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Economics in Context Initiative

Energy Economics and Policy

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An ECI Teaching Module on Social and Environmental Issues in Economics

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NOTE – terms denoted in **bold face** are defined in the **KEY TERMS AND CONCEPTS** section at the end of the module.

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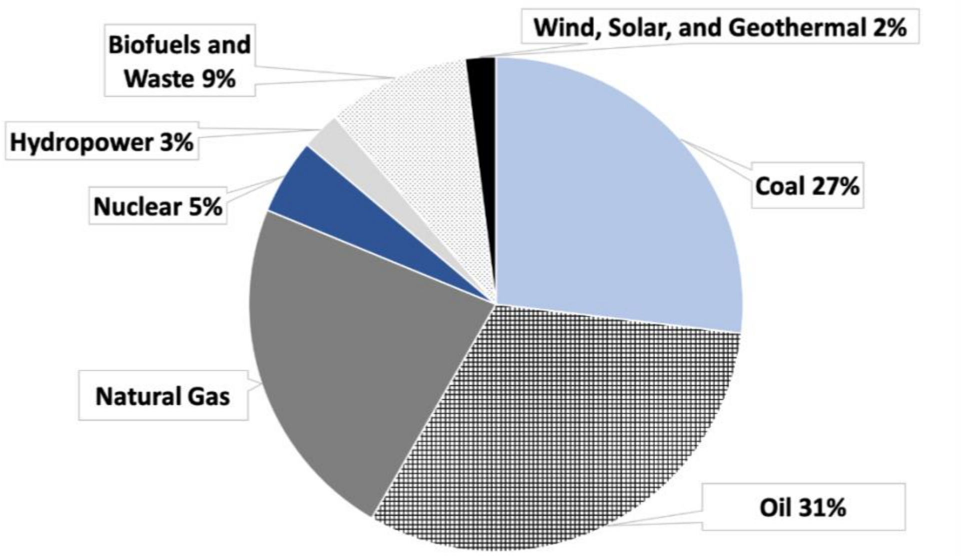
1. FOUR GLOBAL ENERGY CHALLENGES

The Industrial Revolution in the 18th and 19th centuries was driven by a transition away from traditional energy sources such as wood and animal power to fossil fuel energy. If humanity is to achieve a sustainability revolution in the 21st century, it will be driven by a transition away from fossil fuel energy to renewable sources such as wind and solar power. Modern economies are absolutely dependent on a continual supply of energy. While energy expenditures only represent about 6% of GDP in the United States, the other 94% of the economy would collapse without sufficient energy supplies.[1]

The great transition away from fossil fuels is already underway, being driven by changes in technology, prices, and government policies. But the transition is not occurring fast enough to prevent unacceptable climate change – the world's first energy challenge we consider in this section.[2] Currently the world obtains over 80% of its energy from fossil fuels, as shown in Figure 1 – a percentage which has remained essentially constant over the last few decades. While the amount of global energy obtained from wind and solar power has tripled in the last 10 years, these sources are still only a small percentage of total energy use.[3] According to a 2019 report:

Figure 1. *Global Energy Supplies by Source, 2018*



Source: International Energy Agency, Data and Statistics, "Total Energy Supply by Source".

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[1] U.S. EIA, 2019a.
[2] Climate Action Tracker, https://climateactiontracker.org/.
[3] International Energy Agency, Data and Statistics, https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy%20supply&indicator=TPESbySource.

> the energy transformation must happen much faster. To meet global climate objectives, the deployment of renewables must increase at least six-fold compared to current government plans. This would require the impressive progress that we are already witnessing in the power sector to accelerate even further, while efforts to decarbonise transport and heating would need to be stepped-up significantly.[4]

The challenge of transitioning away from fossil fuels raises the related challenge of electrification of the world's energy system. Fossil fuels provide energy both directly through combustion and indirectly by generating electricity. For example, when gasoline is burned in a car engine or natural gas is burned in a furnace, we use the resulting energy directly to drive a car or heat a home. Indirectly, fossil fuels can generate electricity that is then used for various purposes. The energy from renewable sources such as wind and solar energy can also be converted to electricity for final use.

Currently only about 25% of the world's energy comes from electricity, including electricity generated from renewable and nonrenewable sources. For a large-scale transition to renewable energy, processes that currently rely on the direct burning of fossil fuels will have to be converted to electric power. For example, rather than powering vehicles by burning gasoline we can switch to electric vehicles powered indirectly from wind or solar energy. Fortunately, electric technologies for transportation, heating, industrial production, and other uses are developing rapidly, along with battery technology to store electric energy. (See Box 1 for more on electric vehicles.) The global infrastructure to deliver electricity will also need to be expanded and modernized.

BOX 1: THE ADVANTAGES OF ELECTRIC VEHICLES

Electric Vehicles (EVs) are starting to penetrate the global automobile market. A step beyond hybrids and plug-in hybrids, which use both gasoline and electric power, fully electric vehicles use electricity only. EVs offer numerous advantages over traditional vehicles.

According to an analysis by the Union of Concerned Scientists, over a vehicle's lifetime EVs produce less than half the greenhouse gas emissions of a typical vehicle, even when the higher emissions of EV production are taken into account.[5] As a greater share of electricity is generated from renewable sources, the environmental benefits of EVs will increase further. With fewer moving parts, EVs also require less maintenance. For example, EVs require no oil changes or tune-ups, and have no exhaust systems, belts, or complex transmissions. Another advantage of EVs is lower fuel costs. According to a 2020 analysis from the U.S. Department of Energy, a driver can save as much as $14,500 in lower fuel costs over 15 years by driving an EV instead of a comparable gas vehicle.[6]

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[4] IRENA, 2019a, p. 3.
[5] Nealer *et al*., 2015.
[6] NREL, 2020.

EVs are generally more expensive to purchase than comparable gas vehicles, primarily due to the high cost of the batteries. But the cost savings from lower maintenance and operational costs means that total vehicle ownership costs tend to be less for EVs. For example, a 2020 report by Consumer Reports compared the total ownership cost of nine popular EVs to similar gas-powered vehicles. The results showed that for "all EVs analyzed, the lifetime ownership costs were many thousands of dollars lower than all comparable ICE vehicles' costs, with most EVs offering savings of between \$6,000 and \$10,000."[7] Also, EV battery costs are rapidly declining—dropping by 87 percent between 2010 and 2019.[8] With expected further declines in battery prices, EVs are expected to become cost-competitive with gas vehicles based on purchase price alone as soon as 2023. Once this occurs, "electric vehicles will probably move beyond niche applications and begin to penetrate the market widely, leading to a potential paradigm shift in vehicle technology."[9]

While sales of EVs are growing, they still comprise only about 2% of all new vehicle sales.[10] A 2020 forecast developed by the consulting company Deloitte projects that annual EV sales will increase more than ten-fold during the 2020s, reaching about one-third of all new vehicles sold by 2030.[11]

Norway is an example of how government incentives can dramatically boost the sales of EVs. EV owners in Norway are exempt from purchase taxes, including a 25 percent value-added tax, and pay reduced fees for parking and tolls. EV drivers can use bus lanes and have access to an extensive network of charging stations.[12] As a result of such policies, in the first half of 2020 EVs comprised 48% of all new vehicle sales in Norway.[13]

While technological changes and market forces increasingly favor renewable energy and electrification over fossil fuels, government policies will ultimately determine how fast the transition occurs. Policies that focus on changing a society's energy mix, such as shifting from fossil fuels towards renewables, are referred to as **supply-side energy management**. For example, Germany has set a target of obtaining 65% of its electricity from renewable sources by 2030.

The world's energy challenge is not simply about switching energy sources. Global energy demand has been increasingly steadily, as shown in Figure 2. While the world's consumption of renewable energy increased by a factor of 13 between 2000 and 2019, overall demand for fossil fuels is also increasing. During this same period, the global demand for oil increased by 30%, and demand for natural gas increased by 56%. Despite growth in renewables (seen as the top two sections in Figure 2), the main trend of recent decades has been overall growth in almost all energy sources. (An exception is nuclear energy, with global demand declining slightly in the 2010s.)

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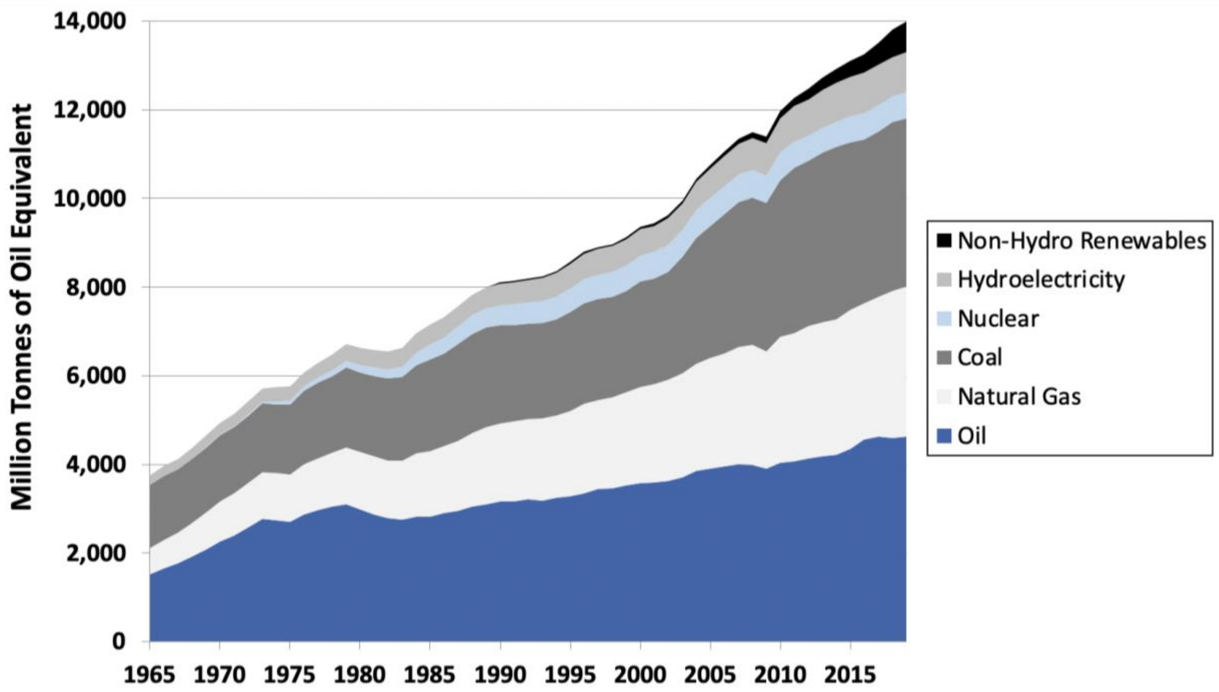
7 Harto, 2020.
8 Gearino, 2020.
9 Nykvist and Nilsson, 2015, p. 330.
10 McKinsey & Company, 2020.
11 Woodward *et al.*, 2020.
12 Norwegian EV Policy, https://elbil.no/english/norwegian-ev-policy/.
13 Doyle, 2020.

Figure 2. *Global Energy Demand by Source, 1965-2019*

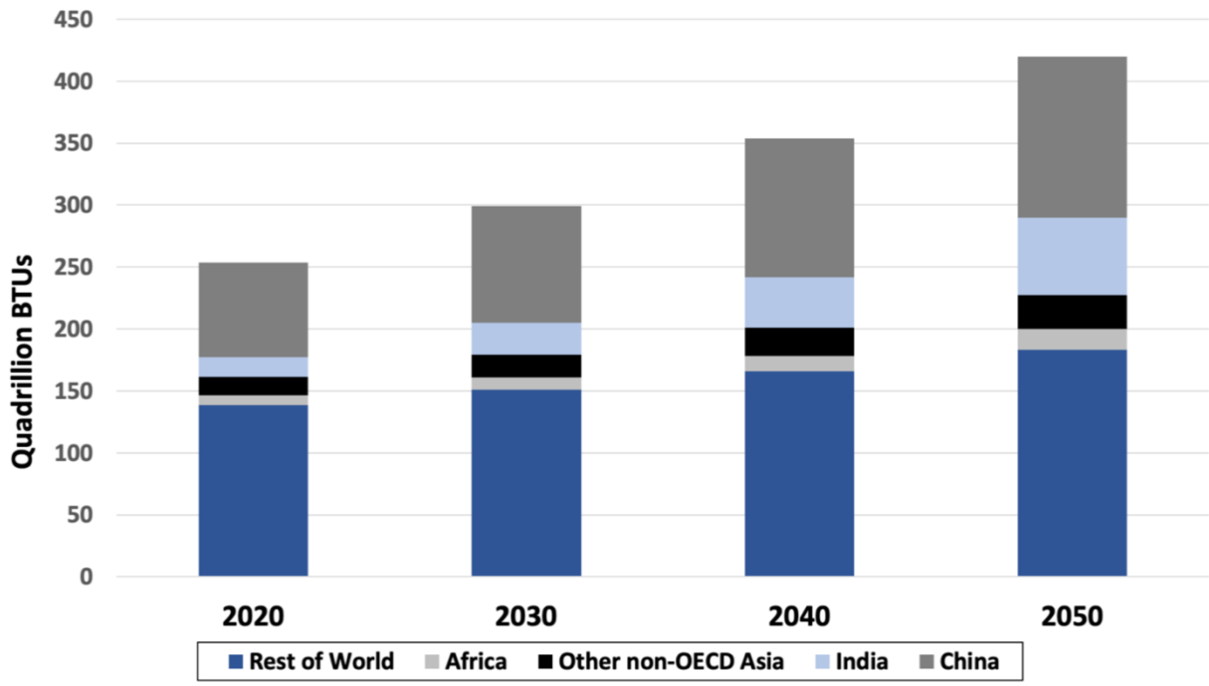


Source: BP Statistical Review of World Energy, various editions

Most projections indicate that global energy demand will continue to increase. The U.S. Energy Information Administration (EIA) projects that the world's energy demand will increase by 66% between 2020 and 2050, as shown in Figure 3. Most of this increase is expected to occur in low- and middle-income countries, with energy demand increasing by 71% in China, 116% in Africa, and 293% in India. Figure 3 illustrates the world's third energy challenge – a focus on **demand-side energy management**, or policies that seek to reduce energy demand (or at least reduce the growth in demand). The projection in Figure 3 is from the EIA's "reference case" which is based on current national energy policies and specific assumptions about future energy prices, technology, and economic growth. Later in the module we will consider whether significant growth in global energy demand can be avoided through energy efficiency improvements, energy pricing, and other policies. Efforts to slow the increase in global energy demand should complement policies that transition the world's energy mix away from fossil fuels, speeding the attainment of a sustainable energy system.

supply-side energy management energy policies that seek to change the energy mix in a society, such as switching from fossil fuels to renewables
demand-side energy management energy policies that seek to reduce total energy consumption, such through energy efficiency improvements

Figure 3. *Projected Global Energy Demand 2020-205, by Country/Region*



Source: U.S. EIA, 2020.

One interpretation of Figure 3 is that policy efforts should be directed toward limiting the growth in energy demand in developing countries such as China and India. But this perspective neglects the world's fourth energy challenge – addressing the global disparity in access to, and consumption of, energy. About 800 million people across the world lack access to electricity.[14] According to the World Bank, as of 2018 there are 28 countries, most in Sub-Saharan Africa, where less than half of the population have access to electricity.[15] While the majority of households in developed countries have access to personal vehicles, a 2015 survey found that only 17% of households in China own a car, 6% in India, and 2% in Bangladesh.[16]

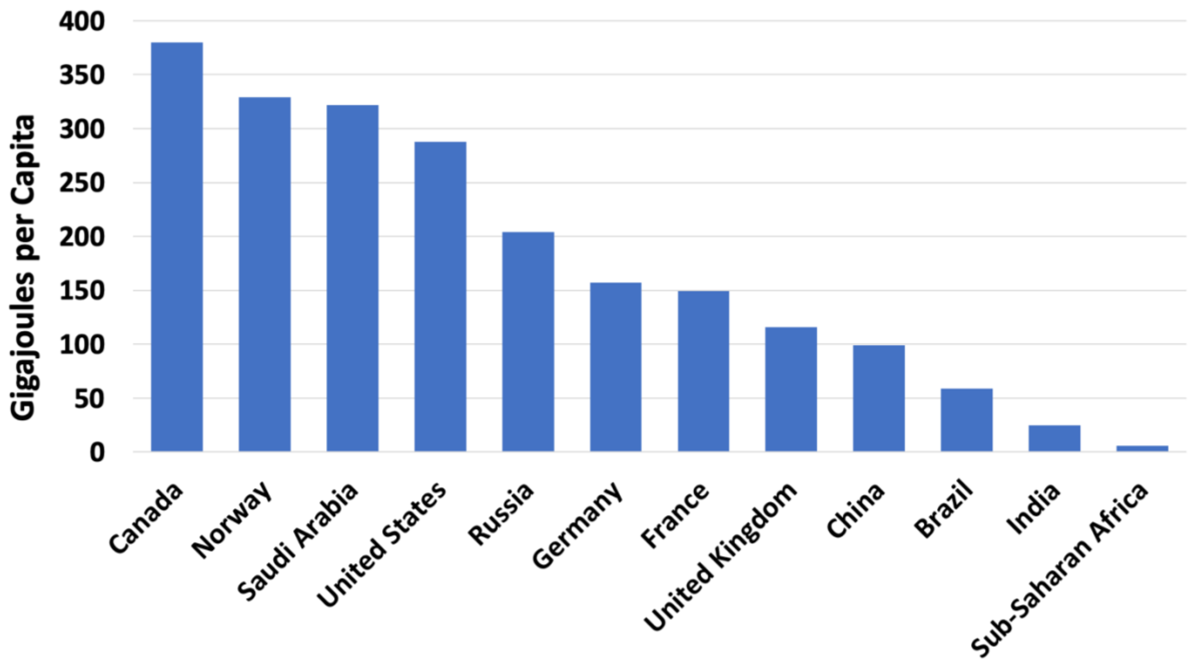
The global disparity in energy consumption is illustrated in Figure 4, which shows annual energy consumption per capita in various countries. The average American consumes more than twice as much energy as the average European, three times as much as the average Chinese, and over 10 times as much as the average Indian. And compared to the average person in Sub-Saharan Africa, Americans consume about 50 times as much energy.

A 2020 paper finds that the world's lowest-income 50% consume less than 20% of all energy, while the richest 10% consume nearly 40% of the world's energy. The authors note that:

[14] IEA *et al*., 2020.
[15] World Bank, World Development Indicators database.
[16] Poushter, 2015.

> Energy provision is considered a fundamental and integral development challenge. A minimum level of energy consumption is required to enable decent well-being. Our results demonstrate that energy consumption is far from equitable and varies to extreme degrees across countries and income groups. … Many people suffer from energy deprivation and quite a few are consuming far too much.[17]

Figure 4. *Annual Energy Consumption per Capita in Select Countries/Regions, 2019*



Source: BP Statistical Review of World Energy 2020.

Most economic studies find that access to energy is an important factor explaining long-term economic growth.[18] Thus reducing disparities in access to energy is critical to reducing global economic inequality. The world cannot meet its first two energy challenges – transitioning to renewables and demand-side energy management – by limiting the development aspirations of the world's poorest. But developing countries cannot take the same energy path that the developed countries took, which has been heavily dependent on fossil fuels. International cooperation between rich and poor countries will be required to ensure that developing countries can utilize their energy resources in a sustainable manner.

In summary, the world's four major energy challenges are:

1. The transition away from fossil fuels toward renewable energy sources needs to be accelerated if the world is to avoid unacceptable climate change.

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[17] Oswald *et al*., 2020.
[18] See, for example, Ouedraogo, 2013.

2. Expanding the world's reliance on renewable energy will require the electrification of most of the world's energy system.
3. This transition needs to be accompanied by efforts to restrain the growth in energy demand, mainly in developed countries.
4. Progress toward the other goals must coincide with a reduction in global energy inequality, ensuring that developing countries have access to the clean energy that is needed to increase their well-being. Accordingly, the United Nation's Sustainable Development Goal #7 is to "Ensure access to affordable, reliable, sustainable, and modern energy for all."

While these challenges are significant, as we proceed through the module we will see there are reasons for optimism. In the next section we will discuss nonrenewable energy sources – fossil fuels and nuclear energy. Then we will discuss renewable energy sources, including wind, solar, and hydroelectric energy. In the final two sections we will focus on energy economics and policies to address the world's energy challenges.

2. NONRENEWABLE ENERGY

Nonrenewable energy sources are those that do not regenerate through natural processes, at least on a human time scale. We consider four nonrenewable energy sources in this section:

1. Oil
2. Coal
3. Natural gas
4. Nuclear energy

The first three energy sources are fossil fuels, formed from the fossilized remains of plants and animals that lived millions of years ago. As these energy sources are nonrenewable, one issue to consider is the availability of supplies. Is running out of any of these sources a significant concern? We also need to consider the environmental impacts of relying on these sources. Average prices, along with the volatility of prices, is another important factor to consider when evaluating different energy sources.

nonrenewable energy sources energy sources that do not regenerate through natural processes, at least on a human time scale, such as oil and coal.

2.1 Oil

Oil is a broad term including all liquid petroleum products such as gasoline, diesel fuel, aviation fuel, and motor oils. Oil is predominately used for transportation – currently about 95% of the world's energy for transportation comes from oil.[19] As an energy source for transportation, oil offers the advantages of being easier to store than other fossil fuels and having a relatively high

[19] BP, 2020a.

energy density (i.e., a high energy to weight ratio). In our evaluation of oil we consider three main issues: oil supplies, oil prices, and environmental impacts.

From the mid-20th century until recently, many oil analysts expressed concern over limited oil supplies. Like other fossil fuels, oil is ultimately a nonrenewable resource that is available in a fixed global quantity. The idea of "peak oil" production states that global oil production will eventually peak and then decline as supplies are depleted. Along with rising demand, declining oil production would lead to rapidly rising oil prices, along with broader negative economic and social impacts such as economic recessions and conflicts over limited oil supplies.

While the global quantity of oil is ultimately limited, new discoveries and technologies can expand the known reserves. Current proven oil reserves are actually 2.5 times larger now than they were in 1980, even as global oil demand has steadily increased. Proven reserves could meet global demands for nearly 50 years at current consumption rates, and new discoveries continue to be made.[20]

Given that oil supplies do not appear to be a limitation on production for the foreseeable future, the focus in oil markets has shifted from the supply side to the demand side. As transportation becomes less reliant on oil and more reliant on electricity and other energy sources, oil market experts are now asking when peak oil demand, rather than peak oil production, will occur. For example, the 2020 World Oil Outlook, published by the Organization of the Petroleum Exporting Countries (OPEC), predicts that global demand for oil will peak sometime in the late 2030s.[21] But the most stunning prediction is that peak oil demand may have already occurred! The COVID-19 pandemic reduced global oil demand in 2020 by about 9%, and the oil company BP (British Petroleum) has predicted that oil demand may never recover to its 2019 peak. As one 2020 energy analysis indicates:

> Until the pandemic none of the major oil forecasters had seen an imminent demand peak. … Most analysts had only predicted declining demand for oil in improbably green scenarios that could only be achieved with far stronger global climate policies. … Like any forecast, only time will tell if peak oil demand happened already or won't come until 2040. That inescapable uncertainty is less important than the newfound agreement that a turning point is here.[22]

One of the other reasons for oil's historical dominance in the transportation sector is that it is normally quite affordable. But the price of oil is also highly volatile, as shown in Figure 5. We see that after adjusting for inflation oil prices were particularly high in the late 1970s and early 1980s, and again in the late 2000s and early 2010s. More the price of oil is more difficult to forecast than any other energy source, as the price depends not only on economic conditions but also on political factors such as conflicts in the Middle East.

Significant uncertainty about future oil prices complicates long-term investment decisions between energy sources. Consider, for example, a delivery business trying to decide whether

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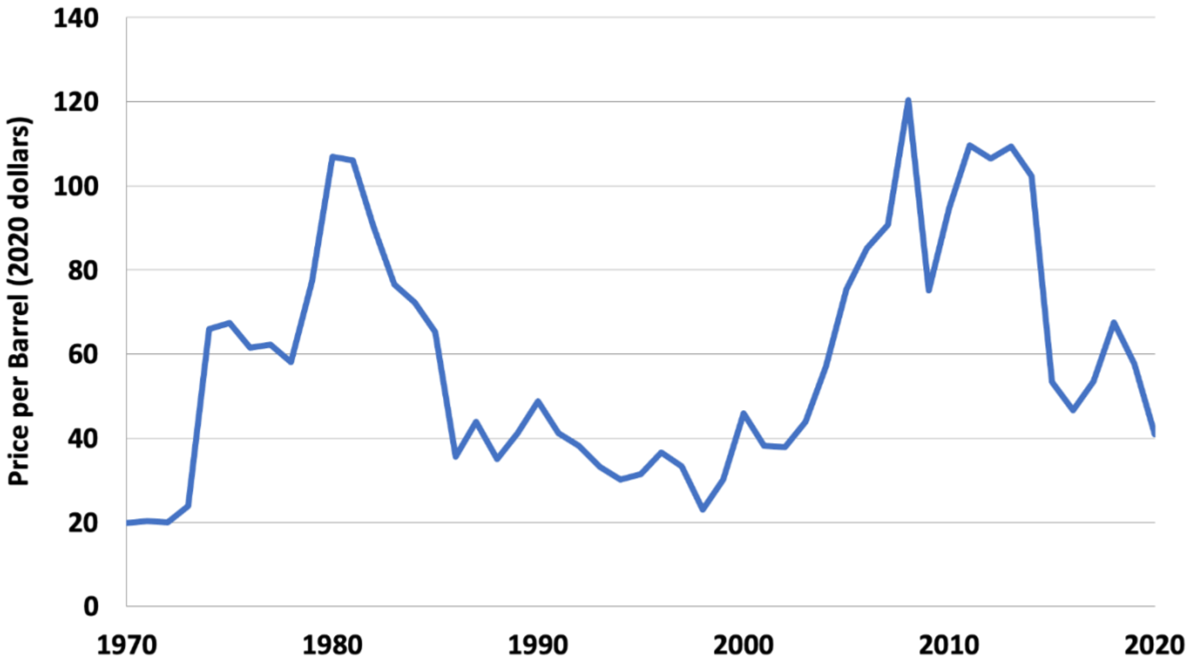
[20] BP, 2020b.
[21] OPEC, 2020.
[22] Randall and Warren, 2020.

to purchase a fleet of delivery vehicles that operate on gasoline or electricity from renewable energy. The business may reasonably assume the price of renewable energy will decline in the future, but will not be able to predict the future price of oil with any certainty. Thus even if the current price of oil is slightly higher than the price of renewable energy, a business may favor renewables as future costs will be known with more certainty.

Figure 5. *Crude Oil Prices in Constant Dollars, 1970-2020*



Sources: U.S. Energy Information Administration, Crude Oil Spot Prices; U.S. Bureau of Labor Statistics, Historical Consumer Price Index for All Urban Consumers

All fossil fuels are carbon-based, meaning they emit carbon dioxide (the main greenhouse gas) when burned. Using fossil fuels generates local air pollutants including nitrogen oxides, particular matter, and sulfur oxides. The environmental impacts of fossil fuels also include habitat destruction and water pollution from mining and the damage from accidental spills.

Table 1 compares the human health impacts and greenhouse gas emissions of various energy sources per unit of energy generated. We see that coal is the most environmentally destructive energy source. Oil is the second most-damaging energy source per unit of energy, both in terms of human deaths and greenhouse gas emissions. Oil is responsible for about 34% of the world's carbon emissions.[23] While large oil spills receive a great deal of media attention, the majority of oil that is released into coastal and marine environments comes from runoff that washes oil from roads and parking lots and leakage from ships other than oil tankers.[24]

[23] Our World in Data, CO_2 Emissions by Fuel, https://ourworldindata.org/emissions-by-fuel.
[24] Global Marine Oil Pollution Information Gateway, http://oils.gpa.unep.org/facts/sources.htm.

2.2 Coal

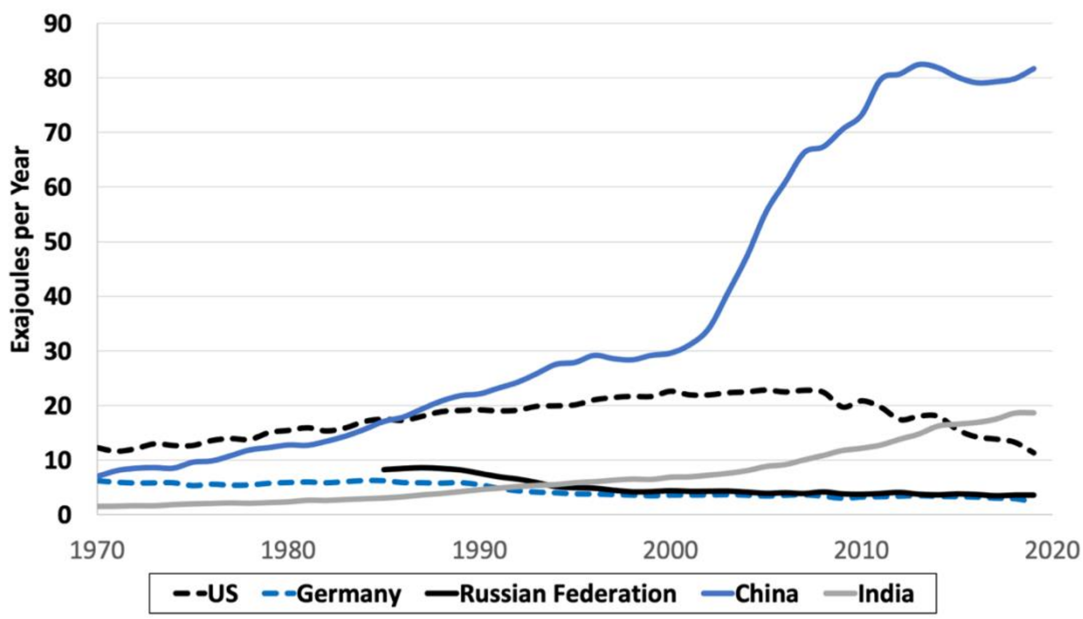
Coal is the world's second-largest source of energy, behind only oil. Coal is primarily used to generate electricity – it provides over one-third of the world's electricity, more than any other source. China is by far the world's largest consumer of coal, with 52% of global demand in 2019. China's rapid expansion of coal consumption, particularly after 2000, is shown in Figure 6. While the United States was the world's largest coal consumer up to 1985, it has since fallen to third after being overtaken by China and then India in 2015. Russia and Germany rank fourth and fifth in coal consumption, with demand less than one-third of the U.S.

Table 1. *Human Health Impacts and Greenhouse Gas Emissions of Various Energy Sources, per Unit of Energy*

Energy Source	Human Deaths from Accidents and Air Pollution per Terawatt of Energy	Greenhouse Gas Emissions per Gigawatt of Energy (Tons)
Coal	24.6	820
Oil	18.4	720
Natural Gas	2.8	490
Biomass	4.6	78-230
Nuclear	0.07	3
Hydropower	0.02	34
Wind	0.04	4
Solar	0.02	5

Source: Ritchie, 2020.

Figure 6. *Coal Consumption, Top Five Coal Consuming Countries, 1970-2019*



Source: BP, 2020b.

Although coal is a nonrenewable resource, the world's coal reserves are extensive. Coal is the most abundant fossil fuel, with known reserves sufficient to meet current global demand for more than 130 years.[25] As shown in Table 1, it also the most environmentally destructive energy source. Even though the world obtains more energy from oil than coal, coal is responsible for 18% more CO_2 emissions than oil.[26] Coal is also the main source of local air pollutants such as sulfur dioxide and nitrogen oxides. The World Health Organization estimates that local outdoor air pollution kills over 4 million people per year, mainly from burning coal, with over 90% of these deaths in middle- and low-income countries.[27] Coal pollution is also a significant source of premature mortality in developed countries. Each year burning coal kills an estimated 15,000 people in the United States, and is responsible for over 10% of the country's health care costs.[28]

Prior to the COVID-19 pandemic, global demand for coal was anticipated to peak sometime before 2030. But as a result of the pandemic, global coal demand fell by about 7% in 2020.[29] Like oil, global demand for coal may never recover to pre-pandemic levels as the world transitions toward more reliance on renewables. Projections revised in the wake of the pandemic by the International Energy Agency show that global coal demand will recover slightly in the short-term as economic activity increases (but not to its 2019 peak), and then gradually decline.[30] Forecasts developed by BP show global coal demand falling more rapidly – by 25% in 2050 under a business-as-usual scenario but by 85-90% in a more aggressive policy scenario.[31]

2.3 Natural Gas

Natural gas is frequently touted as a "transitional" or "bridge" fuel as societies move away from coal and oil but are not able to expand renewable energy rapidly enough due to technical or financial reasons. Natural gas's main advantage over other fossil fuels is that it is generally less environmentally damaging, as we saw in Table 1. Natural gas is more flexible than other fossil fuels. It can be burned directly to power vehicles, heat buildings, and operate industrial machinery. It can generate electricity more efficiently than coal, and generally at lower cost per unit of energy.

The displacement of coal by natural gas has been facilitated by new natural gas extraction technologies, specifically improvements in hydraulic fracturing (or "fracking"). Fracking involves injecting water and chemicals deep underground to fracture surrounding rock, releasing pockets of natural gas, and potentially oil as well, that are then pumped to the surface. While fracking has been used to a limited extent for several decades, it became much more common in several countries starting in the 2000s and 2010s. In 2000 only about 10% of the natural gas produced in the U.S. came from fracking, but by 2015 that share rose to two-thirds.[32]

25 Ibid.
26 Our World in Data, CO_2 Emissions by Fuel, https://ourworldindata.org/emissions-by-fuel.
27 WHO, 2018.
28 Conca, 2017.
29 IEA, https://www.iea.org/news/a-rebound-in-global-coal-demand-in-2021-is-set-to-be-short-lived-but-no-immediate-decline-in-sight.
30 IEA, 2020a.
31 BP, 2020a.
32 U.S. EIA, 2015.

Despite (or perhaps because of) this rapid expansion, fracking is a controversial technology, and some countries have banned the practice (see Box 2).

BOX 2. TAINTED WATER AND EARTHQUAKES LINKED TO HYDRAULIC FRACTURING FOR NATURAL GAS

Fracking can contaminate drinking water supplies in several ways. The chemicals injected during fracking or the natural gas extracted can leak through the well casing, normally constructed out of steel or cement, into groundwater aquifers. Fracking wastes are temporarily stored in above ground ponds, with toxic chemicals that can leach into drinking water supplies. Final disposal of fracking wastes is commonly done by deep well injections, presenting another opportunity for water contamination. A comprehensive 2016 report on fracking by the U.S. EPA concluded that it "can impact drinking water resources under some circumstances."[33] Regulation of fracking in the United States is largely left to the individual states, with different requirements regarding disclosure, containment, and monitoring.

Another concern with fracking is that disposal of the wastes in deep wells increases pressure on underground rock structures, leading to an increase in earthquakes. Fracking activities have been linked to a 900-fold increase in earthquakes in Oklahoma starting in 2008. Four of the state's five largest recorded earthquakes have occurred since then. As a result of stricter fracking regulations, the number of earthquakes in Oklahoma have fallen by about 90% from a peak in 2015.[34]

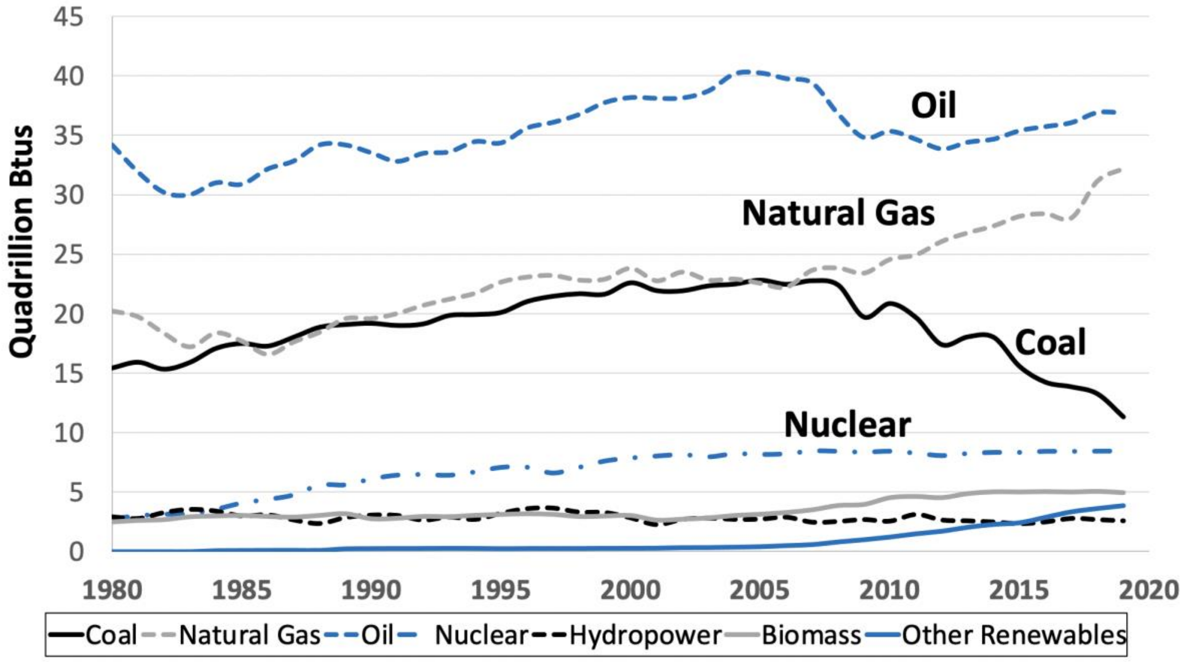
Some energy analysts assert that fracking for natural gas is an important tool in reducing carbon emissions (as compared to using coal) and can be done safely with better regulations.[35] For example, stricter requirements for the lining of wastewater ponds can reduce leakage into water supplies. Stronger standards for well casing construction can also reduce leaks. Other analysts conclude that the risks of fracking outweigh any benefits, and that the practice should be banned. Both Vermont and New York have banned fracking, along with four of Canada's 10 provinces. Countries that have banned fracking include Germany, France, and the United Kingdom.[36]

The switch away from coal toward natural gas in the United States is shown in Figure 7. Up to about 2005 both coal and natural gas provided about one-quarter of the U.S.'s energy supply. But as improvements in fracking technology reduced the cost of natural gas extraction, a rapid increase in natural gas consumption coincided with a reduction in coal consumption. As the total energy obtained from coal and natural gas has changed little since 2005, it is accurate to say that natural gas has been directly displacing coal in the U.S. According to the International Energy Agency, switching electricity generation from coal to natural gas reduces greenhouse gas emissions by 50% on average.[37] The displacement of coal by natural gas in the U.S. is

[33] U.S. EPA, 2016.
[34] Kuchment, 2019.
[35] See, for example, Gold, 2014.
[36] https://en.wikipedia.org/wiki/Hydraulic_fracturing_by_country.
[37] IEA, 2019.

largely responsible for the country's 14% decrease in greenhouse gas emissions from 2005 to 2019.

Figure 7. *Energy Consumption in the United States, by Source, 1980-2019*



Source: U.S. EIA, 2020b.

The environmental benefits of natural gas relative to other fossil fuels, however, are not always unambiguous. Natural gas is primarily composed of methane, which is a greenhouse gas that causes about 25 times the warming effect of an equivalent amount of CO_2. When burned, methane is converted into CO_2, but methane can be directly released to the atmosphere during natural gas extraction and transportation by leaking production facilities and pipelines. Recent analyses indicate that methane leakage rates are higher than previously estimated. A 2019 journal article found that methane emissions from major cities along the East Coast of the U.S., which rely upon natural gas for heating and electricity, are more than twice the levels reported by the U.S. Environmental Protection Agency.[38] Methane monitoring by satellites has recently revealed several large pipeline leaks, including along the Yamal pipeline that supplies natural gas to Europe from Siberia, and from facilities in Northern Africa. A leak identified in Turkmenistan in 2019 is the largest on record, releasing greenhouse gases equivalent to one million cars.[39]

The other concern with switching to natural gas as a transitional energy source is that it postpones the adoption of renewable energy. Though natural gas is generally "greener" than coal or oil, it is clearly more environmentally damaging than renewables (see Table 1). As a 2020 paper explains:

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[38] Plant *et al*., 2019.
[39] Nasralla, 2020.

> Although natural gas might help the energy transition by reducing emissions compared to coal, there are other long-term implications of investing in natural gas which can work against reaching climate goals. One concern is that investments in natural gas might crowd out investments in renewable alternatives. … Our research warns that natural gas' negative delayed and global effects can easily outweigh the positive immediate and local effects unless precautions are taken.[40]

Further, natural gas's role as a transitional fuel rests on the assumption that it should be used until renewable energy technologies develop to the point where they can be widely deployed and cost competitive. As will see shortly, renewable energy technologies have progressed much faster than anticipated, leading to dramatic price reductions. The role of natural gas as a transitional fuel thus appears unnecessary, as a direct transition from all fossil fuels to renewable energy becomes more feasible.

2.4 Nuclear Energy

The final nonrenewable energy source we consider is nuclear energy. Nuclear is a nonrenewable energy source as its fuel, normally plutonium or uranium, is a nonrenewable mineral. In the 1950s nuclear power was promoted as a safe, clean, and cheap source of energy. Proponents of nuclear power stated that it would be "too cheap to meter" and predicted that nuclear power would provide about one-quarter of the world's commercial energy and most of the world's electricity by 2000.[41]

Currently, nuclear power provides only about 4.9 percent of the world's primary energy consumption and about 10 percent of the world's electricity. Most of the world's installed nuclear power capacity predates 1990. The decommissioning of older plants, which had an expected lifespan of 30 to 40 years, has already begun. Recently, however, some people have called for a "nuclear renaissance," mainly because carbon emissions from the nuclear power life cycle are much lower than with fossil fuels (see Table 1).

The catastrophic 2011 Fukushima accident in Japan caused many countries to reconsider their nuclear power plans. Japan is currently re-evaluating its use of nuclear power, with most of its reactors sitting idle. Germany has decided to phase out the use of nuclear power entirely by 2022. In Italy, the debate over nuclear power was put to voters, with 94 percent rejecting plans for an expansion of nuclear power. But other countries are moving ahead with plans to expand their use of nuclear power, particularly China. Currently 11 nuclear plants are under construction in China. Other countries currently expanding use of nuclear power are India, Russia, and South Korea.

The role of nuclear power in the future global energy mix thus remains uncertain. The Fukushima accident has lowered baseline projections of future energy supplies from nuclear power. While some see the accident as evidence that we need to focus more on renewables like wind and solar, others worry that a decline in nuclear power will make it more difficult to meet

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[40] Gürsan and Gooyert, 2020, p. 1.
[41] Miller, 1998.

climate targets. Despite the initial promise of affordable nuclear energy, the cost of building and operating nuclear power plants has generally increased, while the cost of renewable energy has declined. Ultimately, economic factors, rather than safety concerns, may present the main barrier to a nuclear renaissance. As a 2018 MIT report explains:

> we contend that, as of today and for decades to come, the main value of nuclear energy lies in its potential contribution to decarbonizing the power sector. Further, we conclude that cost is the main barrier to realizing this value. Without cost reductions, nuclear energy will not play a significant role.[42]

3. RENEWABLE ENERGY SOURCES

Renewable energy sources are those that are supplied by nature on a continual basis. They are clearly less environmentally damaging than fossil fuels, both in terms of air and water pollution and greenhouse gas emissions (see Table 1). That doesn't mean renewable energy isn't without negative environmental impacts, including damage to river habitats from hydroelectric dams, bird deaths from wind turbines, and land degradation from mining minerals for solar panels.[43]

renewable energy sources energy sources that are supplied on a continual basis, such as wind, solar, water, and biomass energy

In one sense, renewable energy is unlimited, as supplies are continually replenished through natural processes. The total amount of energy embodied in renewable sources is also extremely abundant. The world's current electricity demands could be entirely met by installing wind turbines on an area smaller than Spain.[44] Even more impressive, enough solar energy reaches the earth in a single day to power the planet for an entire year![45] But solar energy and other renewable energy sources are limited in the sense that their availability varies geographically and across time. Some regions of the world are particularly well suited to wind or solar energy. For example, solar energy potential is highest in areas such as the southwestern United States and northern Africa. Geothermal energy, energy from the heat of the earth, is abundant in countries such as Iceland and the Philippines.

A further limitation with renewable energy is that its embodied energy is much less concentrated than for fossil fuels. Consider that the energy density, or the amount of energy stored within a given weight, of gasoline is about 100 times higher than the energy density of the electricity stored in a lithium-ion battery in an electric car.[46] Renewable energy sources are also intermittent – the wind isn't always blowing and the sun isn't always shining. This suggests that either renewable energy needs to be supplemented with another source, such as natural gas, in order to provide a continuous supply of energy, or that renewable energy needs

[42] Buongiorno *et al*., 2018.
[43] See, for example, UCS, 2013a.
[44] Garfield, 2016.
[45] Chandler, 2011.
[46] Schlachter, 2012.

to be stored in batteries to make up for the times when the energy flow isn't sufficient to meet demand.

Perhaps renewable energy's main historical weakness compared to fossil fuels has been price. For example, in 2009 the cost of electricity from solar panels was about three times higher than for coal.[47] But the price of renewable energy has been declining dramatically, making comparisons that are even a few years old obsolete. Rather than being uncompetitive in price, renewable energy is increasingly achieving a price advantage over fossil fuels that will make an energy transition inevitable. Other limitations of renewable energy are also being addressed with improvements in technology, such as higher energy density in batteries and wind turbine designs that reduce the threat to birds.

We now consider various renewable energy sources, focusing on wind and solar power. We will discuss each source's advantages and disadvantages, along with relevant trends.

3.1 Wind Energy

For hundreds of years humans have harnessed wind energy to perform tasks such as pumping water and grinding grain. Modern wind turbines, some more than 500 feet tall, generate electricity by spinning a geared generator. Wind energy currently provides about 1% of the world's energy total supply, and about 5% of its electricity.

Wind energy can be harnessed from onshore and offshore turbines. Onshore wind energy is generally cheaper. Onshore turbines are easier to access for maintenance and repairs, and less subject to damage from severe storms and salt water. On the other hand, winds tend to be stronger and more consistent offshore. As some people consider onshore wind turbines unsightly, offshore turbines may be more aesthetically acceptable, especially if they are located far offshore. Offshore wind turbines are less likely to harm bird populations, although the number of birds killed by onshore wind turbines is rather low. According to a 2015 journal article, collisions with vehicles kill 350 times as many birds as wind turbines. Domestic cats are the largest source of bird mortality, killing over 4,000 times as many as wind turbines.[48]

As mentioned above, wind energy is more abundant in certain regions of the world, such as the central United States, northern Europe, Russia, and southern South America.[49] China has the most installed wind energy, with 36% of the world's capacity. Other top wind energy countries include the United States (16%), Germany (9%), and India (6%).[50]

As wind energy technologies have improved costs have declined and installed capacity has increased, as shown in Figure 8. From 2000 to 2019 the global capacity of wind energy has increased by a factor of 36. During the same period, the cost of generating electricity from wind has declined by 63%.

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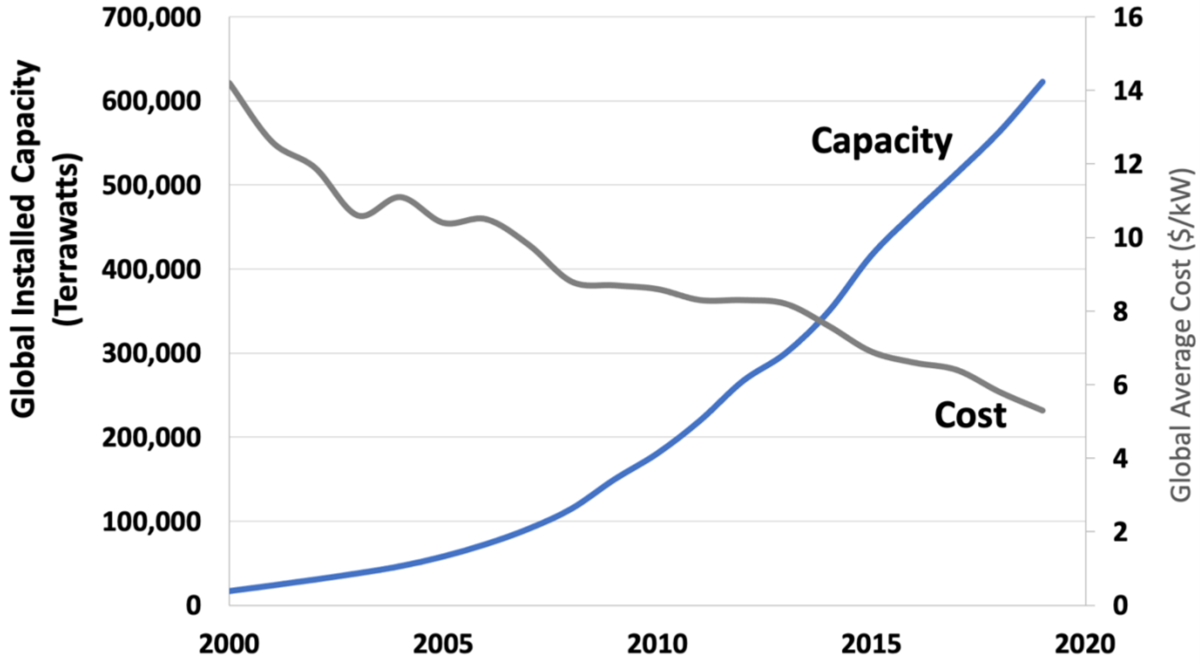
[47] Lazard, 2018.
[48] Loss *et al.*, 2015.
[49] Lu *et al.*, 2009.
[50] https://en.wikipedia.org/wiki/Wind_power_by_country.

Figure 8. *Global Wind Energy Installed Capacity and Average Cost, 2000-2019*



Sources: Capacity data from BP, 2020b. Cost data from IRENA, 2019b.

Although wind energy currently produces a relatively small share of the world's energy, it is the fastest-growing energy source in many countries, including the United States.[51] Considering only the new energy capacity installed globally in 2019, about 25% was wind energy.[52] This suggests that the share of energy obtained from wind will continue to increase, as we will discuss further later in the module.

3.2 Solar Energy

While there are several ways to convert solar energy into electricity, **photovoltaic (PV) cells** (i.e., solar panels) are the most common. PV cells transfer solar energy to electrons, creating an electrical current. Solar energy currently provides only 0.5% of the world's total energy and 3% of the world's electricity.

photovoltaic (PV) cells devices that directly converts solar energy into electricity (i.e., solar panels)

Solar panels, like wind turbines, are often arrayed in large "farms". But unlike wind turbines, solar panels can also be employed at smaller scales, such as on household roofs. In general,

[51] EIA, 2019b.
[52] Bloomberg NEF, 2020.

larger "utility-scale" solar energy is more efficient and less costly than residential-scale solar. But household solar has become increasingly popular, appealing to many people as a way of avoiding dependence on grid electricity. Smaller-scale solar projects can also reach areas not connected to modern energy infrastructure.

The potential for solar energy tends to be greatest in equatorial and arid regions, including the Middle East, most of Africa, Australia, and desert regions in the United States and Central America. China is the world's leader in solar power, with about one-third of the world's capacity. Other leading solar countries include the United States (12%), Japan (10%), Germany (8%), and India (7%).[53]

Solar energy is a particularly appealing option for addressing energy needs in developing countries. Low-income countries tend to have relatively abundant solar resources. A 2020 report by the World Bank found that many of the world's poorest countries are also those with the highest solar potential, including Namibia, Lesotho, Afghanistan, and Sudan.[54] Solar panels can be installed in remote rural areas not connected to existing energy infrastructure such as power lines and gas pipelines. As a 2018 paper explains:

> [For developing] countries, particularly the poorest ones, modern energy is necessary to stimulate production, income generation and social development plus reduce the serious health issues that are caused by the use of fuelwood, charcoal, animal dung and agricultural waste. Solar energy is the best answer to energy poverty and it can provide excellent opportunities for reduction of GHG emissions and indoor air pollution through substituting kerosene for lighting and firewood for cooking. Solar photovoltaic (PV) can be an appropriate technology for a source of renewable electricity in developing nations especially in remote rural areas where grid extensions are financially or technically not viable.[55]

The World Bank's Lighting Africa has provided energy to 32 million people by 2020, primarily through the development of solar powered "mini-grids" connecting several homes. Households then pay for the electricity they use at subsidized rates.[56] China has made large investments to provide solar power to low-income rural areas of the country. Their Solar Energy for Poverty Alleviation Program (SEPAP) seeks to provide solar power to about 35,000 remote villages. A 2020 journal article finds that the SEPAP program has a positive and significant effect on income levels in the years after solar panels are installed in a village. The potential for solar power to alleviate poverty under the SEPAP program is the largest in the poorest regions.[57]

Particularly when compared to fossil fuel energy, the environmental impacts of solar energy are minimal. The main environmental impacts of solar power include the land used to install PV panels and the impacts of producing the panels. Unlike wind power, where land can be used simultaneously for energy and agricultural production, land used for large-scale solar farms

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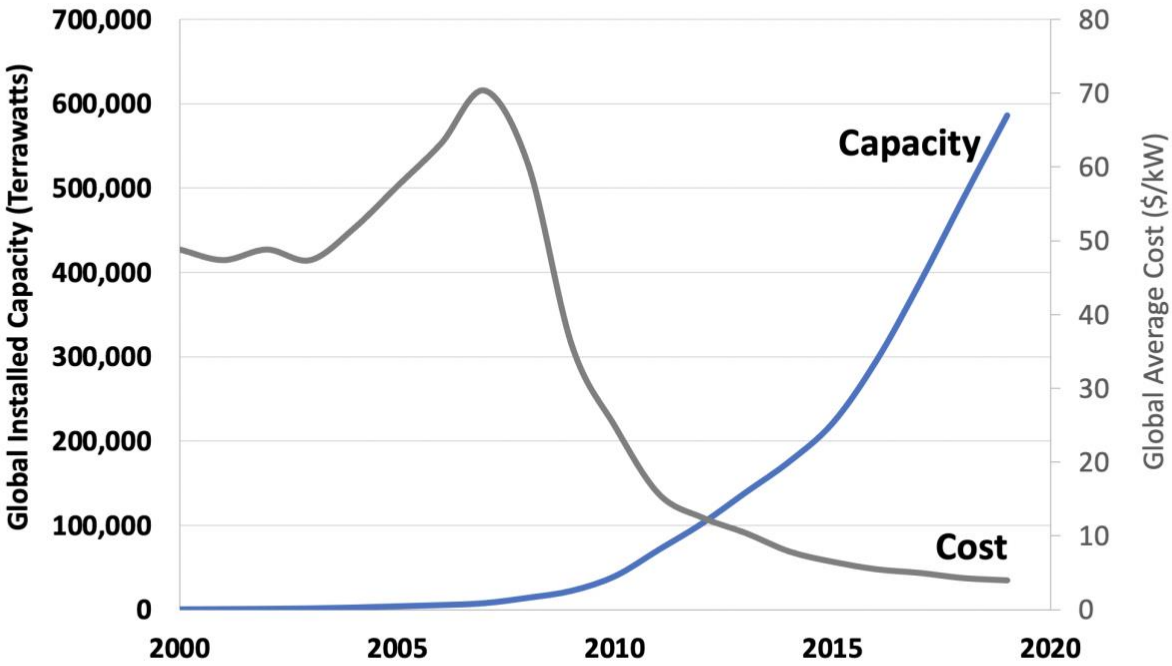
[53] https://en.wikipedia.org/wiki/Solar_power_by_country.
[54] World Bank, 2020a.
[55] Shahsavari and Akbari, 2018, p. 275.
[56] World Bank, 2020b.
[57] Zhang *et al*., 2020.

generally cannot be used for agricultural purposes. PV panels are largely constructed of silicon, a mineral that can harm mining workers when breathed in small particles. Large-scale mining of silicon can also decrease biodiversity and create air and water pollution. Toxic materials such as hydrochloric acid are used in the production of PV panels. Proper environmental regulation can mitigate these impacts.

No other energy source has seen such dramatic changes in prices and installed capacity in the past decade as solar. As PV technology rapidly improves, the cost of solar energy has plummeted. As shown in Figure 9, the cost of solar energy has decreased by more than 90% since the late 2000s (the increase in solar energy costs in the mid-2000s was due to a temporary shortage of silicon). Solar energy is world's fastest-growing energy source, with global capacity up by a factor of 900 from 2000 to 2010.

Figure 9. *Global Solar Energy Installed Capacity and Average Cost, 2000-2019*



Sources: Capacity data from BP, 2020b. Cost data from Lazard, 2020 and Shahan, 2014.

As recently as 10 years ago solar energy was widely considered a niche product that was heavily dependent on subsidies. Now, with costs rapidly declining, solar energy is poised to dominate energy markets in the coming decades. Nearly half (45%) of all new energy installed globally in 2019 was solar.[58] And while the expansion of solar energy is a critical tool in addressing climate change and air pollution, the primary driver of solar energy's growth is cost.

[58] Bloomberg NEF, 2020.

As we will see in Section 4 solar energy has now become, on average, the world's cheapest energy source.

3.3 Other Renewable Energy Sources

Other sources of renewable energy include hydroelectricity, biomass, and geothermal. **Hydroelectricity (or hydropower)** involves using the energy from moving water to spin an electric turbine. Most commonly turbines are installed inside a dam that creates a reservoir of water behind it. The passage of water through the dam and turbines is regulated, producing a relatively reliable, constant supply of electricity. Hydropower currently provides about 3% of the world's energy.

hydroelectricity (or hydropower) using the energy from moving water to spin an electric turbine and generate electricity

Hydropower offers a number of advantages. First, it doesn't create local air pollution or direct carbon emissions. While building a hydroelectric dam entails a significant capital investment, its low operating costs make hydropower one of the lowest-cost energy sources on a lifecycle basis. Hydropower doesn't suffer from the intermittency problems of wind and solar energy; hydroelectric dams operate continuously. Dams reduce flooding and can provide a reliable supply of water for irrigation and municipal needs. Finally, reservoirs can provide recreation benefits such as boating and swimming.

Despite these benefits, the amount of energy generated globally from hydropower is not expected to grow significantly in the future due to its drawbacks. Hydropower dams block the natural flow of rivers, which degrades aquatic habitats. Migrating fish species such as salmon are particularly affected as dams block their movement upstream to spawn. Dams also block the downstream flow of sediment, which builds up behind dams. This not only impacts aquatic species, it also reduces the storage capacity of the reservoir and can affect the operation of turbines. Finally, many of the best locations for hydropower dams have already been developed, especially in the United States and Europe. Besides large dams, other types of hydropower are available with lower environmental impacts, including "run of river" installations that store little to no water in reservoirs and wave and tidal plants in coastal areas. While these technologies appear worthwhile in certain locations, they are not expected to provide a significant share of the world's future energy.

Biomass energy is a broad term referring to the burning of plant or animal material to generate heat or electricity. It includes burning wood or animal dung for cooking, using ethanol made from corn to power a vehicle, and burning agricultural wastes to generate electricity. Biomass currently provides about 9% of the world's energy.

biomass energy generating heat or electricity from burning plant or animal material

Biomass energy is a renewable resource with some advantages but also some significant disadvantages. Many low-income households in developing countries, without affordable access to electricity or fossil fuels, rely on biomass for cooking and heating. Some materials used for biomass energy, such as crop residues and animal dung, can be considered waste materials and thus a "free" energy source. Biomass energy can also allow a country to reduce its dependence on imported energy.

Biomass energy is sometimes touted as being carbon neutral. For example, the CO_2 emissions from a wood-burning electricity plant can in theory be offset by planting new trees that will eventually absorb a similar quantity of CO_2. But numerous scientific papers have found that increasing our reliance on biomass energy will result in a significant net increase in carbon emissions.[59] One problem is that there is no assurance that enough new biomass will be created to fully offset current carbon emissions. A second problem is timing – even if current carbon emissions are fully offset by future biomass absorption, in the interim that atmospheric carbon will contribute to climate change. When standing forests are cut, the resulting surge in carbon emissions will last for fifty years or longer, even if the forest eventually regrows.

Burning biomass also emits local air pollutants such as carbon monoxide, nitrogen oxides, and particulate matter. This is particularly unhealthy when biomass is burned indoors without adequate ventilation. The World Health Organization estimates that 1.6 million people die each year in developing countries from indoor burning of biomass, with over half of these deaths being children.[60]

Finally, **geothermal energy** is energy from the subsurface heat of the earth. In some locations, this heat reaches the surface as hot water or steam. In other locations, wells can be drilled to tap into geothermal reservoirs. Geothermal energy can be used directly to heat water and buildings, or used to generate electricity, normally by using steam to power an electric turbine. Geothermal energy currently provides less than 1% of the world's energy.

geothermal energy energy from the subsurface heat of the earth.

The main limitation of geothermal energy is that it is cost-effective only in certain regions of the world. One country with extensive geothermal resources is Iceland, which relies on it for about half of its total energy supply, including almost all its heating needs. While the world's geothermal resources are mostly untapped, further development of geothermal is normally not the lowest-cost or least environmentally-damaging energy source. Per unit of energy generated, geothermal energy tends to emit more carbon than solar or wind energy.[61] Tapping into geothermal reservoirs can also release air pollutants such as hydrogen sulfide and ammonia. Another concern with developing geothermal sites is that it may increase the risk of earthquakes.[62]

[59] Catanoso, 2020.
[60] WHO, Indoor Air Pollution and Household Fuels, https://www.who.int/heli/risks/indoorair/en/#:~:text=Indoor%20air%20pollution%20generated%20largely,under%20five%20years%20of%20age.
[61] Li, 2013.
[62] UCS, 2013b.

4. ENERGY ECONOMICS: CURRENT ANALYSES AND ALTERNATIVE FUTURES

The main reason that fossil fuels currently provide over 80% of the world's energy is that they have historically been cheaper than other energy sources. But the economics of energy is changing rapidly – more rapidly than most energy experts have predicted. Energy cost comparisons from just a few years ago, which showed that fossil fuels had a clear cost advantage over renewables, are now obsolete. Various economic analyses in 2020 reached the stunning conclusion that "the era of cheap wind and solar has arrived."[63]

4.1 Cost Comparisons of Energy Sources

Comparing the costs of different energy sources is not straightforward. Capital costs vary significantly—a new nuclear power plant can cost $5 billion to $8 billion. Some energy sources require continual fuel inputs, while other sources, such as wind and solar, only require occasional maintenance. We also need to account for the different lifespans of various equipment and plants.

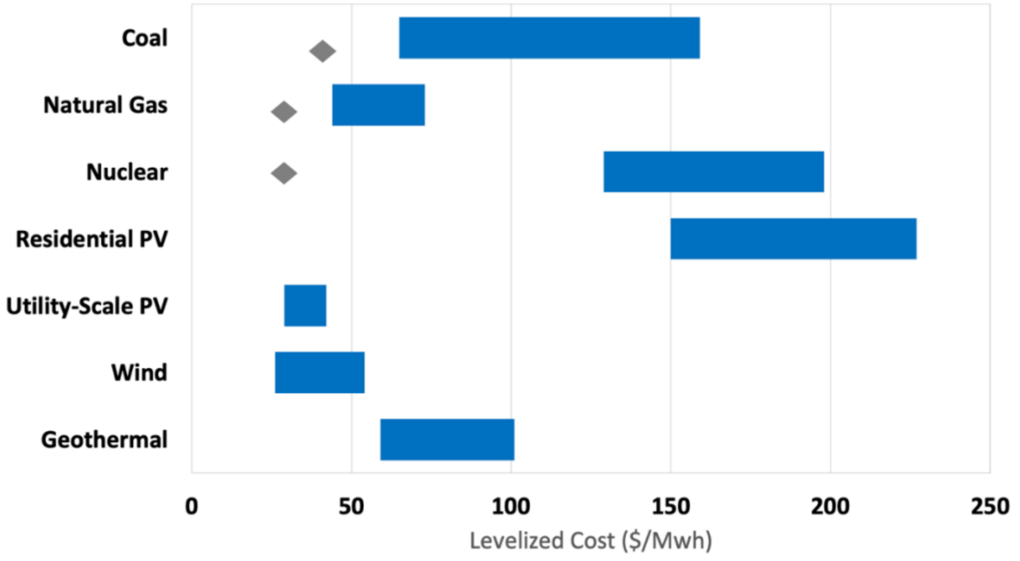
Cost comparisons between different energy sources are made by calculating the **levelized cost** of obtaining energy. Levelized costs include the present value of building and operating a plant over an assumed lifetime, expressed in real terms to remove the effect of inflation. For energy sources that require fuel, assumptions are made about future fuel costs. The levelized construction and operations costs are then divided by the total energy obtained to allow direct comparisons across different energy sources.

levelized costs the per-unit cost of energy production, accounting for all fixed and variable costs over a power source's lifetime.

Figure 10 presents a 2020 comparison of the levelized costs using various energy sources to generate electricity, without any subsidies. The horizontal bars show the typical range of levelized costs worldwide for new energy construction. We see that utility-scale solar and wind energy is clearly cheaper than new nuclear energy, and cheaper than new coal plants in most cases. On average, solar and wind energy is also cheaper than constructing new natural gas plants. In other words, solar and wind energy are now, on average across the world, the two cheapest energy sources, without any subsidies.

[63] Fieber, 2020.

***Figure 10**. Unsubsidized Levelized Cost of Different Energy Sources*



Sources: Lazard, 2020.

Note: Diamond markers indicate the midpoint of marginal operation costs for fully depreciated plants.

In addition, renewable energy is quickly becoming cheaper than the marginal operational costs of traditional power sources, as shown by the diamond markers in Figure 10. For example, it is now frequently cheaper for an electric utility to construct new wind turbines or solar farms than to continue paying just the fuel and operational costs of a coal power plant that is fully depreciated (i.e., fully paid for). A 2019 study found that it was cheaper to construct new wind or solar energy than to continue operating 74% of the coal plants in the United States.[64] With renewable energy expected to become even cheaper in the future, it will increasingly make financial sense to shutdown existing coal, nuclear, and natural gas power plants and replace them with renewable energy.

Other recent economic studies of the costs of different energy sources reach the same conclusion – renewables cost about the same or less, on average, than traditional energy sources. A 2020 analysis by the U.S. Energy Information Administration compared the levelized costs of electricity production for energy sources that will enter service in 2022. On average, solar and wind energy are expected to be cheaper than natural gas.[65] The International Renewable Energy Agency concludes:

> Renewable energy costs continue to fall and renewable power generation is increasingly becoming the default source of least cost new power generation. Renewable power generation technologies are not just competing head-to-head with fossil fuel options without financial support, but increasingly undercutting them, in many cases by a substantial margin.[66]

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64 Gimon *et al*., 2019.
65 U.S. EIA, 2020c.
66 IRENA, 2020.

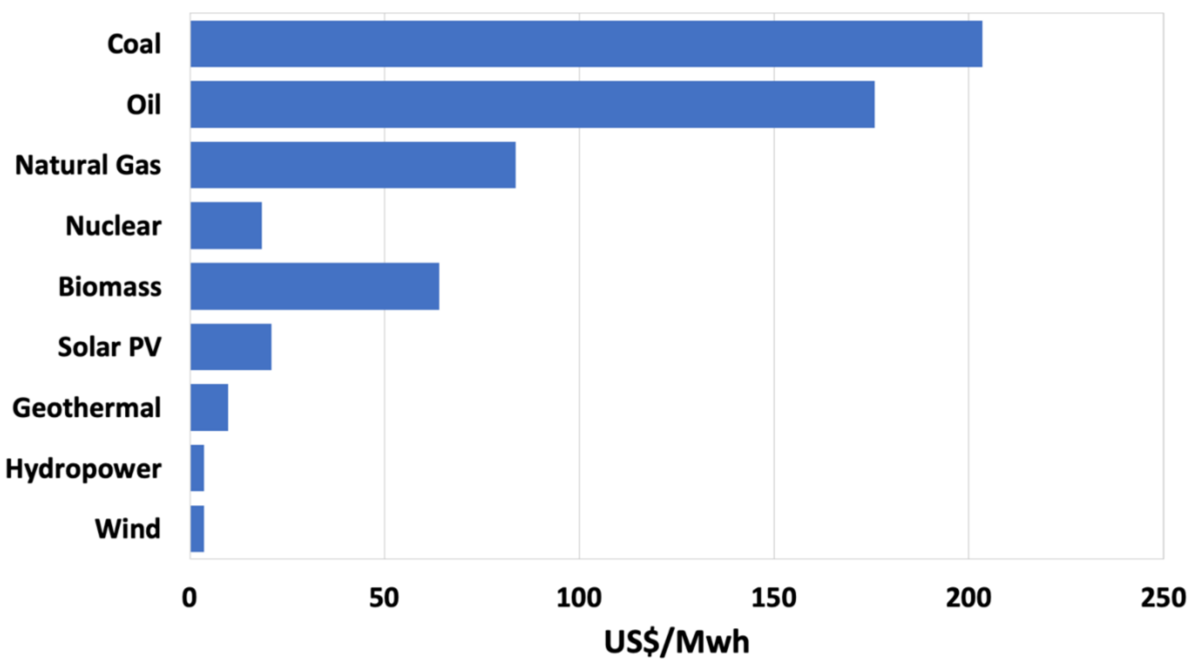
4.2 Externality Costs of Different Energy Sources

Our comparison of the costs of various energy sources is incomplete without inclusion of externality costs. The external costs of energy production include land degradation, water use, climate change damages, and human health effects from air pollution. Several studies have estimated the external costs of various energy sources.

Figure 11 presents the results of a comprehensive 2020 European study of the externality costs of electricity generation. We see that externality costs are highest for coal and oil, primarily damage from local air pollution and carbon emissions. External costs are lowest for hydropower and wind energy. While the external costs of nuclear and solar energy are about the same, the study did not estimate any external costs from the long-term storage of nuclear wastes.

Note that the units in Figure 11 are the same as in Figure 10. Thus the levelized costs can be added to the external costs to obtain an estimate of the total economic cost of each energy source. For example, the levelized cost of new natural gas electricity from Figure 10 is $44-$73/MWh. Adding the external cost of $84/MWh from Figure 11 increases the "true" cost of natural gas by 115-191%. While natural gas is currently reasonably cost competitive with wind and solar energy based solely on levelized costs, especially when only the marginal costs of gas are considered, inclusion of external costs would make natural gas at least twice as costly as wind and solar energy.

Figure 11. *External Costs of Electricity Generation, by Energy Source*



Source: Trinomics, /2020.

Note: Externality estimates are for the EU-27. Values in euros were converted to dollars.

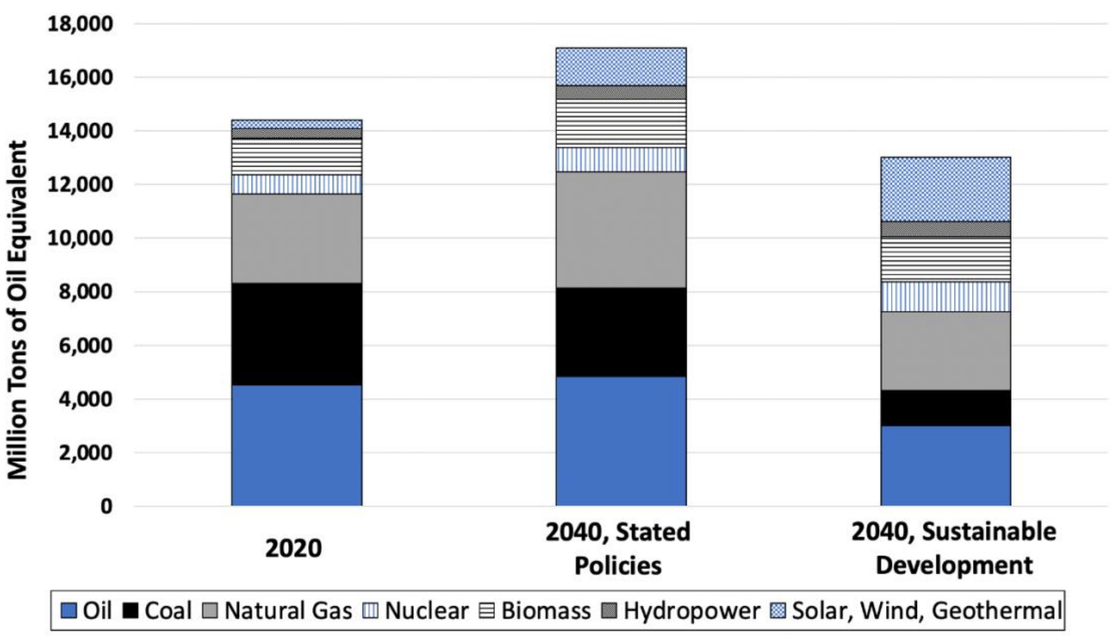
A 2020 journal article summarized several studies on the external costs of energy production, confirming that wind and solar energy tend to have the lowest external costs. Coal and oil energy tend to have the highest external costs. The external costs of hydropower, nuclear, and biomass differ significantly across studies depending on the assumptions and the types of costs that were included. The authors conclude that when all costs are considered "it is profitable to invest in truly clean renewable energy, i.e., in wind power, solar, and [geothermal] that have a minimal negative impact on the natural environment."[67]

4.3 Energy Projections

With renewable energy now as cheap or cheaper than traditional energy sources, even without subsidies and inclusion of external costs, the share of global energy from fossil fuels will decrease in the future. But as we mentioned at the start of the module, the critical question is whether the transition to renewable energy will occur soon enough to prevent unacceptable climate change and other environmental impacts.

Various government agencies and private companies project the global energy mix into the future. One of the most referenced projections is developed by the International Energy Agency (IEA). The IEA produces energy projections for two main scenarios: a "stated policies scenario" in which countries pursue policies currently in place or already planned and a "sustainable development scenario" that aims to meet the Paris Climate Agreement's target of limiting warming to less than 2°C.

Figure 12. *IEA Global Energy Mix. 2020 and Projections to 2040*



Source: IEA, 2020a.

[67] Bielecki *et al.*, 2020, p. 11524.

Figure 12 presents the IEA's global energy mix projections to 2040 under these two scenarios. While the projections for the stated policies scenario show coal production declining relative to 2020 and production of renewables such as wind and solar increasing, it shows little overall change in the global energy mix. The world's total energy share from fossil fuels declines slightly from 81% in 2020 to 73% in 2040. In the sustainable development scenario we see coal production decreasing more significantly and renewable production increasing more. The IEA also projects a significant increase in nuclear energy. Even in this scenario, however, fossil fuels still provide 56% of global energy supplies in 2040. While the stated policies scenario sees global energy demand increasing by 20% from 2020 to 2040, the sustainable development scenario projects a 10% decline in demand, as a result of increased energy efficiency.

The U.S. Energy Information Administration (EIA) projects the global energy mix to 2050 under a "reference case" scenario based on current policies and moderate assumptions about economic growth, energy prices, and technological changes.[68] The EIA projects that renewables (including wind, solar, hydropower, and biomass) will become the world's top energy source in the mid-2040s. But in 2050 fossil fuels combined still provide 68% of the global energy supply – clearly not sufficient to meet climate targets.

Another commonly referenced source of global energy projections is the oil company BP (British Petroleum).[69] BP presents a "business-as-usual" scenario that includes no major policy changes and a "rapid" scenario that pursues more ambitious climate and environmental policies. In BP's business-as-usual scenario fossil fuels still provide two-thirds of global energy supplies in 2050. But in the rapid scenario fossil fuels provide only 40% of global energy in 2050, with solar and wind accounting for 36%. Like the IEA's projections, BP projects lower global energy demand under a more sustainable scenario due to energy efficiency improvements.

Considering these projections, along with other data we've presented in this module, you may notice an apparent inconsistency. Wind and solar are currently the world's two cheapest energy sources, on average. These two sources also made up nearly 70% of the world's new energy in 2019. With the cost advantage of wind and solar relative to other energy sources expected to only increase in the future, it may be surprising that by 2050 wind and solar are projected to comprise no more than about one-third of the world's energy supply.

One factor limiting the expansion of wind and solar energy is that existing fossil fuel and nuclear plants will phase out slowly due to their relatively long lifespans, typically 30-50 years. But remember that the costs of wind and solar are declining so rapidly that they are increasingly cheaper than even the marginal operational costs of traditional power plants, suggesting it would make economic sense to shut down such plants early and replace them with new wind and solar energy.

Another factor to consider is that large-scale adoption of renewable energy requires electrification of the world's energy systems – one of the challenges mentioned at the start of the module. The widespread distribution of renewable energy will require significant private and public investment, as we'll discuss later in the module.

[68] U.S. EIA, 2020a.
[69] BP, 2020a.

But perhaps the most important factor to consider is that energy projections, particularly those developed by the EIA and the IEA, have historically underestimated the expansion of renewable energy – see Box 3 for more on this issue. Consider the EIA's current forecast for solar and wind energy production in the United States. The EIA projects that solar energy generation will grow at an annual rate of about 7% through 2050, while wind energy will grow at less than 3% per year. But from 2015 to 2019, wind energy production increased by 10% per year in the U.S., while solar energy increased by 24% annually! Further, over three-quarters of new electricity generation capacity in the U.S. in 2020 came from wind and solar energy.[70] Thus the EIA's forecast for only modest growth in wind and solar energy seems inconsistent with actual experience.

4.4 Carbon-Neutral Energy Systems

Rather than renewable energy supplying no more than about one-third of the world's energy by 2050, what would it take for a more comprehensive global transition to renewables? A 2017 journal article detailed "roadmaps" for 139 countries, including all major ones, to convert their energy systems to 80% renewables by 2030, and 100% renewables by 2050.[71] In the analysis, each country transitions to obtain all of its energy needs from wind, water, and sunlight (WWS) sources. The study also considers the modernization of each country's electrical grid along with battery storage to meet peak demands. The results include:

- Under a business-as-usual scenario energy demand for the 139 countries increases by 70% from 2012 to 2050. But under the WWS scenario total energy demand actually declines slightly during this same period due to energy efficiency gains.
- Considering the ideal energy mix in each country, the total energy supply in 2050 is met by 24% onshore wind, 14% offshore wind, 31% utility-scale solar, 26% residential, commercial, and government solar, and 5% hydropower and geothermal.
- Complete conversion to WWS energy will create a net gain of about 24 million jobs across the 139 countries. While 28 million jobs are lost in sectors such as fossil fuels and nuclear power, 52 million ongoing jobs are created in the construction, operation, and maintenance of WWS facilities and supporting infrastructure.
- Complete conversion to WWS energy will prevent the deaths of about 5 million people per year due to air pollution.
- Complete conversion to WWS energy by 2050 should limit global warming to no more than 1.5°C – the more ambitious target set by the Paris Climate Agreement. The avoided climate change damages amount to about $29 trillion annually by 2050.
- Complete conversion to WWS energy will require investment of about $125 trillion across the 139 countries. The authors find that the 2050 levelized cost of energy under the WWS scenario is 9.66 cents/kWh, compared to 9.78 cents/kWh under a business-as-usual scenario. The WWS conversion results in a savings of about $85/capita annually by 2050.

[70] U.S. EIA, 2020d.
[71] Jacobson *et al*., 2017.

- The WWS scenario increases energy access for 4 billion people currently suffering from energy poverty. The decentralized nature of WWS energy also reduces the risk of large-scale energy disruptions.

BOX 3. CONSISTENT INACCURACIES IN RENEWABLE ENERGY FORECASTS

The U.S. Energy Information Administration and the International Energy Agency produce annual energy forecasts that are widely quoted. Many people, from academics to politicians, rely upon these forecasts. But in recent years an increasing number of energy experts have been pointing out that the EIA and IEA forecasts have consistently underestimated the growth of renewable energy. Consider just a few examples:

- In 2000 the EIA forecast that under a "high renewables case" wind generation capacity in the U.S. would reach nearly 20 gigawatts in 2020.[72] Actual wind capacity in 2020 exceeded 100 gigawatts.
- In 2010 the EIA forecast that under a favorable "low renewables cost" scenario non-hydropower renewable energy capacity in the U.S. could nearly double from 2015 to 2035.[73] In a quarter of this time, from 2015 to 2019, solar energy capacity in the U.S. more than tripled.
- In 2010 the IEA forecast that global energy production from wind and solar could grow by nearly a factor of 10 from 2008 to 2035 under a "new policies scenario" to encourage a transition to renewable energy.[74] From 2008 to 2019 alone, global wind capacity increased by a factor of 5, but solar capacity increased by a factor of 40.
- In 2015 the IEA predicted that by 2040 the price of solar energy would decline by about 40%.[75] From 2015 to 2020 alone, the price of solar energy fell by 43%.

Many other examples could be presented to show that the growth of wind and solar generation capacity, and the decline in renewable prices, has consistently exceeded the EIA's and IEA's most optimistic forecasts. Part of the problem is that the agencies' models are built to favor the status quo. But as one energy expert explains regarding the EIA's forecasts, "They have constraints that tie their hands a bit, but that doesn't explain why they're so consistently wrong in the same direction. They're not just conservative about change. They're ignoring the evidence of what's actually happening in the market."[76] A 2016 journal article suggests several improvements to the EIA's energy projection methodology, concluding that unless "projections of renewable energy are greatly improved, the reliability of [the EIA's] electricity projections is inherently low."[77]

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72 U.S. EIA, 2000, Figure 83.
73 U.S. EIA, 2010, page 69.
74 IEA, 2010, Table 2.1.
75 IEA, 2015, Figure 1.3.
76 Grunwald, 2015.
77 Gilbert and Sovacoo, 2016, p. 533.

The authors note that most of the technologies needed for a complete conversion to a WWS-powered world are already available, with a few exceptions such as electric aircraft. They conclude that the main barriers to conversion to WWS energy are a lack of awareness and political will:

> While social and political barriers exist, converting to 100% WWS using existing technologies is technically and economically feasible. Reducing the barriers requires disseminating information to make people aware about what is possible, effective policies, and individuals taking actions to transition their own homes and lives.[78]

4.5 The Importance of Energy Efficiency

As mentioned at the start of the module, one of the global energy challenges is to promote energy demand-side management, limiting or even reversing the projected growth in global energy demand. Meeting the world's energy demands primarily, or fully, from renewable energy becomes more feasible if energy demand growth is restrained. Investments in energy efficiency are normally more cost-effective than investments in new energy supplies. In other words, it is normally cheaper to not use energy in the first place, say by increasing insulation in buildings or installing more efficient appliances, than to build new power plants. For example, a 2010 analysis of the United States found that investment of $520 billion in energy efficiency improvements would yield energy savings of $1.2 trillion.[79] The United Nations calls energy efficiency a "game changer":

> Improving energy efficiency is one of the most cost-effective measures countries can take. Energy efficient technologies, such as lighting based on LEDs, use less energy while providing the same or better light output. Deploying such technologies can substantially reduce greenhouse gas emissions. Energy efficiency also provides other benefits such as economic development, job creation, reduction of pollution, improvement in human health, and alleviation of poverty. According to the [International Energy Agency] the global economy could increase by $18 trillion by 2035 if we adopted energy efficiency as the "first choice" for new energy supplies, which would also achieve the emission reductions required to limit global warming to 2°C.[80]

Investments in renewable energy must be accompanied by investments in energy efficiency if the world is to meet its energy challenges. A 2017 analysis by the International Renewable Energy Agency (IRENA) found that successful decarbonization of the world's energy system by 2050 to limit warming to 2°C could be accomplished with 50% of the carbon reduction coming from a transition to renewable energy and 45% from energy efficiency gains (with the remaining reduction being reduced emissions from remaining fossil fuel sources).[81] The

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[78] Ibid, p. 119.
[79] McKinsey and Company, 2010.
[80] UN Environment Programme, Energy Efficiency, https://www.unenvironment.org/explore-topics/energy/what-we-do/energy-efficiency.
[81] IRENA, 2017.

electrification of the world's energy systems will produce a large portion of the efficiency gains, as electric products are generally more efficient than their fossil fuel counterparts (e.g., electric vehicle drivetrains are more efficient than internal combustion engines).
The IRENA report emphasizes the synergistic benefits between renewable energy and energy efficiency – when countries focus primarily on only one approach the economic and environmental benefits are not nearly as significant. Another finding is that developing countries stand to gain the most from energy efficiency investments, as they currently tend to have the least efficient energy systems. A 2020 analysis concludes that energy efficiency investments in developing countries not only produce cost savings, but also foster expanded output of goods and services to reduce poverty.[82]

5. POLICIES FOR THE GREAT ENERGY TRANSITION

In this final section we consider what policies could be implemented to meet the world's energy challenges. We've seen that economic forces are increasingly favoring renewables over fossil fuels, but the transition is not occurring quickly enough to meet climate targets. Government policies can fill the gap by promoting electrification, focusing on demand-side energy management, and addressing global energy disparities.

5.1 Internalizing Externalities

Fossil fuel energy is associated with significant negative externalities, suggesting that taxation or tradable permits could be used to motivate a transition to renewables. In principle, economic policies that internalize the negative externalities of various energy sources (including fossil fuels and renewables) would create a "level playing field" that can produce economically efficient, and potentially environmentally sustainable, outcomes. As we saw in Figure 11, internalizing the externalities associated with different forms of energy would significantly raise the prices of fossil fuels, particularly coal, relative to renewables.

Energy taxes can be implemented in various ways, including taxes on motor fuels and electricity, carbon taxes, and fossil fuel depletion taxes. As shown in Figure 13, most countries have implemented energy taxes via taxes on fuels such as gasoline. Some countries have also implemented carbon and electricity taxes. Overall energy taxes are highest in European countries. India, the United States, China, and Russia only have taxes on motor fuels, with no national carbon or electricity taxes.

The energy taxes illustrated in Figure 13 do not necessarily reflect full internalization of negative externalities. In the United States, the federal gasoline tax of 18 cents per gallon is justified exclusively to fund highway maintenance and other transportation projects. Even in the European Union, with its relatively high fuel taxes, environmental externalities are not fully internalized. The European Environment Agency notes that "to date fuel taxation is not

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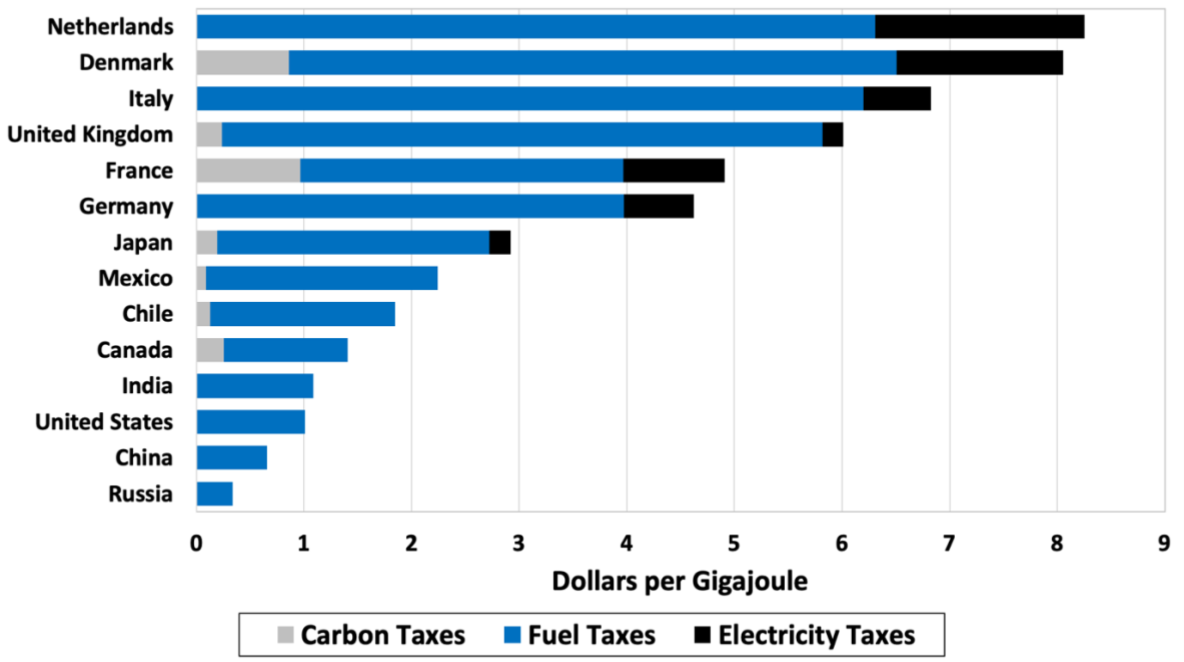
[82] UK Aid *et al.*, 2020.

generally used to internalize the environmental externalities of transport, possibly because high fuel tax is often politically unviable."[83]

Figure 13. *Energy Taxes, 2018, Select Countries*



Source: OECD, 2019.

Note: One gigajoule contains the amount of energy in approximately 8 gallons of gasoline.

All countries could thus do much more to internalize the externalities of energy use through taxes on fossil fuel products such as gasoline, electricity from coal, and natural gas heat. These taxes would motivate both a supply-side and a demand-side response. Producers such as utility companies would have an incentive to shift their energy sources from fossil fuels to renewables to lower their taxes. Consumers would reduce their demand for products whose prices rise significantly from taxation, such as gasoline. The extent to which economically efficient energy taxes would speed the transition to renewables depends on the price elasticity of demand for various energy sources, which we'll discuss later in the module.

5.2 Energy Subsidy Reform

Subsidies can also be used to promote economically efficient outcomes. A subsidy is economically justified when a market creates a positive externality, such as when a homeowner installs solar panels that benefit society as a whole. Subsidies favoring renewable energy can be used as an alternative to Pigouvian taxes on fossil fuels. Subsidies can take the form of direct payments or rebates to households and businesses that install solar panels, purchase electric vehicles, or install energy efficient heating or cooling systems. Subsidies can also take the form of low-cost loans or tax credits. For example, in the United States households or businesses

[83] European Environment Agency, Transport Fuel Prices and Taxes in Europe, https://www.eea.europa.eu/data-and-maps/indicators/fuel-prices-and-taxes.

that install solar panels can deduct a percentage of the system cost from their federal taxes (26% in 2022 and 22% in 2023).

Another form of subsidy is a **feed-in tariff**, which guarantees renewable energy producers access to electricity grids and long-term price contracts. For example, homeowners or businesses that install PV panels can sell excess energy back to their utility at a set price. Feed-in tariff policies have been instituted by dozens of countries and several U.S. states. The most ambitious has been in Germany, which has become a leading country in installed solar PV capacity. Feed-in tariffs are intended to be reduced over time as renewables become cost competitive with traditional energy sources. A reduction in feed-in tariff rates has already begun in Germany. An analysis by the European Union of different approaches for expanding the share of renewables in electricity supplies found that "well-adapted feed-in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity."[84]

feed-in tariffs a policy to provide renewable energy producers long-term contracts to purchase energy at a set price.

The International Renewable Energy Agency (IRENA) estimated that global supply-side renewable energy subsidies were $167 billion in 2017, with the European Union accounting for over half the total.[85] The United States accounted for 14%, Japan 11%, and China 9%. By energy source, solar received 48% of all renewable energy subsidies, wind 30%, and biomass 17%.

While policies such as fossil fuel taxes and renewable energy subsidies are increasingly implemented at national and sub-national levels, fossil fuels unfortunately remain heavily subsidized. According to the International Monetary Fund, global fossil fuel subsidies amount to about $5 trillion annually – equivalent to over 6% of the world economy.[86] The IRENA report mentioned above found that global subsidies supporting fossil fuels are 20 times higher than subsidies for renewable energy.[87] So rather than encouraging an energy transition, government policy overall seems to be slowing the necessary changes. (For more on energy subsidies, see Box 4.)

Fossil fuel subsidies are often justified as making energy more affordable to low-income consumers, especially in developing countries. Economic analyses have found, however, that fossil fuel subsidies primarily benefit higher-income groups. For example, a study by the International Monetary Fund found that:

> Fuel subsidies are a costly approach to protecting the poor due to substantial benefit leakage to higher income groups. In absolute terms, the top income quintile captures six times more in subsidies than the bottom.[88]

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[84] Commission of the European Communities, 2008, p. 3.
[85] Taylor, 2020.
[86] Coady *et al*., 2019.
[87] Taylor, 2020.
[88] Arze del Granado *et al*., 2010, p. 1.

The money governments save by reducing fossil fuel subsidies can benefit the poor more efficiently in other ways, such as spending on education or health programs.

In 2009, the members of the G20, a group of major economies including both developed and developing countries, agreed to "rationalize and phase out over the medium term inefficient fossil-fuel subsidies that encourage wasteful consumption" and "adopt policies that will phase out such subsidies worldwide."[89] But progress has been slow and no specific targets have been set. The International Energy Agency notes:

> Energy subsidies—government measures that artificially lower the price of energy paid by consumers, raise the price received by producers or lower the cost of production—are large and pervasive. When they are well-designed, subsidies to renewables and low-carbon energy technologies can bring long-term economic and environmental benefits. However, when they are directed at fossil fuels, the costs generally outweigh the benefits. [Fossil-fuel subsidies] encourage wasteful consumption, exacerbate energy-price volatility by blurring market signals, incentivize fuel adulteration and smuggling, and undermine the competitiveness of renewables and other low-emission energy technologies.[90]

BOX 4. FOSSIL FUEL SUBSIDIES

Fossil fuels are subsidized by governments in many ways. The most direct subsidies include cash payments, tax breaks, and other financial incentives. According to the International Energy Agency, these subsidies amounted to about $300 billion globally in 2019.[91] About half of this amount benefits the oil industry. In several countries, including China, India, Russia, and Saudi Arabia, these direct subsidies amount to more than 20% of GDP.
Using a different methodology, a 2020 analysis by the International Renewable Energy Agency (IRENA) estimates direct fossil fuel subsidies to be around $450 billion globally.[92] The IRENA subsidy estimate is larger due to the inclusion of additional types of subsidies, such as government policies that lower electricity prices and primarily benefit the fossil fuel industry. The IRENA analysis also considers indirect subsidies that benefit fossil fuels, specifically unpriced negative externalities. For the most part, the fossil fuel industry does not pay for its air pollution, climate change, and other environmental damages. These indirect subsidies are estimated to be $2.6 trillion annually, primarily from air pollution damages.

A 2019 analysis by the International Monetary Fund (IMF) also estimates direct and indirect fossil fuel subsidies.[93] The IMF finds that global fossil fuel subsidies amount to about $5 trillion, or over 6% of world economic production. About half of this arises from underpricing the damages from local air pollution, primarily benefiting the coal industry. The largest fossil fuel subsidizers are, in order: China, the United States, and Russia.

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89 IEA *et al*., 2011.
90 IEA, 2012.
91 IEA, Energy Subsidies, https://www.iea.org/topics/energy-subsidies.
92 Taylor, 2020.
93 Coady *et al*., 2019.

One encouraging sign is that global fossil fuel subsidies are generally declining. According to the Global Subsidies Initiative, between 2015 and 2018 fifty countries instituted some degree of fossil fuel subsidy reform, including Brazil, Canada, China, and India.[94] The IMF notes that individual countries have a strong incentive to reduce fossil fuel subsidies, as the resulting benefits would be primarily local from a reduction in air pollution, while also raising additional tax revenue. The IMF concludes:

> Underpricing of fossil fuels remains pervasive and substantial. … If fuel prices had been set at fully efficient levels in 2015, estimated global CO_2 emissions would have been 28 percent lower, fossil fuel air pollution deaths 46 percent lower, tax revenues higher by 3.8 percent of global GDP, and net economic benefits (environmental benefits less economic costs) would have amounted to 1.7 percent of global GDP.[95]

Promoting Electrification

The recent dramatic declines in the cost of renewable energy production have removed a major barrier to a global transition to renewable energy. But renewable energy production, mainly in the form of electricity, must be accompanied by a system to distribute, store, and utilize it. As we saw earlier, only about 25% of the world's energy is currently provided through electricity. The International Renewable Energy Agency (IRENA) suggests that the global production of electricity will need to at least double by 2050, which will require considerable investment. IRENA estimates that $800 billion needs to be invested globally in renewable energy production each year until 2050 in order to limit warming to no more than 2°C. But in addition more than twice this amount needs to be invested annually for electric infrastructure and energy efficiency improvements.[96]

Electrification increasingly makes financial sense for businesses and households. One example is the use of electric heat pump systems for space and water heating. Particularly in moderate climates, heat pumps can provide space and water heating at a lower lifecycle cost than fossil fuel alternatives. Another example is electric vehicles. As we saw in Box 1, the lifecycle cost of an EV is typically many thousand dollars less than a comparable gas-powered vehicle. But the higher up-front cost of these electric alternatives often prevents consumers from choosing them. Until technological advances lower prices further, government incentives can encourage consumers to purchase electric appliances and vehicles. For example, in the United States purchasers of new EVs are eligible for a federal tax credit of up to $7,500.[97] Many states offer additional economic incentives.

The mass electrification of transportation will require reliable and affordable charging networks. While EV charging is normally provided by private companies, government incentives can spur investment. Businesses and governments can also form collaborative

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[94] Merrill and Quintas, 2019.
[95] Coady, *et al.*, pp. 5-6.
[96] Anonymous, 2020a.
[97] The maximum $7,500 tax credit is available only for the first 200,000 EVs sold by a particular automaker, after which the credit is phased out. As of 2021, the credit is completely phased out for Tesla and General Motors.

partnerships to design and fund charging networks. One example is the West Coast Electric Highway project, which is constructing an EV charging network in California, Oregon, Washington, and British Columbia with a mix of private and public funding.

In partnership with electric utilities, governments have a central role to play in modernizing and expanding electricity grids. The U.S. federal government invested nearly $5 billion in grid modernization as part of the 2009 economic recovery spending. But more is needed: a 2020 analysis by researchers at the University of California-Berkeley estimated that in order for the U.S. to obtain 90% of its electricity from renewable sources an additional investment of $100 billion in electric transmission is needed.[98]

Electric battery storage is another key component of an energy system that heavily relies on intermittent electricity production from wind and solar energy. Fortunately, the cost of battery storage is declining as steeply as the cost of renewable energy production – from 2015 to 2018 the cost of utility-scale battery storage in the United States declined 70%.[99] Further investment in battery storage can be incentivized or directly funded publicly. Government policies in several U.S. states, including California, Massachusetts, and New Jersey, have mandated targets for battery storage by electric utilities.[100] In 2020 the German government announced an investment of €100 million for research into battery storage.[101]

Electrification can be promoted by government phaseouts of fossil fuel products. Numerous countries have announced target dates for banning the sale of new gas-powered vehicles. In 2020 the United Kingdom announced a plan to prohibit the sale of gas-powered vehicles by 2030 and hybrids by 2035, along with public funding for EV charging and battery research. Norway aims to become to the first country to ban the sale of gas-powered vehicles, with a target date of 2025. Other policies ban the use of fossil fuels in new construction. For example, the city of Seattle announced a ban in 2020 on the use of fossil fuel energy for water and space heating in new commercial and large multi-family construction.

Government targets also set dates for the conversion of electricity power to renewable sources. In 2018 Spain announced a plan to convert its electricity generation to 75% renewables by 2030, and 100% by 2050. Sweden has set an even more ambitious target of eliminating fossil fuels from electricity production by 2040. Progress toward renewable electrification will be slower in developing countries. China has set a goal of obtaining 35% of its electricity from renewables by 2030.

5.3 Demand-side Energy Management

Demand-side energy management is generally considered the most cost effective and environmentally beneficial approach to energy policy. As we've seen, shifting a kilowatt of energy supply from coal to solar or wind is desirable, but eliminating that kilowatt of demand entirely is even better. Economists often focus on pricing as a means to induce a demand-side

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98 Anonymous, 2020b.
99 U.S. EIA, 2020e.
100 U.S. EIA. 2020f.
101 Kelly, 2020.

response, either implementing Pigouvian taxes or increasing government-regulated rates for products such as electricity.

The effectiveness of price increases in reducing energy demand depends on the price elasticity. A 2017 study estimated the elasticity of demand for electricity in the United States, finding that demand is rather inelastic in the short-term (within one year), with a value of -0.1.[102] This suggests that a 10% increase in the price of electricity will only reduce demand by 1%. Demand was more elastic in the long-term, with an elasticity value of -1.0 for households and -1.2 for industrial users. A 2018 meta-analysis reviewed 103 studies of residential electricity demand from developing and developed countries and found that the average elasticity of demand was -0.23 in the short-term and -0.58 in the long-term.[103]

Most economic studies find that the demand for gasoline is price inelastic. A 2015 meta-analysis collected 63 international studies of gasoline demand, finding an average demand elasticity of -0.21 in the short-run and -0.44 in the long-run.[104] But several recent studies suggest that gasoline demand may be more elastic than previously thought, with a short-term elasticity around -0.40.[105] As alternatives to gasoline-powered vehicles become more widely available and affordable, one would expect that gasoline demand will become more elastic, especially in the long-run.

Numerous demand-side energy policy tools are available besides pricing. Reductions in energy demand can be achieved by promoting efficient technologies such as electric vehicles and LED lighting using rebates, tax credits, and other economic incentives. Government policies can mandate the phaseout of older, inefficient technologies. For example, numerous countries have been phasing out incandescent lightbulbs, which tend to be highly inefficient and short-lived. Efficiency standards, such as fuel economy standards or new home construction standards, are another demand-side energy policy tool.

Efficiency labeling informs consumers about the energy efficiency of various products. For example, in the United States the U.S. Environmental Protection Agency and U.S. Department of Energy manage the Energy Star program. Products that meet high-efficiency standards, above the minimum requirements, are entitled to receive the Energy Star label. About 75 percent of consumers who purchased an Energy Star product indicated that the label was an important factor in their purchase decision. In 2018 the energy savings from Energy Star products totaled $35 billion.[106]

efficiency labeling labels on goods that indicate energy efficiency, such as a label on a refrigerator indicating annual energy use.

Information campaigns can advocate for behavioral changes such as washing clothes using cold water or switching off lights and appliances when not in use. A meta-analysis found that

[102] Burke and Abayasekara, 2017.
[103] Zhu *et al*., 2018.
[104] Galindo *et al*., 2015.
[105] Kilian and Zhou, 2020.
[106] U.S. EPA, https://www.energystar.gov/about.

providing people with information about the ways they could reduce their energy use resulted in an average energy use reduction of 10-14%.[107] A similar approach is to use social comparisons to motivate energy efficient behavior. A common example is to provide electricity customers information about how they rank in usage compared to their neighbors, with rankings such as "below average" or "most efficient". A 2018 meta-analysis indicated that 18 of 20 studies concluded that social comparisons significantly reduce household energy use, with declines ranging from 1% to 30%.[108] These results suggest that non-price interventions can be at least as effective as raising prices in reducing energy demand, while also being more politically acceptable.

5.4 Addressing Global Energy Disparities

Energy poverty can be defined as lacking access to modern, affordable, and reliable energy. There is no consensus about how to measure whether a household suffers from energy poverty, or how many people globally are energy poor. Often energy poverty is equated to lacking access to electricity, which includes about 800 million people globally.[109] Even if a household is connected to an electrical grid, their energy may not be affordable or reliable. Electricity is expensive in many developing countries, especially relative to income. While the average price of electricity in the United States is about 12 cents per kWh, electric rates are at least double this amount in countries such as Haiti, Ghana, and Liberia. Blackouts are common in Nigeria, where the average household is without power for 19 hours a day.[110] When the electricity is not working, people must either do without or rely upon diesel generators which emit toxic pollutants and are expensive to operate. According to a 2020 journal article, 3.5 billion people globally lack access to a reliable supply of electricity.[111]

energy poverty lacking access to modern, affordable, and reliable energy

While small-scale, decentralized renewable energy can clearly help reduce energy poverty in rural areas, developing countries need access to sufficient levels of energy to foster widespread economic growth and competitiveness in international markets. Also, larger scale energy generation tends to reduce per-unit costs. A 2020 report by the Global Commission to End Energy Poverty (GCEEP) calls for a flexible approach to addressing energy poverty that includes:[112]

- Annual funding of $40 billion per year to provide universal access to electricity, utilizing private and public funding.
- A mixture of on-grid and off-grid energy solutions, emphasizing but not limited to renewable sources, tailored to individual circumstances.
- A focus on energy transmission, which is often the weak link in energy supply systems in developing countries.

[107] Delmas *et al*., 2013.
[108] Andor and Fels, 2018.
[109] IEA *et al*., 2020.
[110] Oseni, 2017.
[111] Ayaburi *et al.*, 2020.
[112] GCEEP, 2020.

- Building the capacity for effective government regulation of energy markets to prevent corruption and inefficiency.

The GCEEP notes that the COVID-19 pandemic has reversed progress being made in reducing energy poverty. The International Energy Agency estimates that 13 million people in Africa lost access to electricity in 2020.[113] Even before the pandemic, the world was not on track to meet the United Nations' goal of ensuring "universal access to affordable, reliable, and modern energy services." While there are no easy solutions to ending energy poverty, redirecting only 13% of global spending on fossil fuel subsidies would be sufficient to fund universal access to electricity.[114]

6. SUMMARY

The world faces four major energy challenges: transitioning from fossil fuels to renewable energy, electrification of much of the world's energy systems, constraining the growth of energy demand through energy efficiency improvements and other approaches, and addressing global energy disparities.

Fossil fuels currently provide about 80% of the world's energy. Despite past concerns about supplies, fossil fuels are generally abundant. The disadvantages of fossil fuels include price volatility, emissions of carbon dioxide and local air pollutants, and the environmental impacts of mining. Nuclear energy results in low emissions, but the main concerns are high costs and the possibility of accidents.

Renewable energy sources, particularly wind and solar energy, were limited in the past due to high costs. But the price of wind and solar energy has declined dramatically in recent years due to technological improvements, such that they are now the two cheapest energy sources in the world, on average, even without subsidies. With the internalization of externalities, the economic advantage of renewable energy over fossil fuels becomes even larger.

The global transition to renewable energy is clearly underway, but needs to be accelerated to meet climate goals. Energy taxes and subsidy reform are two main economic policy tools to speed the transition. A focus on demand-side energy management is also important, using pricing, informational, and behavioral approaches. Finally, additional investment is needed to address energy poverty in developing countries.

[113] IEA, 2020b.
[114] Zinecker, 2018.

DISCUSSION QUESTIONS

1. Would you add any other global energy challenges to the four listed at the start of the module? What do you see as the most effective policies to meet the challenges?
2. How do you see the world's energy systems changing over the next few decades? What will it take to accelerate the pace of change? What are the primary barriers to an effective energy transition?
3. Do you think market forces will motivate most of the transition to renewable energy, or are aggressive government polices required? Which policies are most important, and what are the justifications for such policies from the point of view of environmental economics?

KEY TERMS AND CONCEPTS

Biomass energy – generating heat or electricity from burning plant or animal material.

Demand-side energy management – energy policies that seek to reduce total energy consumption, such through energy efficiency improvements.

Efficiency labeling – labels on goods that indicate energy efficiency, such as a label on a refrigerator indicating annual energy use.

Energy poverty – lacking access to modern, affordable, and reliable energy.

Feed-in tariffs – a policy to provide renewable energy producers long-term contracts to purchase energy at a set price.

Geothermal energy – energy from the subsurface heat of the earth.

Hydroelectricity (or hydropower) – using the energy from moving water to spin an electric turbine and generate electricity.

Levelized costs – the per-unit cost of energy production, accounting for all fixed and variable costs over a power source's lifetime.

Nonrenewable energy sources – energy sources that do not regenerate through natural processes, at least on a human time scale, such as oil and coal.

Photovoltaic (PV) cells – devices that directly converts solar energy into electricity (i.e., solar panels).

Renewable energy sources – energy sources that are supplied on a continual basis, such as wind, solar, water, and biomass energy.

Supply-side energy management – energy policies that seek to change the energy mix in a society, such as switching from fossil fuels to renewables.

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2. **www.nrel.gov**. The web site of the National Renewable Energy Laboratory in Colorado. The NREL conducts research on renewable energy technologies including solar, wind, biomass, and fuel cell energy.
3. **www.rmi.org**. Homepage of the Rocky Mountain Institute, a non-profit organization that "fosters the efficient and restorative use of resources to create a more secure, prosperous, and life-sustaining world." The RMI's main focus has been promoting increased energy efficiency in industry and households.
4. **www.iea.org**. Web site of the International Energy Agency, which maintains an extensive database of energy statistics and publishes numerous reports. While some data are available only to subscribers, other data are available for free, as well as access to informative publications such as the "Key World Energy Statistics" annual report.
5. **www.energystar.gov**. Web site of the Energy Star program, including information about which products meet guidelines for energy efficiency.