Sustainable energy

The use of energy is considered sustainable if it meets the needs of the present without compromising the needs of future generations. Definitions of sustainable energy include environmental aspects such as greenhouse gas emissions, and social and economic aspects such as energy poverty.



The energy transition to meet the world's needs for electricity, heating, cooling, and transport in a sustainable way is one of the greatest challenges facing humanity in the 21st century. Energy production and consumption are responsible for over 70% of greenhouse gas emissions that cause climate change, water scarcity and biodiversity loss, and can generate toxic waste. The burning of fossil fuels and biomass is a major contributor to air pollution, which causes an estimated 7 million deaths each year. 770 million people lack access to electricity and over 2.6 billion rely on polluting fuels such as wood or charcoal to cook.

Renewable energy sources such as wind, hydroelectric power, solar, and geothermal energy are generally far more sustainable than fossil fuel sources. However, some renewable energy projects, such as the clearing of forests for the production of biofuels, can cause severe environmental damage. Nuclear power is a low-carbon source and has a safety record comparable to wind and solar,[1] but its sustainability has been debated due to concerns about nuclear proliferation, nuclear waste, and accidents. Switching from coal to natural gas has environmental benefits, but may lead to a delay in switching to more sustainable options.

Costs of wind, solar, and batteries have fallen rapidly and are projected to continue falling due to innovation and economies of scale. To accommodate larger shares of variable energy sources, the electrical grid needs additional infrastructure such as grid energy storage. These sources generated 8.5% of worldwide electricity in 2019, a share that has grown rapidly. A sustainable energy system is likely to see a shift towards more use of electricity in sectors such as transport, energy conservation, and the use of hydrogen produced by renewables or from fossil fuels with carbon capture and storage. Electricity and clean-burning fuels are being deployed to replace usage of highly polluting cooking fuels in lower-income countries.[2] The Paris Agreement to limit climate change and the United Nation's Sustainable Development Goals aim for a rapid transition to sustainable energy. Governments use various policies to promote more sustainable use of energy, such as energy efficiency standards, carbon pricing, fossil fuel pollution regulations, investments in renewable energy, and a phase-out of fossil fuel subsidies.

# Definitions and background

The concept of sustainable development, for which energy is a key component, was described by the United Nations Brundtland Commission in its 1987 report Our Common Future. It defined sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[3] This description of sustainable development has since been referenced in many definitions and explanations of sustainable energy.[4][5][6][3] No single interpretation of how the concept of sustainability applies to energy has gained worldwide acceptance.[7] The UN Economic Commission for Europe, and various scholars in the field, include several aspects of sustainability in their working definitions:

Environmental aspects include greenhouse gas emissions, impacts on biodiversity and ecosystems, the production of hazardous waste and toxic emissions,[7] water consumption,[8] and depletion of non-renewable resources.[6]

Economic and social aspects include having reliable energy be affordable for all people,[7][6] and energy security so that each country has constant access to sufficient energy.[7][9]

# Sustainable development

The energy transition to meet the world's needs for electricity, heating, cooling, and transport in a sustainable way is one of the greatest challenges facing humanity in the 21st century, both in terms of meeting the needs of the present and in terms of effects on future generations.[10][11] Improving energy access in the least-developed countries, and making energy cleaner, are key to achieving most of the United Nations 2030 Sustainable Development Goals, which cover issues ranging from climate action to gender equality.[12] Sustainable Development Goal 7 calls for "access to affordable, reliable, sustainable and modern energy for all" by 2030.[13]

# Environmental issues

The current energy system contributes to many environmental issues, including climate change, air pollution, biodiversity loss, the release of toxins into the environment, and water scarcity. Energy production and consumption are responsible for 72% of annual human-caused greenhouse gas emissions as of 2014. Generation of electricity and heat contributes 31% of human-caused greenhouse gas emissions, use of energy in transport contributes 15%, and use of energy in manufacturing and construction contributes 12%. An additional 5% is released through processes associated with fossil fuel production, and 8% through various other forms of fuel combustion.[15][16]

The burning of fossil fuels and biomass is a major source of air pollutants that are harmful to human health.[17][18] The World Health Organization estimates that outdoor air pollution causes 4.2 million deaths per year,[19] and indoor air pollution causes 3.8 million deaths per year.[20] Around 91% of the world’s population lives with levels of air pollution that exceed WHO recommended limits.[21] Limiting global warming to 2°C could save about a million of those lives per year by 2050, whereas limiting global warming to 1.5°C could save millions while increasing energy security and reducing poverty.[22][23][24] Multiple analyses of U.S. decarbonization strategies have found that quantified health benefits can significantly offset the costs of implementing these strategies.[25] The combustion of coal releases precursor elements which form into ground-level ozone and acid rain, especially if the coal is not cleaned before combustion.[26]

Environmental impacts extend beyond the byproducts of combustion. Oil spills at sea harm marine life and may cause fires which release toxic emissions.[27] Around 10% of global water use goes to energy production, mainly for cooling thermal energy plants. In already dry regions, this contributes to water scarcity. Bioenergy production, coal mining and processing, and oil extraction also require large amounts of water.[28]

# Energy poverty

As of 2019, 770 million people do not have access to electricity, three quarters of whom live in sub-Saharan Africa.[29] As of 2020, more than 2.6 billion people[30] in developing countries rely on burning polluting fuels such as wood, animal dung, coal, or kerosene for cooking.

Cooking with polluting fuels causes harmful indoor air pollution, resulting in an estimated 1.6 to 3.8 million deaths annually,[31][32] and also contributes significantly to outdoor air pollution.[33] Health effects are concentrated among women, who are likely to be responsible for cooking, and young children.[33] The work of gathering fuel exposes women and children to safety risks and often consumes 15 or more hours per week, constraining their available time for education, rest, and paid work.[33] Serious local environmental damage, including desertification, can be caused by excessive harvesting of wood and other combustible material.[34] Efforts to improve access to clean cooking fuels and stoves have barely kept up with population growth, and current and planned policies would still leave 2.4 billion people without access in 2030.[30]

Reliable and affordable energy, particularly electricity, is essential for health care, education, and economic development.[35] In health clinics, electricity is required for operation of medical equipment, refrigeration of vaccines and medications, and lighting,[35] but a 2018 survey in six Asian and African countries found that half of health facilities had no or poor access to electricity.[36] According to a 2020 report by the IEA, current and planned policies would still leave over 660 million people without electricity by 2030.[29]

# Energy conservation

Increasing energy efficiency is one of the most important ways to reduce energy-related pollution while also delivering economic benefits and improving quality of life. For some countries, efficiency can improve energy security by reducing dependence on fossil fuel imports. Efficiency has the potential to slow the growth of energy demand to allow rising clean energy supplies to make deep cuts in fossil fuel use.[37] The International Energy Agency (IEA) estimates that 40% of greenhouse gas emission reductions needed to fulfill the Paris agreement can be achieved by increasing energy efficiency.[38][39] Climate change mitigation pathways that are in line with these goals show energy usage remaining around the same between 2010 and 2030, and then increase slightly by 2050.[40]

Improvements in energy efficiency slowed in the years between 2015 and 2018, in part because of consumer preferences for bigger cars. Globally, governments did not strongly increase their ambitions in energy efficiency policy over this period either.[39] Policies to improve efficiency can include building codes, performance standards, and carbon pricing.[41] Energy efficiency and renewable energy are often considered the twin pillars of sustainable energy.[42][43]

Behavioural changes are another important way to conserve energy. In the International Energy Agency scenario for reaching net zero greenhouse gas emissions in 2050, several significant behavioural changes are described, about half of them deriving from transport. In their scenario, some business flights are replaced by videoconferencing, cycling and walking increase in popularity, and more people use public transport.[44]

# Renewable energy sources

*Main article: Renewable energy*

Renewable energy technologies are essential contributors to sustainable energy, as they generally contribute to global energy security and reduce dependence on fossil fuel resources, thus mitigating greenhouse gas emissions.[45] The terms sustainable energy and renewable energy are often used interchangeably.[46] However, renewable energy projects sometimes raise significant sustainability concerns, such as risks to biodiversity when areas of high ecological value are converted to bioenergy production or wind or solar farms.[47][48] Hydropower is the largest renewable electricity source while solar and wind have seen substantial growth and progress over the last few years; photovoltaic solar and onshore wind are the cheapest forms of adding new power generation capacity in most countries.[49][50] For more than half of the 770 million people who currently lack access to electricity, decentralised renewable energy solutions such as solar-powered mini grids are likely to be the least-cost method of providing access by 2030.[29]

# Solar

In 2019, solar power provided around 3% of global electricity,[51] mostly through solar panels based on photovoltaic cells (PV). The panels are mounted on top of buildings or used in solar parks connected to the electrical grid. Costs of solar PV have dropped rapidly, which is driving a strong growth in worldwide capacity.[52] The cost of electricity from new solar farms is competitive with, or in many places cheaper than, electricity from existing coal plants.[53]

Concentrated solar power produces heat to drive a heat engine. Because the heat is stored, this type of solar power is dispatchable: it can be produced when needed.[54] Solar thermal heating systems are used for many applications: hot water, heating buildings, drying and desalination.[55] Globally in 2018, solar energy fulfilled 1.5% of final energy demand for heating and cooling.[56]

# Wind power

*Main articles: Wind power and Environmental impact of wind power*

In 2019, wind turbines provided approximately 6% of global electricity.[51] Electricity from onshore wind farms is often cheaper than existing coal plants, and competitive with natural gas and nuclear.[53] Wind turbines can also be placed in the ocean, where winds are steadier and stronger than on land but construction and maintenance costs are higher. According to some analyst forecasts, offshore wind power will become cheaper than onshore wind in the mid-2030s.[57]

Onshore wind farms, often built in wild or rural areas, have a visual impact on the landscape.[58] Local bat populations may be strongly impacted by collisions.[59] The noise and flickering light created by the turbines can be annoying, and constrain construction near densely populated areas. Wind power, in contrast to nuclear and fossil fuel plants, does not consume water to produce power.[60] Little energy is needed for wind turbine construction compared to the energy produced by the wind power plant itself.[61] Turbine blades are not fully recyclable; research into methods of manufacturing easier-to-recycle blades is ongoing.[62]

# Hydropower

Hydroelectric plants convert the energy of moving water into electricity. On average, hydropower ranks among the energy sources with the lowest levels of greenhouse gas emissions per unit of energy produced, but levels of emissions vary enormously between projects.[63] In 2019, hydropower supplied 16% of the world's electricity, down from a high of nearly 20% in the mid-to-late 20th century.[64][65] It produced 60% of electricity in Canada and nearly 80% in Brazil.[64]

In conventional hydropower, a reservoir is created behind a dam. Conventional hydropower plants provide a highly flexible, dispatchable electricity supply and can be combined with wind and solar power to provide peak load and to compensate when wind and sun are less available.[66]

In most conventional hydropower projects, the biological matter that becomes submerged in the flooding of the reservoir decomposes, becoming a source of carbon dioxide and methane.[67] These greenhouse gas emissions are particularly large in tropical regions.[68] In turn, deforestation and climate change can reduce energy generation from hydroelectric dams.[66] Depending on location, the implementation of large-scale dams can displace residents and cause significant local environmental damage.[66]

Run-of-the-river hydroelectricity facilities generally have less environmental impact than reservoir-based facilities, but their ability to generate power depends on river flow which can vary with daily and seasonal weather conditions. Reservoirs provide water quantity controls that are used for flood control and flexible electricity generation output while also providing security during drought for drinking water supply and irrigation.[69]

# Geothermal

Geothermal energy is produced by tapping into the heat that exists below the earth's crust.[70] Heat can be obtained by drilling into the ground and then carried by a heat-transfer fluid such as water, brine or steam.[70] Geothermal energy can be harnessed for electricity generation and for heating. The use of geothermal energy is concentrated in regions where heat extraction is economical: a combination of heat, flow and high permeability is needed.[71] Worldwide in 2018, geothermal provided 0.6% of heating and cooling final energy demand in buildings.[56]

Geothermal energy is a renewable resource because thermal energy is constantly replenished from neighbouring hotter regions.[72] The greenhouse gas emissions of geothermal electric stations are on average 45 grams of carbon dioxide per kilowatt-hour of electricity, or less than 5 percent of that of conventional coal-fired plants.[73] Geothermal energy carries a risk of inducing earthquakes, needs effective protection to avoid water pollution, and emits toxic emissions which can be captured.[74]

# Bioenergy

*Main article: Bioenergy*

Biomass is a versatile and common source of renewable energy. If the production of biomass is well-managed, carbon emissions can be significantly offset by the absorption of carbon dioxide by the plants during their lifespans.[75] Biomass can either be burned to produce heat and to generate electricity or converted to modern biofuels such as biodiesel and ethanol.[76][77] Biofuels are often produced from corn or sugar cane. They are used to power transport, often blended with liquid fossil fuels.[75]

Use of farmland for growing biomass can result in less land being available for growing food. Since photosynthesis only captures a small fraction of the energy in sunlight, and crops require significant amounts of energy to harvest, dry, and transport, a lot of land is needed to produce biomass.[78] If biomass is harvested from crops, such as tree plantations, the cultivation of these crops can displace natural ecosystems, degrade soils, and consume water resources and synthetic fertilizers.[79][80] Approximately one-third of all wood used for fuel is harvested unsustainably.[81] In some cases, these impacts can actually result in higher overall carbon emissions compared to using petroleum-based fuels.[80][82]

In the United States, corn-based ethanol has replaced less than 10% of motor gasoline use since 2011, but has consumed around 40% of the annual corn harvest in the country.[80] In Malaysia and Indonesia, the clearing of forests to produce palm oil for biodiesel has led to serious social and environmental effects, as these forests are critical carbon sinks and habitats for endangered species.[83]

More sustainable sources of biomass include crops grown on soil unsuitable for food production, algae and waste.[75] If the biomass source is agricultural or municipal waste, burning it or converting it into biogas provides a way to dispose of this waste.[79] Second-generation biofuels, produced from non-food plants, reduce competition with food production, but may have other negative effects including trade-offs with conservation areas and local air pollution.[75]

According to the UK Climate Change Committee in the long term all uses of bioenergy must use carbon capture and storage (BECCS),[84] and uses where effective carbon sequestration is not possible, such as the use of biofuels in vehicles, should be phased out.[85]

# Marine energy

Marine energy represents the smallest share of the energy market. It encompasses tidal power, which is approaching maturity, and wave power, which is earlier in its development. Two tidal barrage systems, in France and in Korea, make up 90% of total production. While single devices pose little risk to the environment, the impacts of multi-array devices are less well known.[86]

# Non-renewable energy sources

# Switching to gas

For a given unit of energy produced, the life-cycle greenhouse-gas emissions of natural gas are around 40 times the emissions of wind or nuclear energy, but much less than that of coal. Natural gas produces around half the emissions of coal when used to generate electricity, and around two-thirds the emissions of coal when used to produce heat. Reducing methane leaks in the process of extracting and transporting natural gas further decreases emissions.[87] Natural gas produces less air pollution than coal.[88]

Building gas-fired power plants and gas pipelines is promoted as a way to phase out coal and wood burning pollution, and increase energy supply in some African countries with fast growing populations or economies,[89] however this practice is controversial. Developing natural gas infrastructure risks the creation of carbon lock-in and stranded assets.[90][91] While in early stages, natural gas plants are in planning that burn oxygen and only produce carbon dioxide and water as a byproduct, sequestering the CO  
2 underground.[92][relevant? – discuss]

# Nuclear power

*Main article: Nuclear power debate*

Nuclear power plants have been used since the 1950s to produce a steady low-carbon supply of electricity, without creating local air pollution. In 2020, nuclear power plants in over 30 countries generated 10% of global electricity[93] but nearly 50% of low-carbon power in USA and European Union. Globally, nuclear power is the second largest source of low-carbon power after hydro-power.[94] Nuclear power uses little land use per unit of energy produced, compared to the major renewables.[95]

Nuclear power's lifecycle greenhouse gas emissions (including the mining and processing of uranium), are similar to the emissions from renewable energy sources.[96] Reducing the time and cost of building new nuclear plants have been goals for decades, but progress has been limited.[97][98]

There is considerable controversy over whether nuclear power can be considered sustainable, with debates revolving around the risk of nuclear accidents, the generation of radioactive nuclear waste, and the potential for nuclear energy to contribute to nuclear proliferation. These concerns spurred the anti-nuclear movement. Public support for nuclear energy is often low as a result of safety concerns, however for each unit of energy produced, nuclear energy is far safer than fossil fuel energy and comparable to renewable sources.[99] The uranium ore used to fuel nuclear fission plants is a non-renewable resource, but sufficient quantities exist to provide a supply for hundreds of years.[100] Climate change mitigation pathways that are consistent with ambitious goals typically see an increase in power supply from nuclear, but growth is not strictly necessary.[101]

Various new forms of nuclear energy are in development, hoping to address the drawbacks of conventional plants. Nuclear power based on thorium, rather than uranium, may be able to provide higher energy security for countries that do not have a large supply of uranium.[102] Small modular reactors may have several advantages over current large reactors: it should be possible to build them faster, and their modularization would allow for cost reductions via learning-by-doing.[103] Several countries are attempting to develop nuclear fusion reactors, which would generate very small amounts of waste and no risk of explosions.[104]

# Energy system transformation

# The growing role of electricity

Electrification is a key part of using energy sustainably. Many options exist to produce electricity sustainably, but sustainably producing fuels or heat at large scales is relatively difficult.[105] Specifically, massive electrification in the heat and transport sector may be needed to make these sectors sustainable, with heat pumps and electric vehicles playing important roles.[106] Ambitious climate policy would see a doubling of energy consumed as electricity by 2050, from 20% in 2020.[107]

As of 2018, about a quarter of all electricity generation came from renewable sources other than biomass. The growth of renewable energy usage has been significantly faster in this sector than in heating and transport.[108]

# Managing variable energy sources

Solar and wind are variable renewable energy sources that supply electricity intermittently depending on the weather and the time of day.[109][110] Most electrical grids were constructed for non-intermittent energy sources such as coal-fired power plants.[111] As larger amounts of solar and wind energy are integrated into the grid, changes have to be made to the energy system to ensure that the supply of electricity is matched to demand.[112] In 2019, these sources generated 8.5% of worldwide electricity, a share that has grown rapidly.[51]

There are various ways to make the electricity system more flexible. In many places, wind and solar production are complementary on a daily and a season scale: There is more wind during the night and in winter, when solar energy production is low.[112] Linking different geographical regions through long-distance transmission lines allows for further cancelling out of variability.[113] Energy demand can be shifted in time through energy demand management and the use of smart grids, matching the times when variable energy production is highest. With storage, energy produced in excess can be released when needed.[112] Building additional capacity for wind and solar generation can help to ensure that enough electricity is produced even during poor weather; during optimal weather energy generation may have to be curtailed. The final mismatch may be covered by using dispatchable energy sources such as hydropower, bioenergy, or natural gas.[114]

# Energy storage

Energy storage helps overcome barriers for intermittent renewable energy, and is therefore an important aspect of a sustainable energy system.[115] The most commonly used storage method is pumped-storage hydroelectricity, which requires locations with large differences in height and access to water.[115] Batteries, and specifically lithium-ion batteries, are also deployed widely.[116] They contain cobalt, which is largely mined in Congo, a politically unstable region. More diverse geographical sourcing may ensure the stability of the supply-chain and their environmental impacts can be reduced by downcycling and recycling.[117][118] Batteries typically store electricity for short periods; research is ongoing into technology with sufficient capacity to last through seasons.[119] Pumped hydro storage and power-to-gas with capacity for multi-month usage has been implemented in some locations.[120][121]

As of 2018, thermal energy storage is typically not as convenient as burning fossil fuels. High upfront costs form a barrier for implementation. Seasonal thermal energy storage requires large capacity; it has been implemented in some high-latitude regions for household heat.[122]

# Hydrogen

Hydrogen can be burned to produce heat or can power fuel cells to generate electricity, with zero emissions at the point of usage. The overall lifecycle emissions of hydrogen depend on how it is produced. Very little of the world's current supply of hydrogen is currently created from sustainable sources. Nearly all of it is produced from fossil fuels, which results in high greenhouse gas emissions. With carbon capture and storage technologies, a large fraction of these emissions could be removed.[123]

Hydrogen can be produced through electrolysis, by using electricity to split water molecules into hydrogen and oxygen, and if the electricity is generated sustainably, the resultant fuel will also be sustainable. This process is currently more expensive than creating hydrogen from fossil fuels, and the efficiency of energy conversion is inherently low.[123] Hydrogen can be produced when there is a surplus of intermittent renewable electricity, then stored and used to generate heat or to re-generate electricity. Further conversion to ammonia allows the energy to be more easily stored at room temperature in liquid form.[124]

There is potential for hydrogen to play a significant role in decarbonising energy systems because in certain sectors, replacing fossil fuels with direct use of electricity would be very difficult.[123] Hydrogen fuel can produce the intense heat required for industrial production of steel, cement, glass, and chemicals.[125] Steelmaking is considered to be the use of hydrogen which would be most effective in limiting greenhouse gas emissions in the short-term.[125]

# Carbon capture and storage

The greenhouse gas emissions of fossil fuel and biomass power plants can be significantly reduced through carbon capture and storage (CCS), however deployment of this technology is still very limited, with only 21 large-scale CCS plants in operation worldwide as of 2020.[126] The CCS process is expensive, with costs depending considerably on the location's proximity to suitable geology for carbon dioxide storage.[57][127] CCS can be retrofitted to existing power plants, but is more energy-intensive in that case.[128] Most studies use a working assumption that CCS can capture 85–90% of the CO  
2 emissions from a power plant.[129][130] If 90% of emitted CO  
2 is captured from a coal-fired power plant, its uncaptured emissions would still be many times greater than the emissions of nuclear, solar, or wind energy per unit of electricity produced.[131][132]

When CCS is used to capture emissions from burning biomass in a process known as bioenergy with carbon capture and storage (BECCS), the overall process can result in net carbon dioxide removal from the atmosphere. The BECCS process can result in net positive emissions depending on how the biomass material is grown, harvested, and transported.[133] As of 2014, the lowest-cost mitigation pathways for meeting the 2°C target typically describe massive deployment of BECCS.[133] However, using BECCS at the scale described in these pathways would require more resources than are currently available worldwide. For example, to capture 10 billion tons of CO  
2 per year would require biomass from 40 percent of the world's current cropland.[133]

# Energy usage technologies

# Heating and cooling

A large fraction of the world population cannot afford sufficient cooling for their homes. In addition to air conditioning, which requires electrification and additional power demand, passive building design and urban planning will be needed to ensure cooling needs are met in a sustainable way.[134] Similarly, many households in the developing and developed world suffer from fuel poverty and cannot heat their houses enough.[135] Existing heating practices are often polluting.

Alternatives to fossil fuel heating include electrification (heat pumps, or the less efficient electric heater), geothermal, biomass, solar thermal, and waste heat.[136][137][138] The costs of all these technologies strongly depend on location, and uptake of the technology sufficient for deep decarbonisation requires stringent policy interventions.[138] The IEA estimates that heat pumps currently provide only 5% of space and water heating requirements globally, but could provide over 90%.[139] Use of ground source heat pumps not only reduces total annual energy loads associated with heating and cooling, it also flattens the electric demand curve by eliminating the extreme summer peak electric supply requirements.[140]

# Transport

There are multiple ways to make transport more sustainable. Public transport frequently emits less per passenger than personal vehicles such as cars, especially with high occupancy.[141][142] Transport can be made cleaner and healthier by stimulating nonmotorised transport such as cycling, particularly in cities.[143] The energy efficiency of cars has increased as a consequence of technological progress.[144]

It is easier to sustainably produce electricity than it is to sustainably produce liquid fuels. Therefore, adoption of electric vehicles is a way to make transport more sustainable.[106] Hydrogen vehicles may be an option for larger vehicles which have not yet been widely electrified, such as long distance lorries.[145] Many of the techniques needed to lower emissions from shipping and aviation are still early in their development.[146] Aviation biofuel may be one of the better uses of bioenergy, providing that some carbon is captured and stored during manufacture of the fuel.[84]

# Industry

Over one third of energy use is by industry. Most of that energy is deployed in thermal processes: generating steam, drying, and refrigeration. The share of renewable energy in industry was 14.5% in 2017, which mostly include low-temperature heat supplied by bioenergy and electricity. The more energy-intensive activities in industry have the lowest shares of renewable energy, as they face limitations in generating heat at temperatures over 200°C.[147] For some industrial processes, such as steel production, commercialization of technologies that have not yet been built or operated at full scale will be needed to eliminate greenhouse gas emissions.[148] The production of plastic, cement and fertilizers also requires significant amounts of energy, with limited possibilities available to decarbonise.[149]

# Cooking

*Further information: Clean fuel*

A high priority in global sustainable development is to reduce the health and environmental problems caused by cooking with biomass, coal, and kerosene.[150] Alternatives include electric stoves, solar cookers, stoves that use clean fuels, and stoves that burn biomass more efficiently and with less pollution. Depending on location, clean fuels for cooking are typically liquified petroleum gas (LPG), locally-produced biogas, piped natural gas (PNG), or alcohol.[151] Electric induction stoves create less pollution than LPG even when connected to coal power sources, and are sometimes cheaper.[2] The World Health Organization encourages further research into biomass stove technology, as no widely-available biomass stoves meet recommended emissions limits.[152]

Transitioning to cleaner cooking methods is expected to either raise greenhouse gas emissions by a minimal amount or decrease them, even if the replacement fuels are fossil fuels. There is evidence that switching to LPG and PNG has a smaller climate effect than the combustion of solid fuels, which emits methane and black carbon.[153] The IPCC stated in 2018, "The costs of achieving nearly universal access to electricity and clean fuels for cooking and heating are projected to be between 72 and 95 billion USD per year until 2030 with minimal effects on GHG emissions."[154]

# Government policies

# Climate

Internationally, the main vehicle for climate policy is the Paris Agreement, which encourages countries to pursue efforts to keep global warming under 1.5 °C (2.7 °F).[156] According to the IPCC, both explicit carbon pricing and complementary energy-specific policies are necessary mechanisms to limit global warming to 1.5°C.[157] Average annual investment in low-carbon energy technologies and energy efficiency need to be upscaled by roughly a factor of six by 2050 compared to 2015, overtaking fossil investments by around 2025.[158]

Energy-specific programs and regulations have historically been the mainstays of efforts to reduce fossil fuel emissions. Successful cases include the building of nuclear reactors in France in the 1970s and 1980s, and fuel efficiency standards for cars and light trucks in the United States which has conserved billions of barrels of oil.[159] Other examples of energy-specific policies include energy-efficiency requirements in building codes, banning new coal-fired electricity plants, performance standards for electrical appliances, and support for electric vehicle use.[157][160]

Carbon taxes provide a source of revenue that can be used to lower other taxes[161] or to help lower-income households afford higher energy costs.[162] Carbon taxes have encountered strong political pushback in some jurisdictions, whereas energy-specific policies tend to be politically safer.[159] According to the OECD, climate change cannot be curbed without carbon taxes on energy, but 70% of energy-related CO  
2 emissions were not taxed at all in 2018.[163] Fossil fuel subsidies form a significant barrier to the energy transition.[164] Direct global fossil fuel subsidies reached $319 billion in 2017, and $5.2 trillion when indirect costs such as air pollution are priced in.[165] Ending these can cause a 28% reduction in global carbon emissions and a 46% reduction in air pollution deaths.[166]

In 2020, the International Energy Agency warned that the economic turmoil caused by the COVID-19 pandemic could prevent or delay private-sector investments in green energy.[167][168] The pandemic could potentially spell a slowdown in the world's clean energy transition if no action is undertaken, but also offers possibilities for a green recovery.[169]

# Pollution

Air pollution levels in rich countries have been declining for decades. Improvements are attributable to environmental regulation, switching towards cleaner energy sources, and an economic shift away from heavy industry.[170] Since 1970, emissions of sulphur dioxide (the gas that contributes to acid rain) have fallen by over 90% in the US and UK, and fine particulates by up to 80%.[171] In London, air pollution levels are now 40 times less than they were when the Public Health Act was passed in 1891, and are over 20 times less than they are in Delhi as of 2010.[170]

# Energy security

Energy security is another major policy goal. Historically, energy independence has been the focus of energy security policy, with countries wanting to become less dependent on oil exporters. With the integration of variable renewables, countries are increasingly considering the benefits of interdependence to compensate for intermittency.[172] The markets for metals and minerals required for sustainable energy are sometimes dominated by a small group of countries or companies, raising geopolitical concerns.[173]