5% in 2025**, moving closer to the 20% target.
- **Electric Vehicles:** The rise of electric vehicles and data centres is further driving up power demand, which is expected to grow at 6–6.5% annually over the next five years.

Policy and Infrastructure (2025-26)

- **Grid Expansion:** The transmission network is expanding, with plans to increase from 4.98 lakh ckm in Nov 2025 to 6.48 lakh ckm by 2032.

- **Storage Solutions:** To support renewable energy integration, India is increasing its investment in Pumped Storage Hydro (PSH) and Battery Energy Storage Systems (BESS), with a target of 73.9 GW capacity by 2031–32.

- **Coal Stocking:** Domestic Coal-Based (DCB) power plants held 51.7 MT of coal as of late December 2025, with targets to reach 66 MT by March 2026 to ensure supply security.

1.6.2 Availability of Conventional Sources

Fossil Fuels

As of late 2025 and moving into 2026, India's power sector is experiencing a rapid energy transition where, despite a massive surge in renewable energy, fossil fuels (primarily coal) remain the dominant source of baseload power. By November 2025, India achieved a historic milestone with over 51% of its total installed capacity coming from non-fossil fuel sources, according to a Ministry of Power year-end review.

Fossil Fuel Power Capacity (2025-2026 Estimates)

- **Total Capacity (Nov 2025):** India's total installed capacity reached approximately 509.74 GW.

- **Fossil Fuel Share:** Thermal power (coal, lignite, gas, diesel) accounts for roughly **48% to 49%** of the total, with approximately 244.8 GW to 246.9 GW installed.

- **Coal & Lignite Dominance:** Coal-based capacity alone stands at roughly 220 GW-226 GW, representing over 90% of the total thermal capacity.

- **Capacity Additions (2025-26):** In the FY 2025-26 period (up to Nov 2025), about 7.21 GW of new coal-based thermal capacity was commissioned.

- **Pipeline (2026 & Beyond):** An additional 40.35 GW of coal capacity is under construction, with a further 24.02 GW in planning stages. However, reports suggest that increased renewable generation may make some new coal capacity additions redundant by 2030.

Market and Generation Estimates

- **Generation Mix:** Despite having nearly 50% capacity, thermal power continues to supply approximately **70%** of the total generated electricity.
- **Coal Generation Trend:** 2025 marked a significant shift, with coal-based power generation falling by 3%, marking only the second decline in at least 50 years (the first being during the pandemic), as reported by CREA.
- **Peak Demand:** India met a record peak demand of 242.49 GW in June 2025.
- **Investment Outlook:** The power sector is expected to attract over Rs 17 lakh crore (US$ 205.31 billion) in investments over the next five to seven years.

Key Drivers & Trends

1. **Declining Coal Usage in Generation:** Increased renewable energy generation (up 22% in 2025) and milder weather led to a 3% decrease in coal-based generation.
2. **Increased Coal Stocks:** Domestic coal-based plants held 51.7 MT of coal as of Dec 2025, with a target to increase to 66 MT by March 2026 to ensure supply security.
3. **Revised SHAKTI Policy:** In May 2025, the government approved the Revised SHAKTI policy to streamline coal allocation to the power sector, enhancing flexibility and accessibility.
4. **Rise of Renewables:** In 2025, 76% of all new capacity added was renewable (41 GW), bringing total non-fossil capacity to over 262 GW by November 2025.

Hydropower Sources

As of late 2025, India has solidified its position as a major player in hydropower, focusing on both conventional large-scale projects and Pumped Storage Schemes (PSS) to balance its intermittent solar and wind capacity. Total renewable energy capacity (including large hydro) reached over **253 GW** by November 2025, with large hydro specifically contributing over **50 GW**.

Hydro Power Capacity & Project Pipeline (2025-2026)

- **Total Installed Capacity:** As of June 2025, India's installed capacity reached approximately **49.38 GW** (large hydro) and **5.1 GW** (small hydro). By November 2025, the total non-fossil installed capacity (including large hydro) reached 262.74 GW.

- **Capacity Addition (2025-26):** Around **1,650 MW to 2,170 MW** of large hydro capacity is expected to be commissioned by the end of FY 2025-26. Key projects fueling this include:

  - **NHPC's Parbati-II HPS** (800 MW, fully commissioned on 15.04.2025).
  - **THDC's Tehri PSP** Unit 1 (250 MW).
  - **Greenko's Pinnapuram HPS** Units 1–5 (5x240 MW).

- **Future Pipeline (2026+):** Over 25,000 MW of large hydropower projects are currently under construction (as of Sept 2025), with a goal to reach **88 GW** of total hydro capacity by 2031-32.

Key Market Trends (2025-2026)

- **Rise of Pumped Storage Systems (PSS):** PSS is becoming the primary focus to manage grid stability, with 63 schemes identified and a target to reach ~50 GW by 2032. In 2024-25, the CEA approved 7.5 GW of new PSS.

- **Policy Support:** The government has introduced waivers for Inter State Transmission System (ISTS) charges for hydro projects to encourage investment.

- **Industry Drivers:** Major developers driving the market include NHPC, SJVN, NTPC, JSW Energy, and Greenko.

- **Regional Dominance:** Northern states (Himachal Pradesh, Uttarakhand, Jammu & Kashmir) and the North-Eastern region (Arunachal Pradesh) remain the, hubs, while Tamil Nadu, Karnataka, and Maharashtra are leading in PSS development.
- **Small Hydropower Market:** The small hydropower (up to 10 MW) market is projected to reach USD 169 million by 2031, growing at a CAGR of 6.19% from 2025.

Market Challenges

- **Project Delays:** 61 projects are delayed due to forest clearances and land acquisition issues.
- **Environmental/Geological Risks:** The Himalayan terrain poses significant technical and environmental risks.

Nuclear power Sources

As of early 2026, India is experiencing a significant push in its nuclear power sector, with a focus on increasing operational capacity through indigenous technology and private sector participation. The government has set an ambitious target to reach 100 GW of nuclear capacity by 2047.

Nuclear Power Capacity (2025-2026 Estimate)

- **Current Capacity (Jan/Feb 2026):** India's operational nuclear power capacity stands at approximately **8,780 MW** (8.78 GW) from 24 reactors.
- **2025-26 FY Projection:** The nuclear capacity is set to rise to **9,480 MW** by the end of the 2025-26 financial year as new projects, such as RAPP-7, come online.
- **Expansion Pipeline:** A total capacity of **13,600 MW** (including the 500 MW Prototype Fast Breeder Reactor - PFBR) is currently under construction and expected to be completed progressively by 2031-32.
- **Mid-Term Target:** Nuclear capacity is projected to reach **22,480 MW (22.4 GW) by 2031-32**.

Nuclear Market Estimates & Key Developments (2025-2026)

- **Market Opportunity:** The Indian nuclear market is projected to offer over **$214 Billion (approx. INR 19.3 trillion)** in business potential as the country targets 100 GW by 2047.

- **Nuclear Energy Mission (2025-26 Budget):** A dedicated mission was launched to develop at least five indigenously designed Small Modular Reactors (SMRs) or "Bharat Small Reactors" (BSRs) by 2033, with an initial allocation of ₹20,000 crore.

- **Private Sector Participation (SHANTI Act):** The government enacted the **Sustainable Harnessing and Advancement of Nuclear Energy (SHANTI) Act, 2025**, which allows private firms and international players to take up to 49% equity, breaking the previous Public Sector Unit (PSU) monopoly.

- **Key Projects & Collaborations:**

    ✓ **ASHVINI JV:** NPCIL and NTPC have formed a joint venture (ASHVINI) to develop nuclear plants, including the 4x700 MWe Mahi-Banswara Rajasthan Atomic Power Project.

    ✓ **SMRs for Industry:** Bharat Small Reactors (220 MW) are being upgraded to provide captive power for energy-intensive sectors like steel, aluminum, and cement.

    ✓ **International Collaboration:** In-principle approval was given for a 6 x 1208 MW plant at Kovvada, Andhra Pradesh, in cooperation with the USA.

Key 2025-26 Policy Trends

- **Fuel Security:** A new uranium deposit was discovered near the Jaduguda mines, extending its life by over 50 years.

- **Regulatory Shift:** Amendments to the Atomic Energy Act, 1962, and the Civil Liability for Nuclear Damage Act, 2010, are being enacted to reduce bottlenecks for private investment.

- **Customs Exemptions:** The Union Budget 2026-27 announced customs duty exemptions on imports required for nuclear power projects until 2035.

1.6.3 Availability of Non-Conventional Sources

Solar Energy

As of late 2025 and moving into 2026, India is experiencing a historic surge in solar capacity, solidifying its position as the world's third-largest solar market. India added a record ~35 GW of solar capacity in the first 11 months of 2025, with total renewable energy capacity exceeding 250 GW by November 2025.

Solar Power Capacity Estimates (2025-2026)

- **Cumulative Capacity (Nov 2025):** Solar installed capacity reached **132.85 GW**, marking an increase of over 41% compared to November 2024.
- **Capacity Goal (FY2026):** India is expected to add around **41.5 GW to 50 GW** of new solar capacity in FY2026 (ending March 31, 2026).
- **Project Pipeline:** As of September 2025, the utility-scale solar project pipeline stood at **191.9 GW**, with another 162.5 GW tendered.
- **Manufacturing Capacity:** Domestic solar module manufacturing capacity under ALMM reached ~144 GW per annum in 2025.

Market Estimates and Trends (2025-2026)

- **Market Position:** India is set to overtake the United States as the world's second-largest solar market in 2026.
- **Market Growth (2025-2029):** The India solar power market is valued to increase at a CAGR of 42.4% from 2024 to 2029, driven by high investments and government policy, particularly in the utility segment.
- **Key Drivers:**
    - ✓ **PM Surya Ghar: Muft Bijli Yojana:** Aims for 30 GW of rooftop solar in the residential sector by FY 2026-27.
    - ✓ **PM-KUSUM:** Targets 34.8 GW of solar capacity through solarizing agricultural pumps.

- ✓ **PLI Scheme:** Over 18 GW of module manufacturing and 5 GW of solar cell manufacturing capacity became operational by mid-2025.

- **Top Contributing States:** As of Q3 2025, Rajasthan, Maharashtra, and Gujarat were leading in large-scale solar capacity additions.

- **Key Players (2025):** Top developers included Adani, ReNew, NTPC, Greenko, and JSW Energy. Leading module suppliers in 2025 included Waaree, Jinko, and Longi.

Challenges and Outlook

- **Supply Chain Concerns:** While module capacity is high (~170 GW), cell production capacity lags at approximately 29 GW, leaving the industry dependent on imports for cells and raw materials.

- **Grid Infrastructure:** High-growth regions like Rajasthan and Gujarat are experiencing 10-30% curtailment rates due to delays in transmission system construction.

- **Policy Impact:** The enforcement of the Approved List of Models and Manufacturers (ALMM) for solar cells is expected to raise project costs in late 2025/2026.

Wind Energy

As of late 2025 and moving into 2026, India's wind power sector is experiencing a significant resurgence, reclaiming its spot as the world's third-largest wind energy market. The industry is shifting toward larger turbines, hybrid projects (wind-solar), and accelerated capacity addition driven by high demand for renewable power.

Wind Power Capacity & Trends (2025-2026)

- **Total Capacity (End of 2025):** The cumulative wind power capacity scaled to **54.51 GW** by the end of December 2025.

- **Annual Addition 2025:** India added **6.34 GW** of wind energy capacity in the 2025 calendar year, a massive 85% increase over the 3.42 GW added in 2024.

- **2026 Outlook:** The sector is expected to continue this momentum, with projections showing the capacity reaching approximately **59.5 GW to 60 GW by the end of 2026**.

- **Key Drivers:** Growth is driven by open access, commercial & industrial (C&I) demand for round-the-clock (RTC) power, and non-solar Renewable Purchase Obligations (RPO).

- **Top States:** Gujarat, Tamil Nadu, and Karnataka continue to lead, accounting for over 70-80% of total installations. Gujarat is the leading state with 14.8 GW (as of Dec 2025), followed by Tamil Nadu (12 GW) and Karnataka (8.4 GW).

Market Estimates and Outlook (2025-2030)

- **Market Growth:** The wind energy market is expected to expand at a Compound Annual Growth Rate (CAGR) of over 11% to 14.9% during the 2025-2030 period, aiming for over 100 GW by 2030.

- **Offshore Wind:** The market is transitioning from purely onshore to exploring offshore, with a 1 GW offshore project planned off the coast of Gujarat and Tamil Nadu using viability gap funding (VGF).

- **Manufacturing Capability:** India's manufacturing capacity for wind turbines has grown to 20 GW per annum, with major players like Suzlon and Inox Wind leading the market, which is now focusing on 3 MW–6 MW class turbines.

- **Costs:** While tariffs saw a brief increase, the overall market is focusing on reducing the Levelized Cost of Energy (LCOE) through repowering, which involves replacing older, smaller turbines with larger, more efficient ones.

Key Policy Drivers

- **Approved List of Models and Manufacturers (ALMM):** Strengthened in 2025, it mandates the use of listed components (blades, towers, generators), promoting domestic manufacturing.

- **Wind-Solar Hybrid Policies:** These are increasingly preferred by distribution companies (DISCOMs) because they offer better capacity utilization (over 35%) compared to standalone wind.

- **Target:** India aims to reach **100 GW to 140 GW of wind capacity by 2030** as part of its 500 GW non-fossil fuel goal.

Biomass Energy

As of late 2025/early 2026, India's biomass power and bioenergy sector is experiencing steady growth, with total bioenergy installed capacity reaching approximately **11.61 GW** by November 2025. The market is driven by aggressive government targets, including a 7% co-firing mandate for solid biomass in coal plants by 2026 and a 20% ethanol blending target in petrol for 2025-2026.

Biomass Power Capacity (2025-2026)

- **Total Bioenergy Installed Capacity (Nov 2025):** 11.61 GW (including biomass power, bagasse-based cogeneration, and waste-to-energy).

- **Capacity Breakdown (as of March 31, 2025):**

    - ✓ **Bagasse & IPP (Independent Power Producers):** 9.82 GW.
    - ✓ **Non-Bagasse (Co-generation):** 0.92 GW.
    - ✓ **Waste-to-Energy:** ~840 MWeq (309.34 MW grid-connected).

- **2025 Additions:** In 2025, 12 bio-power plants were commissioned, adding 89.86 MW.

- **Projection:** The installed base for biomass is expected to reach 11.58 gigawatts in 2025 and grow to roughly 14.97 gigawatts by 2030, reflecting a 5.27% CAGR.

Market Estimates & Trends (2025-2026)

- **Market Size:** The Indian biomass market is expanding, with a focus on converting agricultural waste into pellets for power generation.

- **Key Growth Drivers:**

- ✓ **Co-firing in Thermal Power Plants:** The Ministry of Power's policy enables coal plants to purchase biomass pellets, with a target of 7% co-firing by 2026.
- ✓ **National Bioenergy Programme:** This program is active from April 2021 to March 2026 with an outlay of ₹858 crore (Phase-I).
- ✓ **Compressed Biogas (CBG):** The SATAT scheme aims for a 5% CBG blending target by 2028-29. About 170 CBG plants were operational by 2025, with ~300 more under construction.
- ✓ **Feedstock Availability:** India has an annual surplus of ~285 million tonnes of biomass available for energy use.

- **Investment Outlook:** Clean energy investments in India, including bioenergy, reached $68 billion in 2023, with continued growth expected through 2025-2026.

Key Policies and Targets (2025-2026)

- **20% Ethanol Blending:** Target for 2025-2026.
- **7% Biomass Co-firing:** Target for 2026.
- **National Bioenergy Programme (Phase-I):** Runs until March 31, 2026.
- **Financial Assistance:** The government approved ₹564.75 crore for supporting biomass aggregation machinery for CBG producers, applicable from FY 2023-2024 to FY 2026-2027.

Geothermal Energy

In 2025–2026, India is transitioning its geothermal energy sector from exploration to pilot-stage implementation, underpinned by the newly notified **National Policy on Geothermal Energy (September 2025)**. While the country has an estimated **10.6 GW** of geothermal potential across 10 provinces and 381 hot springs, the current operational capacity is negligible, with development focused on pilot projects and direct-use applications.

Geothermal Power Capacity & Developments (2025-2026)

- **National Policy 2025:** The Ministry of New and Renewable Energy (MNRE) notified this policy to tap into high-enthalpy regions, including the Himalayas

(Ladakh, Himachal Pradesh, Uttarakhand), Cambay Graben (Gujarat), and the Andaman & Nicobar Islands.

- **Pilot Projects:** In September 2025, the government sanctioned **five pilot projects**. Key initiatives include:

    - ✓ **Puga Valley, Ladakh:** Identified as the most promising site for a pilot power plant.
    - ✓ **Cambay, Gujarat:** Utilization of abandoned ONGC oil wells for geothermal energy.
    - ✓ **Tawang, Arunachal Pradesh:** Geothermal heating for an army base.
    - ✓ **Barmer, Rajasthan:** A ₹15 crore pilot project to use geothermal energy from abandoned oil fields.

- **Technological Focus:** Initial development focuses on binary cycle plants to utilize moderate-temperature resources, with a long-term goal of integrating with solar-geothermal hybrid systems.

Market Estimates & Trends (2025-2026)

- **Market Size:** The Indian geothermal energy market is expected to grow from approximately USD 0.432 billion in 2025 to USD 0.838 billion by 2035, with a CAGR of around 6.92%.

- **Investment & Growth:** Global reports suggest the Asia-Pacific region is a leader in geothermal growth, and India is diversifying its energy mix with a focus on 24/7 baseload power.

- **Key Drivers:** Rising demand for firm renewable energy (baseload) and the need for decarbonization are driving investment, with policy support providing 30-year leases for exploration.

- **Future Projections:** While current capacity is low, some projections suggest India's geothermal capacity could reach 4.2 GW by 2035.

Key Challenges

High upfront capital costs (estimated at ~₹36 crore per MW) and exploration risks are the primary barriers, with the government exploring Viability Gap Funding (VGF) for upcoming projects. The 2025 policy aims to mitigate these risks by facilitating single-window clearances and promoting public-private partnerships.

Ocean (tidal, thermal and wave) Energy

As of 2025–2026, India is in the pre-R&D or demonstration stage for ocean energy, focusing on mapping potential rather than commercial-scale deployment. While theoretical potential is high, active installed capacity for tidal, wave, and thermal (OTEC) power is negligible or non-existent in the active commercial market.

Ocean Power Potential in India (2025-2026)

- **Total Potential:** Estimated to be around 54 GW of ocean energy, including tidal and wave.
- **Tidal Energy:** Theoretical potential is approximately 12.45 GW, with primary locations in the Gulf of Khambhat and Gulf of Kutch in Gujarat and the Sunderbans in West Bengal.
- **Wave Energy:** The total theoretical potential along India's 7,500 km coastline is estimated at about 40 GW, with the southern coasts of Tamil Nadu, Kerala, and Karnataka being suitable.
- **Ocean Thermal Energy Conversion (OTEC):** Theoretical potential is estimated at 180,000 MW, although this is subject to significant technological evolution.

Market Estimates and Developments (2025-2026)

- **Market Size:** The Indian Wave and Tidal Energy market was projected to be valued at approximately USD 38.84 million in 2025, with a high projected CAGR of 38.5% through 2033.
- **Industry Focus:** The government is focusing on R&D for small-scale demonstration projects, with the National Institute of Ocean Technology (NIOT) leading these efforts.

- **Key Trends:** The government has declared tidal and wave energy as renewable energy sources, allowing them to qualify for Renewable Purchase Obligations (RPO).
- **Barriers:** High capital costs (ranging from Rs 15 crore to over Rs 60 crore per MW) have previously caused planned projects in Gujarat and West Bengal to be shelved.
- **Deep Ocean Mission:** Initiated in 2021, the mission is advancing ocean technology, with milestone deep-sea dives (5000m) reported in 2025, which may provide future support for OTEC infrastructure.

1.5 Energy Conservation, Conversion, Efficiency, Production, Use, Supply, Consumption

Energy Conservation

In any transformation of energy from one from to another, the total quantity of energy remains unchanged. This principle that energy is always remains unchanged, is called energy conservation (**first law of thermodynamics**). For instance, if the quantity of energy in the output of a power station is less than the quantity of the energy in the fuel input, then some of the energy must have been converted into the form of waste heat. This indicates that the total energy is conserved.

Energy Conversion

The energy is usually converted from one form to another. This is called energy conversion. Primary energy is converted in many ways to energy carriers, also known as secondary energy which in turn into other energy carriers is called tertiary energy.

- Coal mainly goes to thermal power stations where coke is derived by destructive distillation of bituminous coal.
- Crude oil goes mainly to oil refineries. After crude oil enters an oil refinery, it goes through **separation (**fractional distillation**), conversion (**cracking**,** reforming**), and treatment**, breaking it down and reconfiguring it into valuable products like gasoline, diesel, jet fuel, asphalt, and petrochemical feedstocks, which are then stored and transported for energy input.

- Natural-gas goes to natural-gas processing plants to remove contaminants such as water, carbon dioxide and hydrogen sulphide. It is used as fuel gas in thermal power stations.
- Biomass is converted to biofuel.
- We burn fuel in an engine, converting its stored chemical energy into heat and then into kinetic energy of the moving vehicle.
- A wind turbine extracts kinetic energy from moving air and converts it into electrical energy, which can in turn be converted into heat the filament of a lamp causing it to radiate light energy.

Energy Efficiency

Renewable energy sources (solar, wind, hydro) are generally more efficient and sustainable, with many technologies operating at higher efficiencies compared to the 25–85% range of fossil fuel power plants. While non-renewables offer high energy density and consistent output, their efficiency is limited by fuel combustion losses. Renewables are increasingly cost-efficient, though they face intermittency challenges.

Renewable Energy Efficiency

- **High Efficiency:** Technologies like wind and solar can have high efficiency rates, with some wind systems providing over 100% of their initial energy input due to the nature of harnessing ambient energy.
- **Sustainability:** Sources like wind, solar, and geothermal are naturally replenished, making them ideal for long-term, sustainable energy production.
- **Low Operational Waste:** Renewable sources generally do not require fuel, resulting in minimal waste compared to fossil fuels.
- **Common Sources:** Solar, wind, hydro, geothermal, and biomass.

Non-Renewable Energy Efficiency

- **Lower Efficiency:** Fossil fuel plants often achieve only 25–85% efficiency. For instance, coal-powered energy may only utilize roughly 29% of its original energy value.

- **High Energy Density:** Non-renewables (coal, oil, natural gas) offer high energy output, making them efficient in terms of, for example, the energy contained within a small volume of fuel.
- **Reliability:** These sources provide consistent, on-demand energy, which is easier to manage in existing grid infrastructures.
- **Drawbacks:** These sources are finite, produce significant pollution, and have high environmental mitigation costs.

Energy Production

Renewable energy comes from sources that replenish naturally and quickly (sun, wind, water, biomass, geothermal), while non-renewable energy comes from finite sources that deplete over time (fossil fuels like coal, oil, gas, and nuclear fuels like uranium). The key difference is sustainability: renewables are virtually endless, whereas non-renewables are exhaustible and often have greater environmental impacts like carbon emissions, though non-renewables currently power much of the world's industry and transport.

Renewable Energy Sources (Sustainable & Replenishing)

- **Solar:** Energy from sunlight.
- **Wind:** Power from moving air.
- **Hydroelectric:** Energy from flowing water.
- **Geothermal:** Heat from within the Earth.
- **Biomass:** Organic matter like wood, crops, and waste.
- **Tidal:** Energy from ocean tides.

Non-Renewable Energy Sources (Finite & Depleting)

- **Fossil Fuels:**
    - ✓ **Coal:** A solid fuel.
    - ✓ **Petroleum (Oil):** A liquid fuel.
    - ✓ **Natural Gas:** A gaseous fuel.

- **Nuclear Fuels:**
    - ✓ **Uranium:** Used for nuclear power.
- **Minerals & Metals:** Finite earth minerals like iron, copper.

Key Differences

- **Replenishment:** Renewables regenerate quickly; non-renewables take millions of years or are finite.
- **Availability:** Renewables are abundant; non-renewables are limited.
- **Environmental Impact:** Renewables generally have lower carbon footprints, while burning fossil fuels causes pollution and climate change.

Energy Use

Renewable Energy Sources & Usage: These sources are constantly replenished and include solar, wind, hydropower, and geothermal energy. They are primarily used for electricity generation, heating, and, increasingly, transportation.

Non-Renewable Energy Sources & Usage: These finite resources, such as coal, petroleum, and natural gas, cannot be replaced once consumed. They are heavily used in transportation (gasoline), electricity generation, and industrial processes

Energy Supply

Total energy supply (TES) constitutes the sum of domestically produced energy (fossil fuels, nuclear, renewables) and imports, minus exports and storage, representing the total energy required for a country's consumption. It includes the entire supply chain—extraction, transformation, and distribution—aimed at meeting demand securely. Key components involve balancing diverse sources, such as oil, coal, and increasing renewable integration, while navigating geopolitical, economic, and infrastructure-related risks.

Key Aspects of Energy Supply

- **Definition:** Total energy supply (TES) includes all energy produced in or imported to a country, minus exports and storage.

- **Components:** This includes fossil fuels (coal, oil, natural gas), nuclear energy, and renewable sources (hydro, wind, solar, bioenergy).
- **Supply Chain:** The process covers extraction, transformation (e.g., electricity generation), transmission, and distribution.
- **Challenges:** The reliability of supply is affected by factors like geopolitical conflicts, infrastructure damage, and fluctuating market prices.
- **Shifting Trends:** There is a global push to transition from traditional fossil fuel-dependent systems to more sustainable, renewable sources.

Regional & Global Context

- **Global Mix:** Oil remains the largest source, followed by coal and gas, with growing shares from renewables.
- **India's Context:** Coal remains the primary energy source, though the country is rapidly expanding its renewable energy infrastructure (solar and wind).
- **Security:** Ensuring a consistent supply involves managing imports, developing domestic resources, and improving energy efficiency to reduce demand.

Energy Consumption

(See earlier)

1.7 Environment-Economy-Energy and Sustainable Development

Sustainable development necessitates balancing economic growth, energy consumption, and environmental protection to meet current needs without compromising future generations. Key strategies include **investing in renewable energy, improving energy efficiency, and reducing emissions.**

Key Pillars and Interactions

- **Environment and Sustainable Development/Sustainability**

- Activities that continuously harm the environment are not sustainable over time for a number of reasons; over time, the cumulative effects of these activities on the environment frequently result in a range of ecological, health, and other issues. A society's use of energy resources is linked to a significant amount of its environmental impact, involves preserving natural resources and making sure they are not depleted, which frequently calls for switching from fossil fuels to renewable energy sources like wind and solar.
- **Economy and Sustainable Development/Sustainability**

In order to meet current demands without endangering future generations, sustainable development strikes a balance between social justice, environmental preservation, and economic progress. Through circular economies, renewable energy, and prudent resource management, it ensures that expansion does not deplete natural capital and does not negatively impact the environment, thereby promoting long-term prosperity. Investing in green technologies, cutting emissions, and encouraging inclusive, moral business practices are important tactics.

- **Energy and Sustainable Development/Sustainability**

Energy is crucial for sustainable development, yet its traditional use drives environmental degradation. Modern approaches emphasize increasing energy efficiency to reduce pollution.

Conclusions

- Energy is an important support for economic development and a key area for environmental protection. The extensive use of traditional fossil fuels is one of the main causes of environmental pollution and climate change. Therefore, promoting the transformation of energy structure and developing clean energy are inevitable choices for achieving sustainable development. For example, vigorously developing renewable energy sources such as solar and wind power can not only reduce dependence on fossil fuels and ensure energy security, but also effectively reduce carbon emissions, mitigate climate change, and leave a clean and beautiful home for future generations.

- In order to establish peaceful coexistence between humans and nature and build a better future, we must follow the path of sustainable development in the face of global difficulties including resource shortages, environmental pollution, and climate change.
- Energy conservation through increased energy efficiency, a decrease in the use of fossil fuels and an increase in the supply of environmentally benign energy forms, which is resulting in the use of renewable energy sources and technologies, the acceleration of forestation to absorb CO2, and a reduction in energy usage through lifestyle changes and public awareness are some potential solutions regarding the potential issues related to CO2 emissions.
- Energy nurtures and builds a brighter future. It is difficult to integrate the economy, energy, and environment; enterprises, the public, and the government must work together. To direct and promote sustainable growth, the government should create sensible laws and policies. Businesses should actively take on social responsibility and incorporate sustainable development into every facet of their operations and production. People should adopt a green lifestyle and increase their awareness of environmental issues. We can only create a thriving economy, safe energy, and a stunning environment for a brighter future by cooperation.