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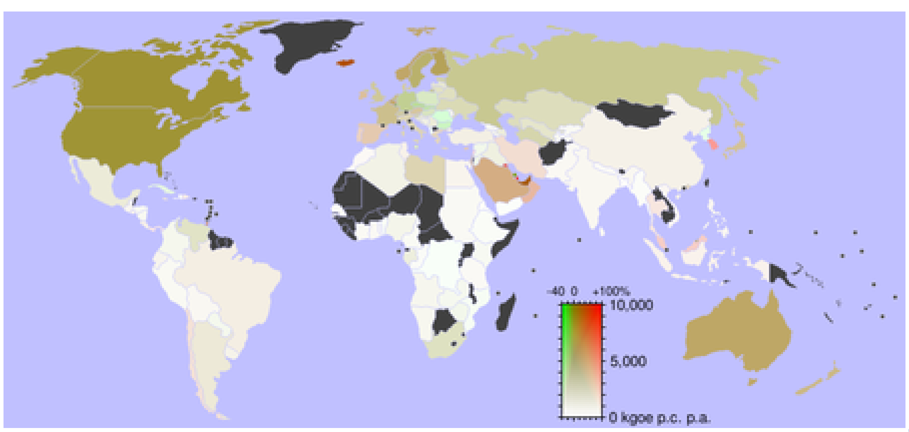
The **energy industry** is the totality of all of the industries involved in the production and sale of energy, including fuel extraction, manufacturing, refining and distribution. Modern society consumes large amounts of fuel, and the energy industry is a crucial part of the infrastructure and maintenance of society in almost all countries.

In particular, the energy industry comprises:

- the fossil fuel industries, which include petroleum industries (oil companies, petroleum refiners, fuel transport and end-user sales at gas stations) coal industries (extraction and processing) and the natural gas industries (natural gas extraction, and coal gas manufacture, as well as distribution and sales);
- the electrical power industry, including electricity generation, electric power distribution and sales;
- the nuclear power industry;
- the renewable energy industry, comprising alternative energy and sustainable energy companies, including those involved in hydroelectric power, wind power, and solar power generation, and the manufacture, distribution and sale of alternative fuels; and,
- traditional energy industry based on the collection and distribution of firewood, the use of which, for cooking and heating, is particularly common in poorer countries.

The increased dependence during the 20th century on carbon-emitting sources of energy such as fossil fuels, and carbon-emitting renewables such as biomass, means that the energy industry has frequently been an important contributor to pollution and environmental impacts of the economy. Until recently, fossil fuels were the main source of energy generation in most parts of the world, and are a major contributor to global warming and pollution. As part of human adaptation to global warming, many economies are investing in renewable and sustainable energy.



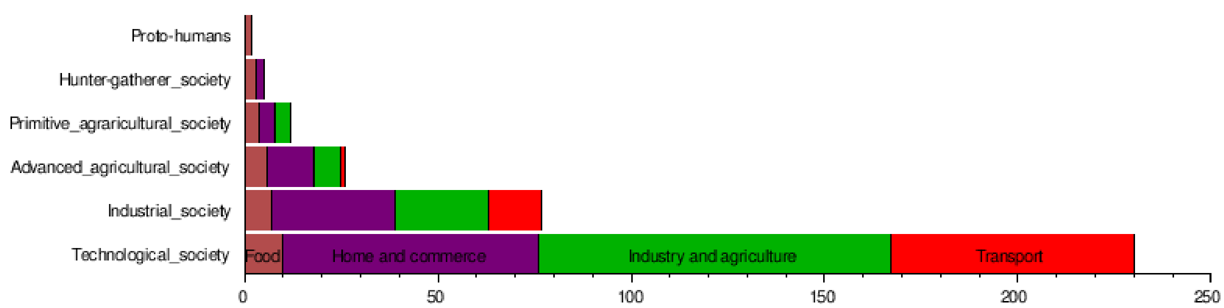
Energy consumption in kilograms of oil equivalent (kgoe) per person per year per country (2001 data). Darker tones indicate larger consumption, while dark grey areas are missing from the dataset. Red hue indicates increasing consumption, green hue indicates decreasing consumption, in the time between 1990 and 2001.

History

The use of energy has been a key in the development of the human society by helping it to control and adapt to the environment. Managing the use of energy is inevitable in any functional society. In the industrialized world the development of energy resources has become essential for agriculture, transportation, waste collection, information technology, communications that have become prerequisites of a developed society. The increasing use of energy since the Industrial Revolution has also brought with it a number of serious problems, some of which, such as global warming, present potentially grave risks to the world.[1]

In some industries, the word *energy* is used as a synonym of energy resources, which refer to substances like fuels, petroleum products and electricity in general, because a significant portion of the energy contained in these resources can easily be extracted to serve a useful purpose. After a useful process has taken place, the total energy is conserved, but the resource itself is not conserved, since a process usually transforms the energy into unusable forms (such unnecessary or excess heat).

Ever since humanity discovered various energy resources available in nature, it has been inventing devices, known as machines, that make life more comfortable by using energy resources. Thus, although the primitive man knew the utility of fire to cook food, the invention of devices like gas burners and microwave ovens has increased the usage of energy for this purpose alone manyfold. The trend is the same in any other field of social activity, be it construction of social infrastructure, manufacturing of fabrics for covering; porting; printing; decorating, for example textiles, air conditioning; communication of information or for moving people and goods (automobiles).



Economics

Main article: Energy economics

Production and consumption of energy resources is very important to the global economy. All economic activity requires energy resources, whether to manufacture goods, provide transportation, run computers and other machines.

Widespread demand for energy may encourage competing energy utilities and the formation of retail energy markets. Note the presence of the "Energy Marketing and Customer Service" (EMACS) sub-sector.[2]

The energy sector accounts for 4.6% of outstanding leveraged loans, compared with 3.1% a decade ago, while energy bonds make up 15.7% of the $1.3 trillion junk bond market, up from 4.3% over the same period.[3]

Management

Main article: Energy demand management

Since the cost of energy has become a significant factor in the performance of economy of societies, management of energy resources has become very crucial. Energy management involves utilizing the available energy resources more effectively; that is, with minimum incremental costs. Many times it is possible to save expenditure on energy without incorporating fresh technology by simple management techniques.[4] Most often energy management is the practice of using energy more efficiently by eliminating energy wastage or to balance justifiable energy demand with appropriate energy supply. The process couples energy awareness with energy conservation.

Classifications

Government

The United Nations developed the International Standard Industrial Classification, which is a list of economic and social classifications.[5] There is no distinct classification for an energy industry, because the classification system is based on *activities*, *products*, and *expenditures according to purpose*.[6]

Countries in North America use the North American Industry Classification System (NAICS). The NAICS sectors #21 and #22 (mining and utilities) might roughly define the energy industry in North America. This classification is used by the U.S. Securities and Exchange Commission.

Financial market

The Global Industry Classification Standard used by Morgan Stanley define the energy industry as comprising companies primarily working with oil, gas, coal and consumable fuels, excluding companies working with certain industrial gases.[7] Add also to expand this section: Dow Jones Industrial Average[8]

Environmental impact

Main article: Environmental impact of the energy industry

Government encouragement in the form of subsidies and tax incentives for energy-conservation efforts has increasingly fostered the view of conservation as a major function of the energy industry: saving an amount of energy provides economic benefits almost identical to generating that same amount of energy. This is compounded by the fact that the economics of delivering energy tend to be priced for capacity as opposed to average usage. One of the purposes of a smart grid infrastructure is to smooth out demand so that capacity and demand curves align more closely. Some parts of the energy industry generate considerable pollution, including toxic and greenhouse gases from fuel combustion, nuclear waste from the generation of nuclear power, and oil spillages as a result of petroleum extraction. Government regulations to internalize these externalities form an increasing part of doing business, and the trading of carbon credits and pollution credits on the free market may also result in energy-saving and pollution-control measures becoming even more important to energy providers.

Consumption of energy resources, (e.g. turning on a light) requires resources and has an effect on the environment. Many electric power plants burn coal, oil or natural gas in order to generate electricity for energy needs. While burning these fossil fuels produces a readily available and instantaneous supply of electricity, it also generates air pollutants including carbon dioxide (CO_2), sulfur dioxide and trioxide (SOx) and nitrogen oxides (NOx). Carbon dioxide is an important greenhouse gas, known to be responsible, along with methane, nitrous oxide, and fluorinated gases, for the rapid increase in global warming since the Industrial Revolution. In the 20th century, global temperature records are significantly higher than temperature records from thousands of years ago, taken from ice cores in Arctic regions. Burning fossil fuels for electricity generation also releases trace metals such as beryllium, cadmium, chromium, copper, manganese, mercury, nickel, and silver into the environment, which also act as pollutants.

The large-scale use of renewable energy technologies would "greatly mitigate or eliminate a wide range of environmental and human health impacts of energy use".[9][10] Renewable energy technologies include biofuels, solar heating and cooling, hydroelectric power, solar power, and wind power. Energy conservation and the efficient use of energy would also help.

In addition, it is argued that there is also the potential to develop a more efficient energy sector. This can be done by:[11]

- Fuel switching in the power sector from coal to natural gas;
- Power plant optimisation and other measures to improve the efficiency of existing CCGT power plants;
- Combined heat and power (CHP), from micro-scale residential to large-scale industrial;
- Waste heat recovery

Best available technology (BAT) offers supply-side efficiency levels far higher than global averages. The relative benefits of gas compared to coal are influenced by the development of increasingly efficient energy production methods. According to an impact assessment carried out for the European Commission, the levels of energy efficiency of coal-fired plants built have now increased to 46-49% efficiency rates, as compared to coals plants built before the 1990s (32-40%).[12] However, at the same time gas can reach 58-59% efficiency levels with the best available technology.[12] Meanwhile, combined heat and power can offer efficiency rates of 80-90%.[12]

Politics

Since now energy plays an essential role in industrial societies, the ownership and control of energy resources plays an increasing role in politics. At the national level, governments seek to influence the sharing (distribution) of energy resources among various sections of the society through pricing mechanisms; or even who owns resources within their borders. They may also seek to influence the use of energy by individuals and business in an attempt to tackle environmental issues.

The most recent international political controversy regarding energy resources is in the context of the Iraq Wars. Some political analysts maintain that the hidden reason for both 1991 and 2003 wars can be traced to strategic control of international energy resources.[13] Others counter this analysis with the numbers related to its economics. According to the latter group of analysts, U.S. has spent about $336 billion in Iraq[14] as compared with a background current value of $25 billion per year budget for the entire U.S. oil import dependence[15]

Policy

Main article: Energy policy

Energy policy is the manner in which a given entity (often governmental) has decided to address issues of energy development including energy production, distribution and consumption. The attributes of energy policy may include legislation, international treaties, incentives to investment, guidelines for energy conservation, taxation and other public policy techniques.

Security

Main article: Energy security

Energy security is the intersection of national security and the availability of natural resources for energy consumption. Access to cheap energy has become essential to the functioning of modern economies. However, the uneven distribution of energy supplies among countries has led to significant vulnerabilities. Threats to energy security include the political instability of several energy producing countries, the manipulation of energy supplies, the competition over energy sources, attacks on supply infrastructure, as well as accidents, natural disasters, the funding to foreign dictators, rising terrorism, and dominant countries reliance to the foreign oil supply.[16] The limited supplies, uneven distribution, and rising costs of fossil fuels, such as oil and gas, create a need to change to more sustainable energy sources in the foreseeable future. With as much dependence that the U.S. currently has for oil and with the peaking limits of oil production; economies and societies will begin to feel the decline in the resource that we have become dependent upon. Energy security has become one of the leading issues in the world today as oil and other resources have become as vital to the world's people. However, with oil production rates decreasing and oil production peak nearing the world has come to protect what resources we have left in the world. With new advancements in renewable resources less pressure has been put on companies that produce the world's oil, these resources are, geothermal, solar power, wind power and hydro-electric. Although these are not all the current and possible future options for the world to turn to as the oil depletes the most important issue is protecting these vital resources from future threats. These new resources will become more useful as the price of exporting and importing oil will increase due to increase of demand.

Development

Main article: Energy development

Producing energy to sustain human needs is an essential social activity, and a great deal of effort goes into the activity. While most of such effort is limited towards increasing the production of electricity and oil, newer ways of producing usable energy resources from the available energy resources are being explored. One such effort is to explore means of producing hydrogen fuel from water. Though hydrogen use is environmentally friendly, its production requires energy and existing technologies to make it, are not very efficient. Research is underway to explore enzymatic decomposition of biomass.[17]

Other forms of conventional energy resources are also being used in new ways. Coal gasification and liquefaction are recent technologies that are becoming attractive after the realization that oil reserves, at present consumption rates, may be rather short lived. See alternative fuels.

Energy is the subject of significant research activities globally. For example, the UK Energy Research Centre is the focal point for UK energy research while the European Union has many technology programmes as well as a platform for engaging social science and humanities within energy research.[18]

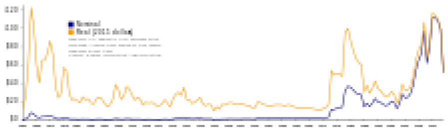
Transportation

All societies require materials and food to be transported over *distances*, generally against some *force* of friction. Since application of force over distance requires the presence of a source of usable energy, such sources are of great worth in society.

While energy resources are an essential ingredient for all modes of transportation in society, the transportation of energy resources is becoming equally important. Energy resources are frequently located far from the place where they are consumed. Therefore, their transportation is always in question. Some energy resources like liquid or gaseous fuels are transported using tankers or pipelines, while electricity transportation invariably requires a network of grid cables. The transportation of energy, whether by tanker, pipeline, or transmission line, poses challenges for scientists and engineers, policy makers, and economists to make it more risk-free and efficient.

Crisis

Main article: Energy crisis


Oil prices from 1861 to 2007

Economic and political instability can lead to an energy crisis. Notable oil crises are the 1973 oil crisis and the 1979 oil crisis. The advent of peak oil, the point in time when the maximum rate of global petroleum extraction is reached, will likely precipitate another energy crisis.

Mergers and acquisitions

Between 1985 and 2018, there have been around 69,932 deals in the energy sector. This cumulates to an overall value of 9,578 bil USD. The most active year was 2010 with about 3.761 deals. In terms of value 2007 was the strongest year (684 bil. USD), which was followed by a steep decline until 2009 (-55,8%).[19]

Here is a list of the top 10 deals in history in the energy sector:

Date Announced	Acquiror Name	Acquiror Mid Industry	Acquiror Nation	Target Name	Target Mid Industry	Target Nation	Value of Transaction ($mil)
12/01/1998	Exxon Corp	Oil & Gas	United States	Mobil Corp	Oil & Gas	United States	78,945.79
10/28/2004	Royal Dutch Petroleum Co	Oil & Gas	Netherlands	Shell Transport & Trading Co	Oil & Gas	United Kingdom	74,558.58
04/08/2015	Royal Dutch Shell PLC	Petrochemicals	Netherlands	BG Group PLC	Oil & Gas	United Kingdom	69,445.02
02/25/2006	Gaz de France SA	Oil & Gas	France	Suez SA	Power	France	60,856.45
07/05/1999	Total Fina SA	Oil & Gas	France	Elf Aquitaine	Oil & Gas	France	50,070.05

08/11/1998	British Petroleum Co PLC	Oil & Gas	United Kingdom	Amoco Corp	Oil & Gas	United States	48,174.09
09/01/2010	Petrobras	Oil & Gas	Brazil	Brazil-Oil & Gas Blocks	Oil & Gas	Brazil	42,877.03
10/16/2000	Chevron Corp	Petrochemicals	United States	Texaco Inc	Petrochemicals	United States	42,872.30
06/20/2000	Vivendi SA	Water and Waste Management	France	Seagram Co Ltd	Motion Pictures / Audio Visual	Canada	40,428.19
12/14/2009	Exxon Mobil Corp	Petrochemicals	United States	XTO Energy Inc	Oil & Gas	United States	40,298.14

See also

- Energy portal
- Alternative energy
- Climate lawsuit
- Energy accounting
- Energy quality
- Energy system – the interpretation of the energy sector in system terms
- Energy transformation
- Economics of climate change
- Hydrogen economy
- List of books about the energy industry
- List of countries by energy consumption per capita
- List of energy resources
- List of largest energy companies
- Stranded asset
- World energy consumption
- Worldwide energy supply

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(Redirected from Alternative energy)

For the journal, see *Renewable Energy* (journal).

Examples of renewable energy options: concentrated solar power with molten salt heat storage in Spain; wind energy in South Africa; the Three Gorges Dam on the Yangtze River in China; biomass energy plant in Scotland.

Part of a series on
Sustainable energy


Energy conservation

Renewable energy

Sustainable transport
- Category - Renewable energy portal
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Renewable energy (or **green energy**) is energy from renewable natural resources that are replenished on a human timescale. Using renewable energy technologies helps with climate change mitigation, energy security, and also has some economic benefits.[1] Commonly used renewable energy types include solar energy, wind power, hydropower, bioenergy and geothermal power. Renewable energy installations can be large or small. They are suited for urban as well as rural areas. Renewable energy is often deployed together with further electrification. This has several benefits: electricity can move heat and vehicles efficiently, and is clean at the point of consumption.[2][3] Variable renewable energy sources are those that have a fluctuating nature, such as wind power and solar power. In contrast, *controllable renewable energy* sources include dammed hydroelectricity, bioenergy, or geothermal power.

Renewable energy systems are rapidly becoming more efficient and cheaper. As a result, their share of global energy consumption is increasing.[4] A large majority of worldwide newly installed electricity capacity is now renewable.[5] In most countries, photovoltaic solar or onshore wind are the cheapest new-build electricity.[6] Renewable energy can help reduce energy poverty in rural and remote areas of developing countries, where lack of energy access is often hindering economic development. Renewable energy resources exist all over the world. This is in contrast to fossil fuels resources which are concentrated in a limited number of countries.

There are also other renewable energy technologies that are still under development, for example enhanced geothermal systems, concentrated solar power, cellulosic ethanol, and marine energy.[7][8]

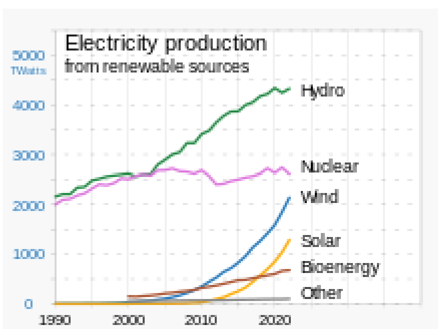
From 2011 to 2021, renewable energy grew from 20% to 28% of global electricity supply. Use of fossil energy shrank from 68% to 62%, and nuclear from 12% to 10%. The share of hydropower decreased from 16% to 15% while power from sun and wind increased from 2% to 10%. Biomass and geothermal energy grew from 2% to 3%.[9][10] In 2022, renewables accounted for 30% of global electricity generation, up from 21% in 1985, and projected to reach over 42% by 2028.[11][12]

Many countries around the world already have renewable energy contributing more than 20% of their total energy supply. Some countries generate over half their electricity from renewables.[13] A few countries generate all their electricity from renewable energy.[14] National renewable energy markets are projected to continue to grow strongly in the 2020s and beyond.[15]

The deployment of renewable energy is being hindered by massive fossil fuel subsidies.[16] In 2022 the International Energy Agency (IEA) requested all countries to reduce their policy, regulatory, permitting and financing obstacles for renewables.[17] This would increase the chances of the world reaching net zero carbon emissions by 2050.[17] According to the IEA, to achieve net zero emissions by 2050, 90% of global electricity generation will need to be produced from renewable sources.[18]

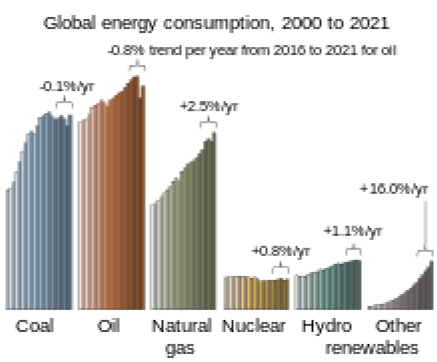
Whether nuclear power is renewable energy or not is still controversial. There are also debates around geopolitics, the metal and mineral extraction needed for solar panels and batteries, possible installations in conservation areas and the need to recycle solar panels. Although most renewable energy sources are sustainable, some are not. For example, some biomass sources are unsustainable at current rates of exploitation.[19]

Overview



Renewable energy sources, especially solar photovoltaic and wind, are generating an increasing share of electricity.[20]

See also: Lists of renewable energy topics



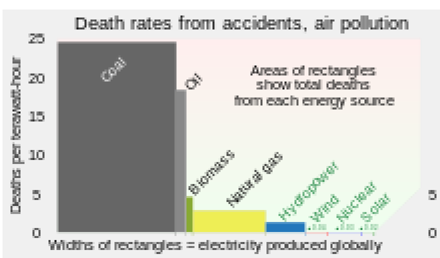
Coal, oil, and natural gas remain the primary global energy sources even as renewables have begun rapidly increasing.[21]

Definition

Renewable energy is usually understood as energy harnessed from continuously occurring natural phenomena. The International Energy Agency defines it as "energy derived from natural processes that are replenished at a faster rate than they are consumed". Solar power, wind power, hydroelectricity, geothermal energy, and biomass are widely agreed to be the main types of renewable energy.[22] Renewable energy often displaces conventional fuels in four areas: electricity generation, hot water/space heating, transportation, and rural (off-grid) energy services.[23]

Although almost all forms of renewable energy cause much fewer carbon emissions than fossil fuels, the term is not synonymous with low-carbon energy. Some non-renewable sources of energy, such as nuclear power,[contradictory]generate almost no emissions, while some renewable energy sources can be very carbon-intensive, such as the burning of biomass if it is not offset by planting new plants.[24] Renewable energy is also distinct from sustainable energy, a more abstract concept that seeks to group energy sources based on their overall permanent impact on future generations of humans. For example, biomass is often associated with unsustainable deforestation.[25]

Role in addressing climate change



Deaths caused as a result of fossil fuel use (areas of rectangles in chart) greatly exceed those resulting from production of renewable energy (rectangles barely visible in chart).[26]

As part of the global effort to limit climate change, most countries have committed to net zero greenhouse gas emissions.[27] In practice, this means phasing out fossil fuels and replacing them with low-emissions energy sources.[24] At the 2023 United Nations Climate Change Conference, around three-quarters of the world's countries set a goal of tripling renewable energy capacity by 2030.[28] The European Union aims to generate 40% of its electricity from renewables by the same year.[29]

Renewable energy is also more evenly distributed around the world than fossil fuels, which are concentrated in a limited number of countries.[30] It also brings health benefits by reducing air pollution caused by the burning of fossil fuels. The potential worldwide savings in health care costs have been estimated at trillions of dollars annually.[31]

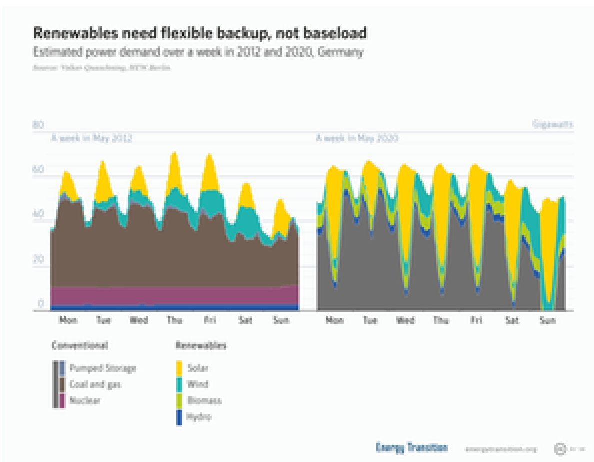
Other benefits

Main article: Climate change mitigation § Co-benefits

Moving to modern renewable energy has very large health benefits due to reducing air pollution from fossil fuels.[32][33][34]

Intermittency

Main article: Variable renewable energy



Estimated power demand over a week in May 2012 and May 2020, Germany, showing the need for dispatchable generation rather than baseload generation in the grid[*clarification needed*]

The two most important forms of renewable energy, solar and wind, are *intermittent energy sources*: they are not available constantly. In contrast, fossil fuel power plants are usually able to produce precisely the amount of energy an electricity grid requires at a given time. Solar energy can only be captured during the day, and ideally in cloudless conditions. Wind power generation can vary significantly not only day-to-day, but even month-to-month.[35] This poses a challenge when transitioning away from fossil fuels: energy demand will often be higher or lower than what renewables can provide.[36] Both scenarios can cause electricity grids to become overloaded, leading to power outages.

Energy storage is an important way of dealing with this variability.[37] Implementation of energy storage, using a wide variety of renewable energy technologies, and implementing a smart grid can reduce risks and costs of renewable energy implementation.[38]

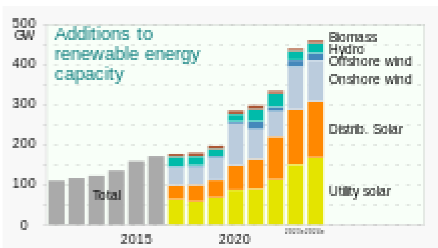
Sector coupling of the power generation sector with other sectors may increase flexibility: for example the transport sector can be coupled by charging electric vehicles and sending electricity from vehicle to grid.[39] Similarly the industry sector can be coupled by hydrogen produced by electrolysis,[40] and the buildings sector by thermal energy storage for space heating and cooling.[41]

Electrical energy storage

Main articles: Energy storage and Grid energy storage

Electrical energy storage is a collection of methods used to store electrical energy. Electrical energy is stored during times when production (especially from intermittent sources such as wind power, tidal power, solar power) exceeds consumption, and returned to the grid when production falls below consumption. Pumped-storage hydroelectricity accounts for more than 85% of all grid power storage.[42] Batteries are increasingly being deployed for storage[43] and grid ancillary services[44] and for domestic storage.[45] Green hydrogen is a more economical means of long-term renewable energy storage, in terms of capital expenditures compared to pumped hydroelectric or batteries.[46][47]

Mainstream technologies



Renewable energy capacity has steadily grown, led by solar photovoltaic power.[48]

Solar energy

Main articles: Solar energy, Solar power, and Outline of solar energy

Installed capacity and other key design parameters	Value and year
Global electricity power generation capacity	1419.0 GW (2023)[49]
Global electricity power generation capacity annual growth rate	25% (2014-2023)[50]
Share of global electricity generation	5.5% (2023)[51]

Levelized cost per megawatt hour	Utility-scale photovoltaics: USD 38.343 (2019)[52]
Primary technologies	Photovoltaics, concentrated solar power, solar thermal collector
Main applications	Electricity, water heating, heating, ventilation, air conditioning (HVAC)


A small, roof-top mounted PV system in Bonn, Germany


Komekurayama photovoltaic power station in Kofu, Japan

Solar power produced around 1.3 terrawatt-hours (TWh) worldwide in 2022,[13] representing 4.6% of the world's electricity. Almost all of this growth has happened since 2010.[53] Solar energy can be harnessed anywhere that receives sunlight; however, the amount of solar energy that can be harnessed for electricity generation is influenced by weather conditions, geographic location and time of day.[54]

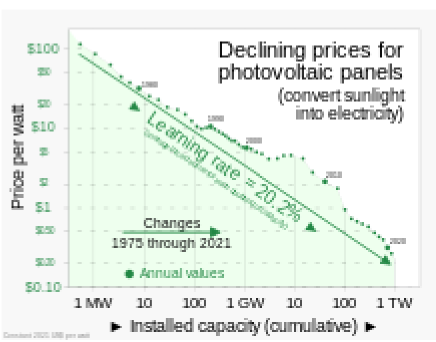
There are two mainstream ways of harnessing solar energy: solar thermal, which converts solar energy into heat; and photovoltaics (PV), which converts it into electricity.[24] PV is far more widespread, accounting for around two thirds of the global solar energy capacity as of 2022.[55] It is also growing at a much faster rate, with 170 GW newly installed capacity in 2021,[56] compared to 25 GW of solar thermal.[55]

Passive solar refers to a range of construction strategies and technologies that aim to optimize the distribution of solar heat in a building. Examples include solar chimneys,[24] orienting a building to the sun, using construction materials that can store heat, and designing spaces that naturally circulate air.[57]

From 2020 to 2022, solar technology investments almost doubled from USD 162 billion to USD 308 billion, driven by the sector's increasing maturity and cost reductions, particularly in solar photovoltaic (PV), which accounted for 90% of total investments. China and the United States were the main recipients, collectively making up about half of all solar investments since 2013. Despite reductions in Japan and India due to policy changes and COVID-19, growth in China, the United States, and a significant increase from Vietnam's feed-in tariff program offset these declines. Globally, the solar sector added 714 gigawatts (GW) of solar PV and concentrated solar power (CSP) capacity between 2013 and 2021, with a notable rise in large-scale solar heating installations in 2021, especially in China, Europe, Turkey, and Mexico.[58]

Photovoltaics

Main articles: Growth of photovoltaics, Solar power by country, and List of photovoltaic power stations



Swanson's law–stating that solar module prices have dropped about 20% for each doubling of installed capacity—defines the "learning rate" of solar photovoltaics.[59][60]

A photovoltaic system, consisting of solar cells assembled into panels, converts light into electrical direct current via the photoelectric effect.[61] PV has several advantages that make it by far the fastest-growing renewable energy technology. It is cheap, low-maintenance and scalable; adding to an existing PV installation as demanded arises is simple. Its main disadvantage is its poor performance in cloudy weather.[24]

PV systems range from small, residential and commercial rooftop or building integrated installations, to large utility-scale photovoltaic power station.[62] A household's solar panels can either be used for just that household or, if connected to an electrical grid, can be aggregated with millions of others.[63]

The first utility-scale solar power plant was built in 1982 in Hesperia, California by ARCO.[64] The plant was not profitable and was sold eight years later.[65] However, over the following decades, PV cells became significantly more efficient and cheaper.[66] As a result, PV adoption has grown exponentially since 2010.[67] Global capacity increased from 230 GW at the end of 2015 to 890 GW in 2021.[68] PV grew fastest in China between 2016 and 2021, adding 560 GW, more than all advanced economies combined.[69] Four of the ten biggest solar power stations are in China, including the biggest, Golmud Solar Park in China.[70]

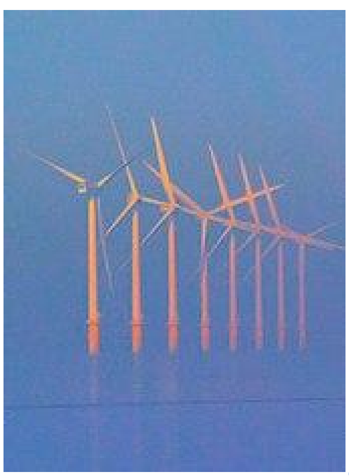
Solar thermal

Main article: Solar thermal energy

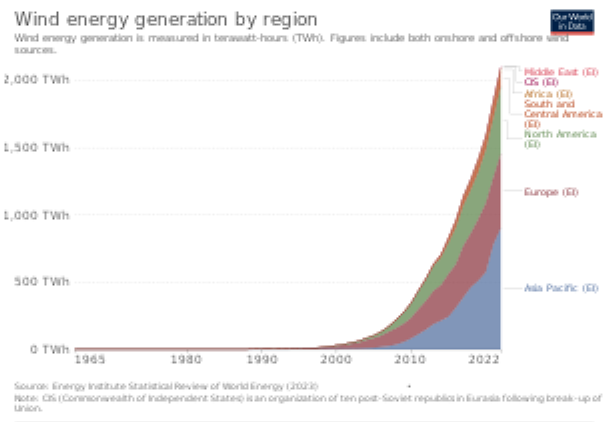
Unlike photovoltaic cells that convert sunlight directly into electricity, solar thermal systems convert it into heat. They use mirrors or lenses to concentrate sunlight onto a receiver, which in turn heats a water reservoir. The heated water can then be used in homes. The advantage of solar thermal is that the heated water can be stored until it is needed, eliminating the need for a separate energy storage system.[71] Solar thermal power can also be converted to electricity by using the steam generated from the heated water to drive a turbine connected to a generator. However, because generating electricity this way is much more expensive than photovoltaic power plants, there are very few in use today.[72]

Wind power

Main articles: Wind power and Wind power by country


Burbo, NW-England


Sunrise at the Fenton Wind Farm in Minnesota, United States



Wind energy generation by region over time[73]

Installed capacity and other key design parameters	Value and year
Global electricity power generation capacity	1017.2 GW (2023)[74]
Global electricity power generation capacity annual growth rate	13% (2014-2023)[75]
Share of global electricity generation	7.8% (2023)[51]
Levelized cost per megawatt hour	Land-based wind: USD 30.165 (2019)[76]
Primary technology	Wind turbine, windmill
Main applications	Electricity, pumping water (windpump)

Humans have harnessed wind energy since at least 3500 BC. Until the 20th century, it was primarily used to power ships, windmills and water pumps. Today, the vast majority of wind power is used to generate electricity using wind turbines.[24] Modern utility-scale wind turbines range from around 600 kW to 9 MW of rated power. The power available from the wind is a function of the cube of the wind speed, so as wind speed increases, power output increases up to the maximum output for the particular turbine.[77] Areas where winds are stronger and more constant, such as offshore and high-altitude sites, are preferred locations for wind farms.

Wind-generated electricity met nearly 4% of global electricity demand in 2015, with nearly 63 GW of new wind power capacity installed. Wind energy was the leading source of new capacity in Europe, the US and Canada, and the second largest in China. In Denmark, wind energy met more than 40% of its electricity demand while Ireland, Portugal and Spain each met nearly 20%.[78]

Globally, the long-term technical potential of wind energy is believed to be five times total current global energy production, or 40 times current electricity demand, assuming all practical barriers needed were overcome. This would require wind turbines to be installed over large areas, particularly in areas of higher wind resources, such as offshore, and likely also industrial use of new types of VAWT turbines in addition to the horizontal axis units currently in use. As offshore wind speeds average ~90% greater than that of land, offshore resources can contribute substantially more energy than land-stationed turbines.[79]

Investments in wind technologies reached USD 161 billion in 2020, with onshore wind dominating at 80% of total investments from 2013 to 2022. Offshore wind investments nearly doubled to USD 41 billion between 2019 and 2020, primarily due to policy incentives in China and expansion in Europe. Global wind capacity increased by 557 GW between 2013 and 2021, with capacity additions increasing by an average of 19% each year.[58]

Hydropower

Main articles: Hydroelectricity and Hydropower

The Three Gorges Dam for hydropower on the Yangtze River in China

Three Gorges Dam and Gezhouba Dam, China

Installed capacity and other key design parameters	Value and year
Global electricity power generation capacity	1,267.9 GW (2023)[80]
Global electricity power generation capacity annual growth rate	1.9% (2014-2023)[81]
Share of global electricity generation	14.3% (2023)[51]
Levelized cost per megawatt hour	USD 65.581 (2019)[82]
Primary technology	Dam
Main applications	Electricity, pumped storage, mechanical power

Since water is about 800 times denser than air, even a slow flowing stream of water, or moderate sea swell, can yield considerable amounts of energy. Water can generate electricity with a conversion efficiency of about 90%, which is the highest rate in renewable energy.[83] There are many forms of water energy:

- Historically, hydroelectric power came from constructing large hydroelectric dams and reservoirs, which are still popular in developing countries.[84] The largest of them are the Three Gorges Dam (2003) in China and the Itaipu Dam (1984) built by Brazil and Paraguay.
- Small hydro systems are hydroelectric power installations that typically produce up to 50 MW of power. They are often used on small rivers or as a low-impact development on larger rivers. China is the largest producer of hydroelectricity in the world and has more than 45,000 small hydro installations.[85]
- Run-of-the-river hydroelectricity plants derive energy from rivers without the creation of a large reservoir. The water is typically conveyed along the side of the river valley (using channels, pipes and/or tunnels) until it is high above the valley floor, whereupon it can be allowed to fall through a penstock to drive a turbine. A run-of-river plant may still produce

a large amount of electricity, such as the Chief Joseph Dam on the Columbia River in the United States.[86] However many run-of-the-river hydro power plants are micro hydro or pico hydro plants.

Much hydropower is flexible, thus complementing wind and solar.[87] In 2021, the world renewable hydropower capacity was 1,360 GW.[69] Only a third of the world's estimated hydroelectric potential of 14,000 TWh/year has been developed.[88][89] New hydropower projects face opposition from local communities due to their large impact, including relocation of communities and flooding of wildlife habitats and farming land.[90] High cost and lead times from permission process, including environmental and risk assessments, with lack of environmental and social acceptance are therefore the primary challenges for new developments.[91] It is popular to repower old dams thereby increasing their efficiency and capacity as well as quicker responsiveness on the grid.[92] Where circumstances permit existing dams such as the Russell Dam built in 1985 may be updated with "pump back" facilities for pumped-storage which is useful for peak loads or to support intermittent wind and solar power. Because dispatchable power is more valuable than VRE[93][94] countries with large hydroelectric developments such as Canada and Norway are spending billions to expand their grids to trade with neighboring countries having limited hydro.[95]

Bioenergy

Main article: Bioenergy

Further information: Biomass (energy) § Environmental impacts

Installed capacity and other key design parameters	Value and year
Global electricity power generation capacity	150.3 GW (2023)[96]
Global electricity power generation capacity annual growth rate	5.8% (2014-2023)[97]
Share of global electricity generation	2.4% (2022)[51]
Levelized cost per megawatt hour	USD 118.908 (2019)[98]

Primary technologies	Biomass, biofuel
Main applications	Electricity, heating, cooking, transportation fuels

Biomass is biological material derived from living, or recently living organisms. Most commonly, it refers to plants or plant-derived materials. As an energy source, biomass can either be used directly via combustion to produce heat, or converted to a more energy-dense biofuel like ethanol. Wood is the most significant biomass energy source as of 2012[99] and is usually sourced from a trees cleared for silvicultural reasons or fire prevention. Municipal wood waste – for instance, construction materials or sawdust – is also often burned for energy.[100] The biggest per-capita producers of wood-based bioenergy are heavily forested countries like Finland, Sweden, Estonia, Austria, and Denmark.[101]

Bioenergy can be environmentally destructive if old-growth forests are cleared to make way for crop production. In particular, demand for palm oil to produce biodiesel has contributed to the deforestation of tropical rainforests in Brazil and Indonesia.[102] In addition, burning biomass still produces carbon emissions, although much less than fossil fuels (39 grams of CO_2 per megajoule of energy, compared to 75 g/MJ for fossil fuels).[103]


A CHP power station using wood to supply 30,000 households in France

Biofuel

Main article: Biofuel

See also: Ethanol fuel, Sustainable biofuel, and Issues relating to biofuels

[Biofuels](#) are primarily used in transportation, providing 3.5% of the world's transport energy demand in 2022,[104] up from 2.7% in 2010.[105] Biojet is expected to be important for short-term reduction of carbon dioxide emissions from long-haul flights.[106]

Aside from wood, the major sources of bioenergy are bioethanol and biodiesel.[24] Bioethanol is usually produced by fermenting the sugar components of crops like sugarcane and maize, while biodiesel is mostly made from oils extracted from plans, such as soybean oil and corn oil.[107] Most of the crops used to produce bioethanol and biodiesel are grown specifically for this purpose,[108] although used cooking oil accounted for 14% of the oil used to produce biodiesel as of 2015.[107] The biomass used to produce biofuels varies by region. Maize is the major feedstock in the United States, while sugarcane dominates in Brazil.[109] In the European Union, where biodiesel is more common than bioethanol, rapeseed oil and palm oil are the main feedstocks.[110] China, although it produces comparatively much less biofuel, uses mostly corn and wheat.[111] In many countries, biofuels are either subsidized or mandated to be included in fuel mixtures.[102]


Sugarcane plantation to produce ethanol in Brazil

There are many other sources of bioenergy that are more niche, or not yet viable at large scales. For instance, bioethanol could be produced from the cellulosic parts of crops, rather than only the seed as is common today.[112] Sweet sorghum may be a promising alternative source of bioethanol, due to its tolerance of a wide range of climates.[113] Cow dung can be converted into methane.[114] There is also a great deal of research involving algal fuel, which is attractive because algae is a non-food resource, grows around 20 times faster than most food crops, and can be grown almost anywhere.[115]

A bus fueled by biodiesel

Geothermal energy

Main articles: Geothermal energy, Geothermal power, Renewable thermal energy, and Geothermal energy in the United States


Steam rising from the Nesjavellir Geothermal Power Station in Iceland


Geothermal plant at The Geysers, California, US


Krafla, a geothermal power station in Iceland

Installed capacity and other key design parameters	Value and year
Global electricity power generation capacity	14.9 GW (2023)[116]

Global electricity power generation capacity annual growth rate	3.4% (2014-2023)[117]
Share of global electricity generation	<1% (2018)[118]
Levelized cost per megawatt hour	USD 58.257 (2019)[119]
Primary technologies	Dry steam, flash steam, and binary cycle power stations
Main applications	Electricity, heating

Geothermal energy is thermal energy (heat) extracted from the Earth's crust. It originates from several different sources, of which the most significant is slow radioactive decay of minerals contained in the Earth's interior,[24] as well as some leftover heat from the formation of the Earth.[120] Some of the heat is generated near the Earth's surface in the crust, but some also flows from deep within the Earth from the mantle and core.[120] Geothermal energy extraction is viable mostly in countries located on tectonic plate edges, where the Earth's hot mantle is more exposed.[121] As of 2023, the United States has by far the most geothermal capacity (2.7 GW,[122] or less than 0.2% of the country's total energy capacity[123]), followed by Indonesia and the Philippines. Global capacity in 2022 was 15 GW.[122]

Geothermal energy can be either used directly to heat homes, as is common in Iceland, or to generate electricity. At smaller scales, geothermal power can be generated with geothermal heat pumps, which can extract heat from ground temperatures of under 30 °C (86 °F), allowing them to be used at relatively shallow depths of a few meters.[121] Electricity generation requires large plants and ground temperatures of at least 150 °C (302 °F). In some countries, electricity produced from geothermal energy accounts for a large portion of the total, such as Kenya (43%) and Indonesia (5%).[124]

Technical advances may eventually make geothermal power more widely available. For example, enhanced geothermal systems involve drilling around 10 kilometres (6.2 mi) into the Earth, breaking apart hot rocks and extracting the heat using water. In theory, this type of geothermal energy extraction could be done anywhere on Earth.[121]

Emerging technologies

There are also other renewable energy technologies that are still under development, including enhanced geothermal systems, concentrated solar power, cellulosic ethanol, and marine energy.[7][8] These technologies are not yet widely demonstrated or have limited commercialization. Many are on the horizon and may have potential comparable to other renewable energy technologies, but still depend on attracting sufficient attention and research, development and demonstration (RD&D) funding.[8]

There are numerous organizations within the academic, federal,[clarification needed] and commercial sectors conducting large-scale advanced research in the field of renewable energy. This research spans several areas of focus across the renewable energy spectrum. Most of the research is targeted at improving efficiency and increasing overall energy yields.[125] Multiple government-supported research organizations have focused on renewable energy in recent years. Two of the most prominent of these labs are Sandia National Laboratories and the National Renewable Energy Laboratory (NREL), both of which are funded by the United States Department of Energy and supported by various corporate partners.[126]

Enhanced geothermal systems

Main article: Enhanced geothermal systems

Enhanced geothermal systems (EGS) are a new type of geothermal power which does not require natural hot water reservoirs or steam to generate power. Most of the underground heat within drilling reach is trapped in solid rocks, not in water.[127] EGS technologies use hydraulic fracturing to break apart these rocks and release the heat they contain, which is then harvested by pumping water into the ground. The process is sometimes known as "hot dry rock" (HDR).[128] Unlike conventional geothermal energy extraction, EGS may be feasible anywhere in the world, depending on the cost of drilling.[129] EGS projects have so far primarily been limited to demonstration plants, as the technology is capital-intensive due to the high cost of drilling.[130]

Marine energy

Main article: Marine energy

Aerial view of Sihwa Tidal Power Station in South Korea

Marine energy (also sometimes referred to as ocean energy) is the energy carried by ocean waves, tides, salinity, and ocean temperature differences. Technologies to harness the energy of moving water include wave power, marine current power, and tidal power. Reverse electrodialysis (RED) is a technology for generating electricity by mixing fresh water and salty sea water in large power cells.[131][page needed] Most marine energy harvesting technologies are still at low technology readiness levels and not used at large scales. Tidal energy is generally considered the most mature, but has not seen wide deployment.[132] The world's largest tidal power station is on Sihwa Lake, South Korea,[133] which produces around 550 gigawatt-hours of electricity per year.[134]

Earth infrared thermal radiation

Earth emits roughly 10^{17} W of infrared thermal radiation that flows toward the cold outer space. Solar energy hits the surface and atmosphere of the earth and produces heat. Using various theorized devices like emissive energy harvester (EEH) or thermoradiative diode, this energy flow can be converted into electricity. In theory, this technology can be used during nighttime.[135][136]

Others

Algae fuels

Main article: Algae fuels

Producing liquid fuels from oil-rich (fat-rich) varieties of algae is an ongoing research topic. Various microalgae grown in open or closed systems are being tried including some systems that can be set up in brownfield and desert lands.[137]

Water vapor

Collection of static electricity charges from water droplets on metal surfaces is an experimental technology that would be especially useful in low-income countries with relative air humidity over 60%.[138]

Nuclear energy

Breeder reactors could, in principle, extract almost all of the energy contained in uranium or thorium, decreasing fuel requirements by a factor of 100 compared to widely used once-through light water reactors, which extract less than 1% of the energy in the actinide metal (uranium or thorium) mined from the earth.[139] The high fuel-efficiency of breeder reactors could greatly reduce concerns about fuel supply, energy used in mining, and storage of radioactive waste. With seawater uranium extraction (currently too expensive to be economical), there is enough fuel for breeder reactors to satisfy the world's energy needs for 5 billion years at 1983's total energy consumption rate, thus making nuclear energy effectively a renewable energy.[140][141] In addition to seawater the average crustal granite rocks contain significant quantities of uranium and thorium that with breeder reactors can supply abundant energy for the remaining lifespan of the sun on the main sequence of stellar evolution.[142]

Artificial photosynthesis

Main article: Artificial photosynthesis

Artificial photosynthesis uses techniques including nanotechnology to store solar electromagnetic energy in chemical bonds by splitting water to produce hydrogen and then using carbon dioxide to make methanol.[143] Researchers in this field strived to design molecular mimics of photosynthesis that use a wider region of the solar spectrum, employ catalytic systems made from abundant, inexpensive materials that are robust, readily repaired, non-toxic, stable in a variety of environmental conditions and perform more efficiently allowing a greater proportion of photon energy to end up in the storage compounds, i.e., carbohydrates (rather than building and sustaining living cells).[144] However, prominent research faces hurdles, Sun Catalytix a MIT spin-off stopped scaling up their prototype fuel-cell in 2012 because it offers few savings over other ways to make hydrogen from sunlight.[145]

Consumption by sector

One of the efforts to decarbonize transportation is the increased use of electric vehicles (EVs).[146] Despite that and the use of biofuels, such as biojet, less than 4% of transport energy is from renewables.[147] Occasionally hydrogen fuel cells are used for heavy transport.[148] Meanwhile, in the future electrofuels may also play a greater role in decarbonizing hard-to-abate sectors like aviation and maritime shipping.[149]

Solar water heating makes an important contribution to renewable heat in many countries, most notably in China, which now has 70% of the global total (180 GWth). Most of these systems are installed on multi-family apartment buildings[150] and meet a portion of the hot water needs of an estimated 50–60 million households in China. Worldwide, total installed solar water heating systems meet a portion of the water heating needs of over 70 million households.

Heat pumps provide both heating and cooling, and also flatten the electric demand curve and are thus an increasing priority.[151] Renewable thermal energy is also growing rapidly.[152] About 10% of heating and cooling energy is from renewables.[153]

Some studies say that a global transition to 100% renewable energy across all sectors – power, heat, transport and industry – is feasible and economically viable.[154][155][156]

Market and industry trends

Main article: Renewable energy commercialization

Most new renewables are solar, followed by wind then hydro then bioenergy.[157] Investment in renewables, especially solar, tends to be more effective in creating jobs than coal, gas or oil.[158][159] Worldwide, renewables employ about 12 million people as of 2020, with solar PV being the technology employing the most at almost 4 million.[160] However, as of February 2024, the world's supply of workforce for solar energy is lagging greatly behind demand as universities worldwide still produce more workforce for fossil fuels than for renewable energy industries.[161]

In 2021, China accounted for almost half of the global increase in renewable electricity.[162]

There are 3,146 gigawatts installed in 135 countries, while 156 countries have laws regulating the renewable energy sector.[9][10]

Globally in 2020 there are over 10 million jobs associated with the renewable energy industries, with solar photovoltaics being the largest renewable employer.[163] The clean energy sectors added about 4.7 million jobs globally between 2019 and 2022, totaling 35 million jobs by 2022.[164]:5

Cost comparison

The International Renewable Energy Agency (IRENA) stated that ~86% (187 GW) of renewable capacity added in 2022 had lower costs than electricity generated from fossil fuels.[165] IRENA also stated that capacity added since 2000 reduced electricity bills in 2022 by at least $520 billion, and that in non-OECD countries, the lifetime savings of 2022 capacity additions will reduce costs by up to $580 billion.[165]

Installed[166] TWp	Gr T	Production per installed capacity*[167]	E T	Gr T	Levelized cost US¢/kWh[16	Av. auction prices US¢/kWh[	Cost development 2010–2019[168]

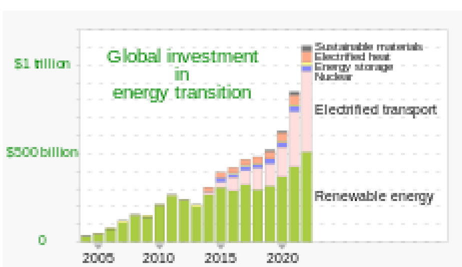
						8]	169]	
Solar PV	0.580	0.	13%	5	12	6.8	3.9	−82%
Solar CSP	0.006	0.	13%	6.	0.	18.2	7.5	−47%
Wind Offshore	0.028	0.	33%	6	11	11.5	8.2	−30%
Wind Onshore	0.594	0.	25%	11	11	5.3	4.3	−38%
Hydro	1.310	0.	38%	4	90	4.7		+27%

Bioenergy	0.12	0.	51%	5	27	6.6		−13%
Geothermal	0.014	0.	74%	1	0.	7.3		+49%

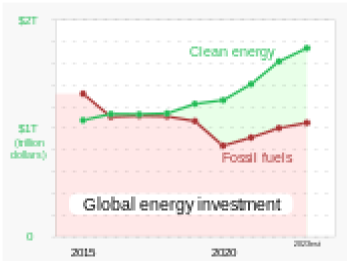
* = 2018. All other values for 2019.

Growth of renewables

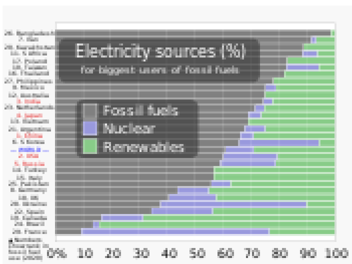
Investment and sources



Investment: Companies, governments and households have committed increasing amounts to decarbonization, including renewable energy (solar, wind), electric vehicles and associated charging infrastructure, energy storage, energy-efficient heating systems, carbon capture and storage, and hydrogen.[170][171]

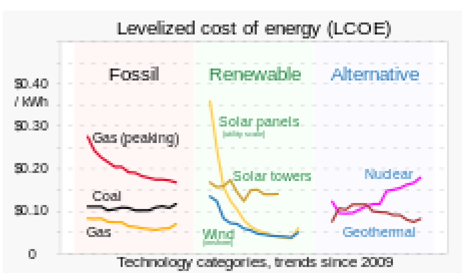


Clean energy investment has benefited from post-pandemic economic recovery, a global energy crisis involving high fossil fuel prices, and growing policy support across various nations.[172]



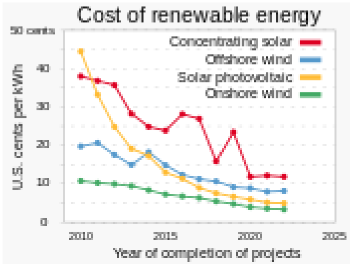
The countries most reliant on fossil fuels for electricity vary widely on how great a portion of that electricity is generated from renewables, leaving wide variation in renewables' growth potential.[173]

Costs

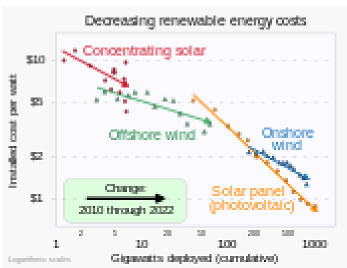


Levelized cost: With increasingly widespread implementation of renewable energy sources, costs have declined, most notably for energy generated by solar panels.[174][175]

Levelized cost of energy (LCOE) is a measure of the average net present cost of electricity generation for a generating plant over its lifetime.



Past costs of producing renewable energy declined significantly,[176] with 62% of total renewable power generation added in 2020 having lower costs than the cheapest new fossil fuel option.[177]



"**Learning curves**": Trend of costs and deployment over time, with steeper lines showing greater cost reductions as deployment progresses.[178] With increased deployment, renewables benefit from learning curves and economies of scale.[179]

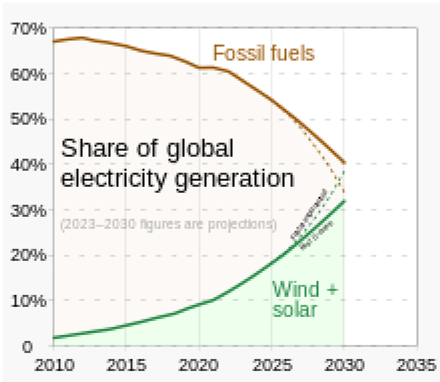
The results of a recent review of the literature concluded that as greenhouse gas (GHG) emitters begin to be held liable for damages resulting from GHG emissions resulting in climate change, a high value for liability mitigation would provide powerful incentives for deployment of renewable energy technologies.[180]

In the decade of 2010–2019, worldwide investment in renewable energy capacity excluding large hydropower amounted to US$2.7 trillion, of which the top countries China contributed US$818 billion, the United States contributed US$392.3 billion, Japan contributed US$210.9 billion, Germany contributed US$183.4 billion, and the United Kingdom contributed US$126.5 billion.[181] This was an increase of over three and possibly four times the equivalent amount invested in the decade of 2000–2009 (no data is available for 2000–2003).[181]

As of 2022, an estimated 28% of the world's electricity was generated by renewables. This is up from 19% in 1990.[182]

Future projections

See also: Energy transition



In 2023, electricity generation from wind and solar sources was projected to exceed 30% by 2030.[183]

A December 2022 report by the IEA forecasts that over 2022-2027, renewables are seen growing by almost 2 400 GW in its main forecast, equal to the entire installed power capacity of China in 2021. This is an 85% acceleration from the previous five years, and almost 30% higher than what the IEA forecast in its 2021 report, making its largest ever upward revision. Renewables are set to account for over 90% of global electricity capacity expansion over the forecast period.[69] To achieve net zero emissions by 2050, IEA believes that 90% of global electricity generation will need to be produced from renewable sources.[18]

In June 2022 IEA Executive Director Fatih Birol said that countries should invest more in renewables to "ease the pressure on consumers from high fossil fuel prices, make our energy systems more secure, and get the world on track to reach our climate goals."[184]

China's five year plan to 2025 includes increasing direct heating by renewables such as geothermal and solar thermal.[185]

REPowerEU, the EU plan to escape dependence on fossil Russian gas, is expected to call for much more green hydrogen.[186]

After a transitional period,[187] renewable energy production is expected to make up most of the world's energy production. In 2018, the risk management firm, DNV GL, forecasts that the world's primary energy mix will be split equally between fossil and non-fossil sources by 2050.[188]

Demand

In July 2014, WWF and the World Resources Institute convened a discussion among a number of major US companies who had declared their intention to increase their use of renewable energy. These discussions identified a number of "principles" which companies seeking greater access to renewable energy considered important market deliverables. These principles included choice (between suppliers and between products), cost competitiveness, longer term fixed price supplies, access to third-party financing vehicles, and collaboration.[189]

UK statistics released in September 2020 noted that "the proportion of demand met from renewables varies from a low of 3.4 per cent (for transport, mainly from biofuels) to highs of over 20 per cent for 'other final users', which is largely the service and commercial sectors that consume relatively large quantities of electricity, and industry".[190]

In some locations, individual households can opt to purchase renewable energy through a consumer green energy program.

Developing countries

This section is an excerpt from Renewable energy in developing countries.[edit]

Shop selling PV panels in Ouagadougou, Burkina Faso

Solar cookers use sunlight as energy source for outdoor cooking.

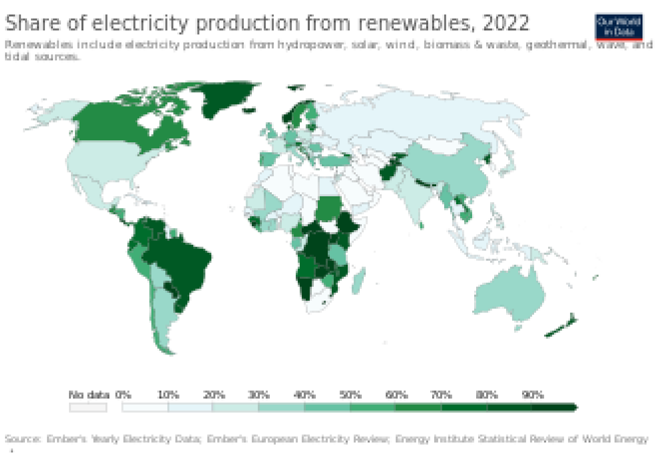
Renewable energy in developing countries is an increasingly used alternative to fossil fuel energy, as these countries scale up their energy supplies and address energy poverty. Renewable energy technology was once seen as unaffordable for developing countries.[191] However, since 2015, investment in non-hydro renewable energy has been higher in developing countries than in developed countries, and comprised 54% of global renewable energy investment in 2019.[192] The International Energy Agency forecasts that renewable energy will provide the majority of energy supply growth through 2030 in Africa and Central and South America, and 42% of supply growth in China.[193]

Most developing countries have abundant renewable energy resources, including solar energy, wind power, geothermal energy, and biomass, as well as the ability to manufacture the relatively labor-intensive systems that harness these. By developing

> such energy sources developing countries can reduce their dependence on oil and natural gas, creating energy portfolios that are less vulnerable to price rises. In many circumstances, these investments can be less expensive than fossil fuel energy systems.[194]

In Kenya, the Olkaria V Geothermal Power Station is one of the largest in the world.[195] The Grand Ethiopia Renaissance Dam project incorporates wind turbines.[196] Once completed, Morocco's Ouarzazate Solar Power Station is projected to provide power to over a million people.[197]

Policy



Share of electricity production from renewables, 2022[11]

Policies to support renewable energy have been vital in their expansion. Where Europe dominated in establishing energy policy in the early 2000s, most countries around the world now have some form of energy policy.[198]

The International Renewable Energy Agency (IRENA) is an intergovernmental organization for promoting the adoption of renewable energy worldwide. It aims to provide concrete policy advice and facilitate capacity building and technology transfer. IRENA was formed in 2009, with 75 countries signing the charter of IRENA.[199] As of April 2019, IRENA has 160 member states.[200] The then United Nations Secretary-General Ban Ki-moon has said that renewable energy can lift the poorest nations to new levels of prosperity,[201] and in September 2011 he launched the UN Sustainable Energy for All initiative to improve energy access, efficiency and the deployment of renewable energy.[202]

The 2015 Paris Agreement on climate change motivated many countries to develop or improve renewable energy policies.[15] In 2017, a total of 121 countries adopted some form of renewable energy policy.[198] National targets that year existed in 176 countries.[15] In addition, there is also a wide range of policies at the state/provincial, and local levels.[105] Some public utilities help plan or install residential energy upgrades.

Many national, state and local governments have created green banks. A green bank is a quasi-public financial institution that uses public capital to leverage private investment in clean energy technologies.[203] Green banks use a variety of financial tools to bridge market gaps that hinder the deployment of clean energy.

Climate neutrality by the year 2050 is the main goal of the European Green Deal.[204] For the European Union to reach their target of climate neutrality, one goal is to decarbonise its energy system by aiming to achieve "net-zero greenhouse gas emissions by 2050."[205]

Finance

The International Renewable Energy Agency's (IRENA) 2023 report on renewable energy finance highlights steady investment growth since 2018: USD 348 billion in 2020 (a 5.6% increase from 2019), USD 430 billion in 2021 (24% up from 2020), and USD 499 billion in 2022 (16% higher). This trend is driven by increasing recognition of renewable energy's role in mitigating climate change and enhancing energy security, along with investor interest in alternatives to fossil fuels. Policies such as feed-in tariffs in China and Vietnam have significantly increased renewable adoption. Furthermore, from 2013 to 2022, installation costs for solar photovoltaic (PV), onshore wind, and offshore wind fell by 69%, 33%, and 45%, respectively, making renewables more cost-effective.[206][58]

Between 2013 and 2022, the renewable energy sector underwent a significant realignment of investment priorities. Investment in solar and wind energy technologies markedly increased. In contrast, other renewable technologies such as hydropower (including pumped storage hydropower), biomass, biofuels, geothermal, and marine energy experienced a substantial decrease in financial investment. Notably, from 2017 to 2022, investment in these alternative renewable technologies declined by 45%, falling from USD 35 billion to USD 17 billion.[58]

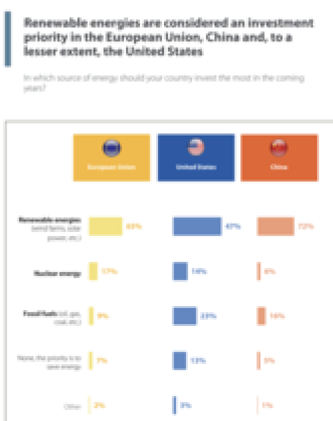
In 2023, the renewable energy sector experienced a significant surge in investments, particularly in solar and wind technologies, totaling approximately USD 200 billion—a 75% increase from the previous year. The increased investments in 2023 contributed between 1% and 4% to the GDP in key regions including the United States, China, the European Union, and India.[207]

Debates

Main articles: Renewable energy debate, Green job, and Intermittent power source

Further information: Climate change mitigation § Overviews, strategies and comparisons of measures

Most respondents to a climate survey conducted in 2021-2022 by the European Investment Bank say countries should back renewable energy to fight climate change.[208]



The same survey a year later shows that renewable energy is considered an investment priority in the European Union, China and the United States[209]

Renewable electricity generation by wind and solar is variable. This results in reduced capacity factor and may require keeping some gas-fired power plants or other dispatchable generation on standby[210][211][212] until there is enough energy storage, demand response, grid improvement, and/or base load power from non-intermittent sources like hydropower, nuclear power or bioenergy.

The market for renewable energy technologies has continued to grow. Climate change concerns and increasing in green jobs, coupled with high oil prices, peak oil, oil wars, oil spills, promotion of electric vehicles and renewable electricity, nuclear disasters and increasing government support, are driving increasing renewable energy legislation, incentives and commercialization.[213][better source needed]

The International Energy Agency has stated that deployment of renewable technologies usually increases the diversity of electricity sources and, through local generation, contributes to the flexibility of the system and its resistance to central shocks.[214]

Nuclear power proposed as renewable energy


The Leibstadt Nuclear Power Plant in Switzerland

This section is an excerpt from Nuclear power proposed as renewable energy.[edit]

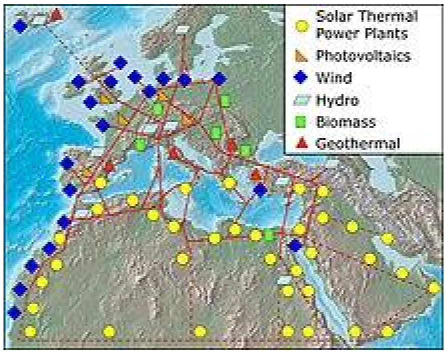
Whether nuclear power should be considered a form of renewable energy is an ongoing subject of debate. Statutory definitions of renewable energy usually exclude many present nuclear energy technologies, with the notable exception of the state of Utah.[215] Dictionary-sourced definitions of renewable energy technologies often omit or explicitly exclude mention of nuclear energy sources, with an exception made for the natural nuclear decay heat generated within the Earth.[216][217]

The most common fuel used in conventional nuclear fission power stations, uranium-235 is "non-renewable" according to the Energy Information Administration, the organization however is silent on the recycled MOX fuel.[217] The National Renewable Energy Laboratory does not mention nuclear power in its "energy basics" definition.[218]

> In 1987, the Brundtland Commission (WCED) classified fission reactors that produce more fissile nuclear fuel than they consume (breeder reactors, and if developed, fusion power) among conventional renewable energy sources, such as solar power and hydropower.[219] The monitoring and storage of radioactive waste products is also required upon the use of other renewable energy sources, such as geothermal energy.[220]

Geopolitics

See also: Russia in the European energy sector



A concept of a super grid

The geopolitical impact of the growing use of renewable energy is a subject of ongoing debate and research.[221] Many fossil-fuel producing countries, such as Qatar, Russia, Saudi Arabia and Norway, are currently able to exert diplomatic or geopolitical influence as a result of their oil wealth. Most of these countries are expected to be among the geopolitical "losers" of the energy transition, although some, like Norway, are also significant producers and exporters of renewable energy. Fossil fuels and the infrastructure to extract them may, in the long term, become stranded assets.[222] It has been speculated that countries dependent on fossil fuel revenue may one day find it in their interests to quickly sell off their remaining fossil fuels.[223]

Conversely, nations abundant in renewable resources, and the minerals required for renewables technology, are expected to gain influence.[224][225] In particular, China has become the world's dominant manufacturer of the technology needed to produce or store renewable energy, especially solar panels, wind turbines, and lithium-ion batteries.[226] Nations rich in solar and wind energy could become major energy exporters.[227] Some may produce and export green hydrogen,[228][227] although electricity is projected to be the dominant energy carrier in 2050, accounting for almost 50% of total energy consumption (up from 22% in 2015).[229] Countries with large uninhabited areas such as Australia, China, and many African and Middle Eastern countries have a potential for huge installations of renewable energy. The production of renewable energy technologies requires rare-earth elements with new supply chains.[230]

Countries with already weak governments that rely on fossil fuel revenue may face even higher political instability or popular unrest. Analysts consider Nigeria, Angola, Chad, Gabon, and Sudan, all countries with a history of military coups, to be at risk of instability due to dwindling oil income.[231]

A study found that transition from fossil fuels to renewable energy systems reduces risks from mining, trade and political dependence because renewable energy systems don't need fuel – they depend on trade only for the acquisition of materials and components during construction.[232]

In October 2021, European Commissioner for Climate Action Frans Timmermans suggested "the best answer" to the 2021 global energy crisis is "to reduce our reliance on fossil fuels."[233] He said those blaming the European Green Deal were doing so "for perhaps ideological reasons or sometimes economic reasons in protecting their vested interests."[233] Some critics blamed the European Union Emissions Trading System (EU ETS) and closure of nuclear plants for contributing to the energy crisis.[234][235][236] European Commission President Ursula von der Leyen said that Europe is "too reliant" on natural gas and too dependent on natural gas imports. According to Von der Leyen, "The answer has to do with diversifying our suppliers ... and, crucially, with speeding up the transition to clean energy."[237]

Metal and mineral extraction

See also: Environmental footprint of electric cars and Rare-earth element § Environmental considerations

The renewable energy transition requires increased extraction of certain metals and minerals.[238] Solar power panels require large amounts of aluminum.[239] This impacts the environment and can lead to environmental conflict.[240]

The International Energy Agency does not recognise shortages of resources but states that supply could struggle to keep pace with the world's climate ambitions. Electric vehicles (EV) and battery storage are expected to cause the most demand. Wind farms and solar PV are less consuming. The extension of electrical grids requires large amounts of copper and aluminium. The IEA recommends to scale up recycling. By 2040, quantities of copper, lithium, cobalt, and nickel from spent batteries could reduce combined primary supply requirements for these minerals by around 10%.[238]

The demand for lithium by 2040 is expected to grow by the factor of 42. Graphite and nickel exploration is predicted to grow about 20-fold. For each of the most relevant minerals and metals, a significant share of resources are concentrated in only one country: copper in Chile, nickel in Indonesia, rare earths in China, cobalt in the Democratic Republic of the Congo (DRC), and lithium in Australia. China dominates processing of them all.[238]

A controversial approach is deep sea mining. Minerals can be collected from new sources like polymetallic nodules lying on the seabed,[241] but this could damage biodiversity.[242]

The transition to renewable energy depends on non-renewable resources, such as mined metals.[243] Manufacturing of photovoltaic panels, wind turbines and batteries requires significant amounts of rare-earth elements[244] which has significant social and environmental impact if mined in forests and protected areas.[245] Due to co-occurrence of rare-earth and radioactive elements (thorium, uranium and radium), rare-earth mining results in production of low-level radioactive waste.[246] In Africa, the green energy transition created a mining boom, causing deforestation and creating possibility to zoonotic spillover. To mitigate climate change and prevent epidemics some territories should stay intact.[247]

Conservation areas

Installations used to produce wind, solar and hydropower are an increasing threat to key conservation areas, with facilities built in areas set aside for nature conservation and other environmentally sensitive areas. They are often much larger than fossil fuel power plants, needing areas of land up to 10 times greater than coal or gas to produce equivalent energy amounts.[248] More than 2000 renewable energy facilities are built, and more are under construction, in areas of environmental importance and threaten the habitats of plant and animal species across the globe. The authors' team emphasized that their work should not be interpreted as anti-renewables because renewable energy is crucial for reducing carbon emissions. The key is ensuring that renewable energy facilities are built in places where they do not damage biodiversity.[249]

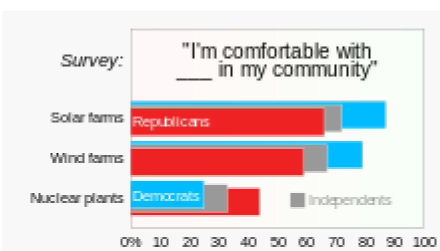
In 2020 scientists published a world map of areas that contain renewable energy materials as well as estimations of their overlaps with "Key Biodiversity Areas", "Remaining Wilderness" and "Protected Areas". The authors assessed that careful strategic planning is needed.[250][251][252]

Recycling of solar panels

Solar panels are recycled to reduce electronic waste and create a source for materials that would otherwise need to be mined,[253] but such business is still small and work is ongoing to improve and scale-up the process.[254][255][256]

Society and culture

Public support



Acceptance of wind and solar facilities in one's community is stronger among U.S. Democrats (blue), while acceptance of nuclear power plants is stronger among U.S. Republicans (red).[257]

Solar power plants may compete with arable land,[243][258] while on-shore wind farms face opposition due to aesthetic concerns and noise, which is impacting both humans and wildlife.[259][260][261][*need quotation to verify*] In the United States, the Massachusetts Cape Wind project was delayed for years partly because of aesthetic concerns. However, residents in other areas have been more positive. According to a town councilor, the overwhelming majority of locals believe that the Ardrossan Wind Farm in Scotland has enhanced the area.[262] These concerns, when directed against renewable energy, are sometimes described as "not in my back yard" attitude (NIMBY).

A 2011 UK Government document states that "projects are generally more likely to succeed if they have broad public support and the consent of local communities. This means giving communities both a say and a stake."[263] In countries such as Germany and Denmark many renewable projects are owned by communities, particularly through cooperative structures, and contribute significantly to overall levels of renewable energy deployment.[264][265]

In international public opinion surveys there is strong support for renewables such as solar power and wind power.[213][266]

History

See also: History of climate change policy and politics

Prior to the development of coal in the mid 19th century, nearly all energy used was renewable. The oldest known use of renewable energy, in the form of traditional biomass to fuel fires, dates from more than a million years ago. The use of biomass for fire did not become commonplace until many hundreds of thousands of years later.[267] Probably the second oldest usage of renewable energy is harnessing the wind in order to drive ships over water. This practice can be traced back some 7000 years, to ships in the Persian Gulf and on the Nile.[268] From hot springs, geothermal energy has been used for bathing since Paleolithic times and for space heating since ancient Roman times.[269] Moving into the time of recorded history, the primary sources of traditional renewable energy were human labor, animal power, water power, wind, in grain crushing windmills, and firewood, a traditional biomass.

In 1885, Werner Siemens, commenting on the discovery of the photovoltaic effect in the solid state, wrote:

> In conclusion, I would say that however great the scientific importance of this discovery may be, its practical value will be no less obvious when we reflect that the supply of solar energy is both without limit and without cost, and that it will continue to pour down upon us for countless ages after all the coal deposits of the earth have been exhausted and forgotten.[270]

Max Weber mentioned the end of fossil fuel in the concluding paragraphs of his Die protestantische Ethik und der Geist des Kapitalismus (The Protestant Ethic and the Spirit of Capitalism), published in 1905.[271] Development of solar engines continued until the outbreak of World War I. The importance of solar energy was recognized in a 1911 *Scientific American* article: "in the far distant future, natural fuels having been exhausted [solar power] will remain as the only means of existence of the human race".[272]

The theory of peak oil was published in 1956.[273] In the 1970s environmentalists promoted the development of renewable energy both as a replacement for the eventual depletion of oil, as well as for an escape from dependence on oil, and the first electricity-generating wind turbines appeared. Solar had long been used for heating and cooling, but solar panels were too costly to build solar farms until 1980.[274]